Australian Journal of Crop Science AJCS

AJCS 5(4):473-478 (2011) ISSN:1835-2707

Physical, mechanical and aerodynamic properties of Acorn (*Quercus suber* L.) as potentials for development of processing machines

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Abstract

This study determined a number of physical, mechanical and aerodynamic attributes of acorn nuts grown in Iran at a moisture content of 5.84% dry basis (d.b). The mean of major diameter, intermediate diameter, minor diameter and geometric mean diameter were 31.27, 18.20, 16.64 and 21.89mm, respectively. Mean values for sphericity and surface area were 68.29% and 1462.73 mm^2, respectively. The true density, bulk density and porosity were 1028.33 kgm^{-3}, 512.62 kgm^{-3} and 49.84%, respectively. Cracking forces with loading on the lateral axis, vertical axis and thickness of the nuts were determined to be 367.84, 480.53 and 401.19N, respectively. Static friction coefficient on plywood, galvanized steel sheet and fiberglass were 0.38, 0.33 and 0.27, respectively, while the dynamic angle of repose on plywood, galvanized steel sheet and fiberglass were 25.53°, 21.74° and 16.31°, respectively. The terminal velocity for the nut, kernel and hull were 19.52, 16.80 and 4.07 ms^{-1}, respectively. These findings provide useful data for the suitable design and development of crop-processing machines such as sorting, grading, grinding, drying and extraction equipments.

Keywords: acorn, geometric properties, gravimetric properties, cracking force, terminal velocity

Abbreviations:

L	Major diameter, mm	H	Height of the cone, mm
W	Intermediate diameter, mm	θ	Angle of repose, deg
T	Minor diameter, mm	ρ_b	Bulk density, kg m^{-3}
D_g	Geometric mean diameter, mm	ρ_t	True density, kg m^{-3}
S	Surface area of seed, mm^2	ε	Porosity, %
ϕ	Sphericity, %	d.b	Dry basis, moisture content of the sample
D	Diameter of the cone, mm		

Introduction

Acorn nuts have been a part of traditional diets across Europe and the Middle East furnishing up to 25% of the food consumed by Italy and Spain (Rakic et al., 2007). The use of acorns in the human diet and their beneficial influence on human health in Serbia has been reported since the end of the 19th century (Jevtovic, 1980). The preparation of drinks based on thermally treated acorns (dry roasting) was especially recommended for children (Chiou, 1989). Moreover, these nuts are used in bread and cake, and as a coffee substitute (Teresina et al., 2011). The exploitation of acorns for livestock feeding and oil extraction has appeared in most Mediterranean countries (as acorns contain 47 to 60% starch, 7 to 14.4% lipids and some unsaturated fatty acids, similar to olive oil). The major fatty acids in acorns are oleic (66.8%), palmitic (18.4%), linoleic (13.5%) and linoleic (only 0.6%, compared to 0.9% in corn) (Keddam et al., 2010). The knowledge of the morphology and size distribution of acorn nut and its kernel is essential for the accurate design of the equipment for cleaning, grading and separation. Gravimetric properties are important in design of equipment related to aeration, drying, storage and transport. Bulk density determines the capacity of storage and transport systems, while true density is useful for separation equipment; porosity of the mass of seeds determines the resistance to air

Table 1. Size, shape and density characteristics of acorn nuts at 5.48% moisture content (d.b.)

Properties	Number of replications	Mean value	Range of values	Standard deviation
Moisture (% dry basis)	5	5.84	5.32 - 6.56	0.40
Major diameter (mm)	100	31.27	30.61 - 33.74	2.57
Intermediate diameter (mm)	100	18.21	17.14 - 19.23	1.48
Minor diameter (mm)	100	16.64	15.88 - 18.01	1.62
Geometric mean diameter (mm)	100	21.89	2.48 - 23.15	3.75
Surface area (mm^2)	100	1462.73	1380.10 - 1520.58	43.66
Sphericity (%)	100	68.29	65.32 - 71.64	4.86
True density (kgm^{-3})	20	1028.33	984.39 - 1112.57	37.91
Bulk density (kgm^{-3})	20	512.62	493.21 - 542.75	18.34
Porosity (%)	20	49.84	47.55 - 52.36	7.49

