Some physical properties of almond nut and kernel and modeling dimensional properties

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Abstract: Three main dimensions of nut and kernel of almonds were measured. Then some dimensional properties of nut and kernel were calculated. Effect of the moisture content on bulk density, true density, porosity and coefficient of friction of kernels and nuts were studied. Angle of repose on iron, plywood and galvanized sheet were measured. Also in order to examine the correlation between two dimensions of kernels and nuts and correlation between one dimension of nuts and similar dimension of kernels, linear and quadratic regression were used. Length, width and thickness distributions of nuts and kernels were modeled using normal, log normal, Weibull and Generalized Extreme Value distributions. For modeling other dimensional properties, only Generalized Extreme Value was used. The estimated parameters of the PDF for three main dimensions of nuts and kernels indicated that G.E.V was best fit. With increasing moisture content of the kernels from 4.20% to 29.64% (w.b.), true density and porosity were increased from 939.629 to 1,077.428 kg m^{-3} and 37.704% to 57.088%, respectively; and bulk density was decreased from 585.350 kg m^{-3} to 462.343 kg m^{-3}. When the moisture content of the nuts increased from 4.03% to 28.13% (w.b.), true density and porosity were increased from 1,025.124 kg m^{-3} to 1,149.700 kg m^{-3} and 38.562% to 56.55%, respectively, and bulk density was decreased from 629.81 kg m^{-3} to 499.532 kg m^{-3}. Values of coefficient of friction on all surfaces were increased with increasing moisture content.

Keywords: gravimetric properties, regression, log likelihood, normal distribution, Weibull distribution,generalized extreme value distribution, almond nut

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1 Introduction

Almond (*Amygdalus Communis* L.) is a perennial plant grown in cold and temperate regions. The kernel forms an important source of energy with 6 kcal g^{-1}, protein 15.64% and the oil content ranges from 35.27% to 40% (Aydin, 2003). Oil of almond kernel is an important source of oleic acid with 40% (Aydin, 2003). Iran is one of the major producers of almond. At present, harvesting and handling of the crop are carried out manually in Iran. The threshing is usually carried out manually or by using a homemade sheller machine. For optimum performance of threshing, conveying, sorting, storing and other processes of almond nuts and kernels, physical and mechanical properties of almond nuts and kernels must be known.

The relation between the size and rupture strength of almond nuts of 10 almond varieties was investigated by Kalyoncu (1990). Moisture dependent physical properties of the almond nut and kernel were investigated by Aydin (2003). Effect of the irrigation regime, type of fertilization and culture year on the physical properties of almond were investigated by Valverde et al. (2006).

A limited number of researches have been conducted on the physical properties of almond nut and kernel. But there are many researches on physical and mechanical properties of other agricultural products. Fracture resistance of sunflower seed and kernel to compressive loading was calculated by Gupta and Das (2000). Altuntas et al. (2004) measured some physical properties

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such as length, width, thickness, geometric mean diameter, sphericity, mass, porosity, and bulk density of fenugreek seeds. Some physical and morphological properties of wild sunflower seeds were investigated by Perez et al. (2007). Moisture dependent physical properties of cucurbit seeds were examined by Milani et al. (2007). Some physical properties of rough rice grain were measured by Ghasemi et al. (2008). Tabarsa et al. (2011) studied physical and mechanical properties of wheat straw boards bonded with tannin modified phenol-formaldehyde adhesive.

Generally, it is of no interest to know the properties of each individual nut or kernel, but for designing threshing and separating machines, the frequency distributions of dimensions and dimensional properties of a set of almond nuts and kernels needs to be explained. Many continuous distributions have been used to describe the natural phenomena. The most common functions used to describe natural phenomena are the Normal distribution, Weibull distribution and Log-normal distribution. There are many researches on modeling with statistical distributions in agriculture and other sciences.

Suitability of the Normal, Log-normal and Weibull distributions for fitting diameter distributions of neem was examined by Nanag (1998). Modeling diameter distributions of Betula alba L. with the two-parameter Weibull function were investigated by Gorgoso et al. (2007). Log-normal vs. Normal and Weibull distributions for modeling the mass and size distributions of sunflower seeds and kernels were investigated by Khazaei et al. (2008). Zinck (2011) investigated sample size dependence of flaw distributions for the prediction of brittle solids strength using additive Weibull bimodal distributions.

The aim of this work was to measure dimensional properties (length, width, thickness, sphericity, volume, surface area, and projected area) of nuts and kernels of Sangi variety of almond grown in Iran. In other hand effect of moisture content on bulk density, true density, porosity and coefficient of friction of kernels and nuts were studied. Also static angle of repose on iron, plywood and galvanized sheet, using pouring method were measured.

Normal, Log normal, Weibull, and G.E.V distribution for modeling three main dimensions of nuts and kernels, were used. But for modeling other dimensional properties (sphericity, volume, surface area, and projected area) of nuts and kernels, Generalized Extreme Value was used.

2 Material and Method

2.1 Sampling preparation

Almond nuts and kernels of Sangi variety were used for all the measurement. e Green shell nuts collected from local farms of Mehriz, Iran in September 2012 was used in this study. The broken nuts, unwanted debrises and materials were removed from 10 kg samples of almonds nut. Under different moisture content, bulk, true density, porosity, friction coefficient and angle of repose for nuts and kernel were measured. Then 125 almonds were randomly selected from the bulk sample. Three principal dimensions and mass of the nuts were measured. Dimensions and mass of the nuts were measured when the value of moisture content equals 6.13%. Dimensions and mass of the kernels were measured when the value of moisture content equals 8.41% (w.b).

2.2 