Table 2. The correlation coefficient between length and other geometrical properties of acorn nuts

Particulars	Ratio	Degrees of freedom	Correlation coefficient (R)
L/W	1.72	98	0.347**
L/T	1.88	98	0.588**
L/Dg	1.43	98	0.624**
L/S	0.02	98	0.613**
L/ø ^{a}	0.46	98	0.451**

**Significant at the level 1%. ^{a} L/ø is length to-sphericity ratio.

Table 3. Cracking force of acorn nut under different loading orientations at a moisture content of 5.48% (d.b.)

Cracking force	Number of replications	Mean value (N)	Range of values (N)	Standard deviation
Loading on lateral axis	15	367.84^{C}	328.76 - 435.60	48.13
Loading on vertical axis	15	480.53^{A}	443.96 - 516.37	86.24
Loading on thickness	15	401.19^{B}	386.24 - 425.52	23.16

* $^{A, B, C}$ letters indicate the significant statistical difference in 1% level.

flow during aeration and drying of seeds. The frictional properties such as the angle of repose and the coefficient of external friction are recognized by engineers as important properties concerned with rational design of seed bins and other storage structures including the compressibility and flow behavior of materials (Mirzaee et al., 2009; Gharibzahedi et al., 2010b). The physical properties of numerous nuts including gorgon nut, neem nut, cashew nut, Bambara groundnut, arecanut, pine nut and castor nut have been determined by other researchers (Jha and Prasad, 1993; Visvanathan et al., 1996; Balasubramanian, 2001; Baryeh, 2001; Kaleemullah and Gunasekar, 2002; Gharibzahedi et al., 2010a; Gharibzahedi et al., 2011). Several researchers have also determined the mechanical properties of nuts such as macadamia (Braga et al., 1999), shea nut (Olaniyan and Oje, 2002), and walnut (Koyuncu et al., 2004). Aydin (2002) studied the physical properties of the Turkish hazelnut cultivar Tombul, and determined the forces for cracking the nuts. Generally, nut cracking is usually carried out manually or with homemade cracking machines, and damage occurring during cracking is among the major causes of quality reduction of kernels. The percentage of the damage depends on the mechanical force applied to the nut, the rotational speed of the cracker, the thickness of shell, the shape of the nuts, the number of sizing grades and the efficiency of sizing (Özdemir and Akıncı, 2004). These parameters are important for the design and fabrication of all equipment involved in processes such as harvesting, sorting, grading and extraction (Mirzaee et al., 2008; Gorji et al., 2010). However, no published literature was found on the detailed physical and mechanical properties of the acorn nut. The objective of this study was to investigate some physical, mechanical and aerodynamic properties of acorns at a moisture content that permitted safe storage. The properties examined included size, sphericity, surface area, bulk density, true density, porosity, static coefficient of fraction, angle of repose and cracking force under compressive loading.

Materials and methods

Sample preparation

The acorn nut (*cv.* Uri) and its kernel were used for all the experiments in this study (Fig. 1). The acorn nuts used in this study were collected in the 2007 season from the oak forests of Arasbaran (longitude 46˚40' to 47˚2' and latitude 36˚56' to 38˚58') and the north of Iran (longitude 48˚38' to 54˚24' and latitude 38˚26' to 38˚58'). The samples were manually cleaned to remove foreign matter and broken and immature nuts. The initial moisture content of the acorns was determined using the oven method at 103 ± 2˚C until a constant weight was reached (Kashaninejad et al., 2007). The initial moisture contents of nut and kernel were found to be 5.84 and 6.42 dry basis (d.b), respectively.

Measurement of physical properties

Nut size was determined by measuring the dimension of the principal diameter on three axes – major (L), intermediate (W) and minor (T) – for 100 randomly selected nuts using digital calipers with a sensitivity of 0.01 mm. Nut mass was measured with an electronic balance with 0.001 g sensitivity. The geometric mean diameter (D_g) and sphericity ($ø$) were calculated using the following equations (Gharibzahedi et al., 2010b):

$$D_g = (LWT)^{1/3} \tag{1}$$

$$\phi = \frac{(LWT)^{1/3}}{L} \qquad (2)$$

where L is the major diameter, W is the intermediate diameter and T is the minor diameter.

The surface area of uri nuts was found by analogy with a sphere of the same geometric mean diameter. The equations given by Mohsenin (1978) were used to determine the surface area (S in mm^2) of the samples:

$$S = \pi D_g^2 \qquad (3)$$

The true volume was determined using the liquid-displacement method. Toluene (C_7H_8) was used instead of water because it is absorbed by acorns to a lesser extent. In addition, its surface tension is low, so that it fills even shallow dips in an acorn, and its dissolution power is low (Mohsenin, 1978). True density (ρ_t, kgm^{-3}) of samples was also calculated by dividing the unit mass of each sample by its true volume. In order to determine the bulk density at a given moisture content, a cylindrical container of 0.3 m height and 0.2 m diameter was filled with acorn nuts from a height of 0.15 m from the top surface of the container, and the top was leveled. No separate or additional manual compaction was done. The electronic balance was used for weighing, and the samples' bulk density (ρ_b, kgm^{-3}) was defined as the ratio of the mass of the bulk sample to the volume of the container. Several researchers have employed this method for other grains and seeds (Deshpande et al., 1993; Jain and Bal, 1997; Suthar and Das, 1996; Baryeh and Mangope, 2002; Kashaninejad et al., 2007). According to Mohsenin (1978), porosity (ε) can be expressed as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \qquad (4)$$

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using a topless and bottomless cylinder of 30 cm diameter and 50 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 70 cm and was filled with acorn nuts. The cylinder was raised slowly until it formed a cone on the circular plate. The height of the cone was measured and the angle of repose (θ) was calculated using the following equation (Kaleemullah and Gunasekar, 2002):

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \qquad (5)$$

where H is the height of the cone (mm) and D is the diameter of the cone (mm).

Measurement of aerodynamic properties

Terminal velocity was measured using an air column (Fig. 2). For each test, a sample (nut, kernel and hull) was dropped into the air stream from the top of the air column, 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 anemometer having a least count of 0.1 ms^{-1} (Gharibzahedi et al., 2010a,b).

Measurement of mechanical properties

To determine the mechanical properties of acorn nut under compression load, a biological material test device was used. This device, a SANTAM SMT-5 (Tehran, Iran), has three main components: a moving platform, a driving unit and a data-acquisition system (load cell, PC card, software and monitor), as shown in Fig. 3. The nut was placed on the moving platform at the 5 mm min^{-1} speeds and pressed with a plate fixed on the load cell until rupture occurred, as denoted by a bio-yield point in the force-deformation curve. Coefficient of static fraction was measured by a frictional device with the plywood, galvanized steel sheet and fiberglass surfaces. For this measurement, the material was placed on the surface and gradually raised by the screw. Vertical and horizontal height values were read from the ruler when the material started sliding over the surface; the tangent value of the angle was used to find the coefficient of friction (Baryeh, 2001; Gezer et al., 2002). Rupture force, terminal velocity, dynamic angle of repose and coefficient of static friction were determined with 15 replications for each test.

Fig 1. Acorn (*Quercus suber* L.) fruit: a- nuts, b- kernels

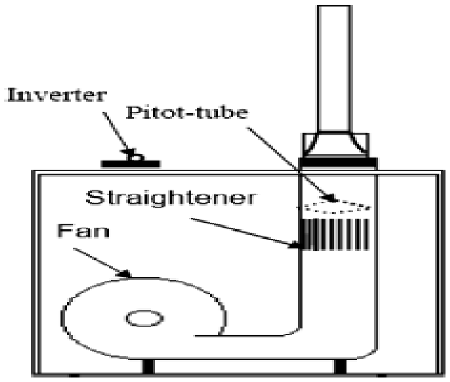

Fig 2. Used air column for measuring terminal velocity

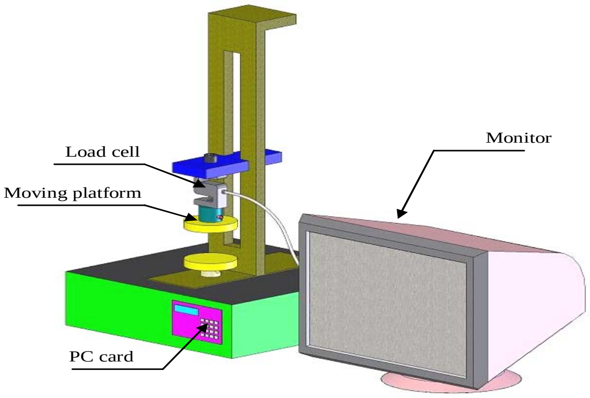

Fig 3. Instron Universal Testing Machine

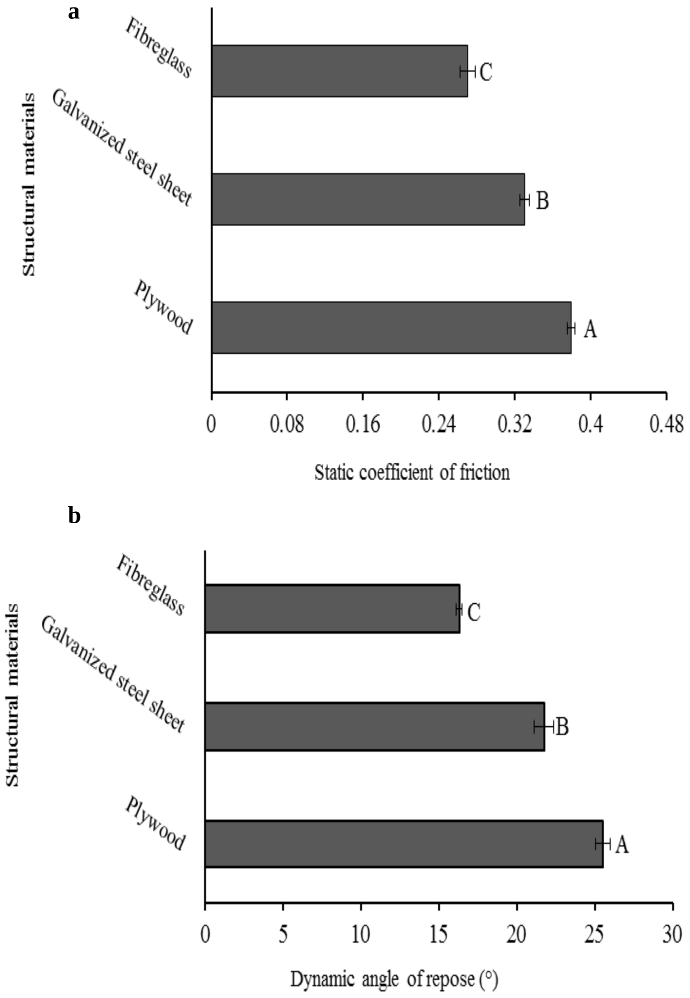

Fig 4. Static coefficient of friction (a) and dynamic angle of repose (b) of acorn nut for the different structural materials (error bars and significant values ($P<0.05$) by different letters (A-C) are shown)

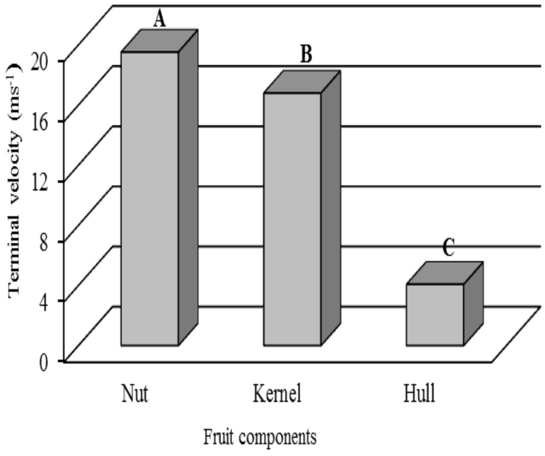

Fig 5. Terminal velocity of nut, hull and kernel of acorn fruit (significant values ($P<0.05$) by different letters (A-C) are shown)

The results obtained were subjected to analysis of variance (ANOVA) and Duncan's test using SPSS 13 (SPSS Inc., USA) software.

Results and discussion

Geometrical and gravimetrical properties

Table 1 shows the data on moisture content and some physical properties of acorn nuts. The major diameter, intermediate diameter, minor diameter and geometric mean diameter of the acorn nuts were found to be 31.27, 18.21, 16.64 and 21.89 mm at 5.84% moisture content (db), respectively. Corresponding values reported for the almond nut are 25.49, 12.12 and 17.03 mm at 2.77% moisture content (db) (Aydin, 2003), and those for the Ojji castor nut are16.0, 12.2 and 7.2 mm at 5.11% moisture content (wb) (Olaoye, 2000). Sphericity and surface area of the acorn nuts were found to be 68.29% and 1462.73 mm^2, respectively.

The following general expression can be used to describe the relationship among the average dimensions of the nuts at 5.84% moisture content (d.b):

$$L = 1.72\ W = 1.88\ T = 1.43\ D_g = 0.02\ S = 0.46\ ø \quad (6)$$

The coefficient of correlation shows that the L/W, L/T, L/D_g, L/S and $L/ø$ ratios are highly significant (Table 2). This indicates that width, thickness, geometric mean diameter, sphericity and surface area are closely related to the length of the acorn nut.The results indicate that the acorn nut is quite far from the shape of a sphere. This has several implications for handling and processing: for example, a sieving or separating machine with circular holes will not easily let nuts through, and during unloading the nuts will not roll too far from the intended unloading spot. The true density of acorn nuts was found to be 1028.33kgm^{-3}, while the bulk density was 512.62kgm^{-3}. These values were higher than the corresponding values of 674 and 305kgm^{-3} reported for hazel nuts (Aydin, 2002), but lower than the values of 1053 to 1161 kgm^{-3} reported for apricot pits (Gezer et al., 2002). At a true density of more than 1000kgm^{-3}, acorn nuts will tend to sink in water (density 1000kgm^{-3}), which can be useful in their hydrodynamic separation and transportation.

Mechanical and aerodynamic properties

Table 3 shows the experimental values for cracking force of acorn nuts. As illustrated in Table 3, effect of loading direction in the force required to initiate acorn nut rupture was significant ($P<0.01$). The cracking force measured in loading along the thickness lay between 386.24 and 425.52 N. Acorn nuts loaded along the vertical axis gave the highest resistance to cracking. Loading of acorn nuts along the lateral axis generally presented the least resistance to, and energy requirement for, shell rupture. Hence, cracking operations should be made along the lateral axis to decrease the cracking force. The same trend was also observed by Gezer et al. (2002) for apricot pits and Aydin (2003) for almond nuts. Static coefficient of friction and dynamic angle of repose of acorn nut for the different structural materials are given in Fig. 4. Static coefficient of friction for acorn nuts was 0.38 on plywood, 0.33 on galvanized steel sheet and 0.27 on fiberglass; in contrast, the dynamic angle of repose on plywood, galvanized steel sheet and fibreglass were 25.53˚, 21.74˚ and 16.31˚, respectively. These values of static coefficient of friction and angle of repose for various surfaces were significant at the 5% probability level. These frictional properties present an interesting trend. The decrease in the static coefficient of friction decreased the dynamic angle of repose. This might have been due to the surface differences and the nuts' surface properties. The angle of repose observed here was higher than the 25.40˚, 20.32˚ and 17.00˚ reported for ackee apples, locust-bean seeds and groundnut kernels, respectively (Ogunjimi et al., 2002; Olajide and Igbeka, 2003; Omobuwajo et al., 2000), but lower than the 28.22˚ for calabash nutmeg seeds (Omobuwajo et al., 2003). In other words, the forces of solid friction at the seed/material interface were generally lower in ackee apples, locust-bean seeds and groundnut kernels compared with acorn nuts, while the converse was true for calabash nutmeg seeds. The data on frictional properties can be useful in hopper design for gravity flow, since the angle of inclination of the hopper walls should be greater than the angle of repose to ensure continuous flow of the material. The terminal velocities required for suspending the nuts, kernels and hulls depicted in Fig. 5. The corresponding values were found to be 19.52, 16.80 and 4.07 ms^{-1}, respectively ($P<0.05$). These values were higher than African breadfruit seeds (2.90-8.02 ms^{-1}) and ackee apple seeds (5.45-9.95 ms^{-1}) (Omobuwaj et al., 1999; Omobuwajo et al., 2000). As expected, the terminal velocity of the hull was lower than for the nut and kernel. The significant difference between the suspension air velocities for the kernel and hull indicate that separation of these fractions by pneumatic means is feasible. The data on terminal velocity can be used in designing an aspiration unit.

Conclusion

The following conclusions were drawn from this study about the engineering characteristics of acorn nut at a moisture content of 5.84% (d.b.). The average major, intermediate and minor diameters of the acorn nut were 31.27, 18.20, 16.64 mm, respectively, with a geometric mean of 21.89 mm. Information of the length, width, thickness of the seeds is necessary in determining aperture sizes in the design of seed handling equipment. Moreover, assessment of the mean geometric diameter is useful in evaluation of the projected area of a particle moving in the turbulent or near-turbulent area of an air stream. Also, the results demonstrated that the acorn nut is quite far from the shape of a sphere, and that, consequently, a sieving or separating machine with circular holes will not easily let nuts through. Plywood surface was observed to be the highest coefficient of static friction and dynamic angle of repose for acorn nuts. Experimental results from compression tests showed that acorn nut required less compressive force to extract the kernel when loaded along the vertical axis as compared to other two compression axes. Therefore, in designing cracking machines the axes should be taken into consideration. The significant difference between the suspension air velocities for the kernel and hull indicated that separation of these fractions by pneumatic means is feasible.

Acknowledgements

The authors would like to thank the University of Tehran for providing the laboratory facilities and financial support for this project. The authors are also grateful to Mehrdad Nazari Galedar for his help.

References

Aydin C (2002) Physical properties of hazel nuts. Biosyst Eng. 65: 297–303.

Aydin C (2003) Physical properties of almond nut and kernel. J Food Eng. 60: 315–320.

Balasubramanian D (2001) Physical properties of raw cashew nut. J Agric Eng Res. 78: 291–297.

Baryeh EA (2001) Physical properties of bambara groundnuts. J Food Eng. 47: 321–326.

Baryeh EA, Mangope BK (2002) Some physical properties of QP-38 variety pigeon pea. J Food Eng. 56: 59–65.

Braga GC, Couto SM, Hara T, Neto JTPA (1999) Mechanical behaviour of macadamia nut under compression loading. J Agric Eng Res. 72: 239–245.

Chiou JW (1989) The antioxidant activity and the chemical structure of selected components acorns and their potential use as inhibitors of milk oxidation. A Dissertation of Cornell University, USA.

Deshpande SD, Bal S, Ojha TP (1993) Physical properties of soybean. J Agric Eng Res. 56: 89–98.

Gezer I, Hacıseferogulları H, Demir F (2002) Some physical properties of Hacıhaliloglu apricot pit and its kernel. J Food Eng. 56: 49–57.

Gharibzahedi SMT, Etemad V, Mirarab-Razi J, Fos'hat M (2010a) Study on some engineering attributes of pine nut (*Pinus pinea*) to the design of processing equipment. Res Agr Eng. 56 (3): 99–106.

Gharibzahedi SMT, Mousavi SM, Ghaderijani M (2011) A survey on moisture-dependent physical properties of castor seed (*Ricinus communis* L.). Aust J Crop Sci. 5(1): 1-7.

Gharibzahedi SMT, Mousavi SM, Moayedi A, Taheri Garavand A, Alizadeh SM (2010b) Moisture-dependent engineering properties of black cumin (*Nigella Sativa L.*) seed. Agric Eng Int: CIGR Journal. 12 (1): 194-202.

Gorji A, Rajabipour A, Tavakoli H (2010) Fracture resistance of wheat grain as a function of moisture content, loading rate and grain orientation. Aust J Crop Sci. 4(6):448-452.

Jain RK, Bal S (1997) Physical properties of pearl millet. J Agric Eng Res. 66: 85–91.

Jevtovic M (1980) Pelagicev Narodni Ucitelj (in Serbian). Beograd, Sloboda.

Jha SN, Prasad S (1993) Physical and thermal properties of gorgon nut. J Food Process Eng. 16: 237-245.

Kaleemullah S, Gunasekar JJ (2002) Moisture-dependent physical properties of arecanut kernels. Biosyst Eng. 82: 331–338.

Kashaninejad M, Mortazavi A, Safekordi A, Tabil LG (2007) Some physical properties of pistachio (*Pistacia vera* L.) nut and its kernel. J Food Eng. 72: 30–38.

Keddam R, Bouderoua K, El-Affifi M, Selselet-Attou G (2010) Growth performances, carcasses parameters and meat fatty acid composition of lamb fed green oak acorns (*Quercus ilex*) based diet. Afr J Biotechnol. 9 (29): 4631-4637.

Koyuncu MA, Ekinci K, Savran E (2004) Cracking characteristics of walnut. Biosyst Eng. 87: 305–311.

Mirzaee E, Rafiee S, Keyhani A, Emam Djom-eh Z (2009) Physical properties of apricot to characterize best post harvesting options. Aust J Crop Sci. 3(2): 95-100.

Mirzaee E, Rafiee S, Keyhani AR, Emam Djom-eh Z, Kheiralipour K (2008) Mass modeling of two varieties of apricot *(prunus armenaica L.*) with some physical characteristics. Plant Omics. 1(1): 37-43.

Mohsenin NN (1978) Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publications, New York.

Ogunjimi LAO, Aviara NA, Aregbesola OA (2002) Some engineering properties of locust bean seed. J Food Eng. 55: 95–99.

Olajide JO, Igbeka JC (2003) Some physical properties of groundnut kernels. J Food Eng. 58: 201–204.

Olaniyan AM, Oje K (2002) Some aspects of the mechanical properties of shea nut. Biosyst Eng. 81: 413-420.

Olaoye JO (2000) Some physical properties of castor nut relevant to design of processing equipment. J Agric Eng Res. 77: 113–118.

Omobuwajo TO, Akande EA, Sanni LA (1999) Selected physical, mechanical and aerodynamic properties of Africa breadfruit (*Treculia africana*) seeds. J Food Eng. 40: 241–244.

Omobuwajo TO, Omobuwajo OR, Sanni LA (2003) Physical properties of calabash nutmeg (*Monodora myristica*) seeds. J Food Eng. 57: 375–381.

Omobuwajo TO, Sanni LA, Olajide JO (2000) Physical properties of ackee apple (*Blighia sapida*) seeds. J Food Eng. 45: 43–48.

Özdemir F, Akıncı I (2004) Physical and nutritional properties of four major commercial Turkish hazelnut varieties. J Food Eng. 63: 341–347.

Rakic S, Petrovic S, Kukic J, Jadranin M, Tesevic V, Povrenovic D, Siler-Marinkovic S (2007) Influence of thermal treatment on phenolic compounds and antioxidant properties of oak acorns from Serbia. Food Chem. 104: 830–834.

Sabati H (2007) Forests, trees, and sharubs of Iran. Yazd university publication, Yazd.

Suthar SH, Das SK (1996) Some physical properties of karingda [*Citrullus lanatus* (Thumb) *Mansf*] seeds. J Agric Eng Res. 65: 15–22.

Teresina D, García-Torres S, Cabeza de Vaca M, Vázquez FM, Cava R (2011) Acorns (*Quercus rotundifolia* Lam.) and grass as natural sources of antioxidants and fatty acids in the "montanera" feeding of Iberian pig: Intra- and inter-annual variations. Food Chem. 124 (3): 997–1004.

Visvanathan R, Palanisamy PT, Gothandapani L, Sreenarayanan VV (1996) Physical properties of neem nut. J Agric Eng Res. 63: 19 – 26.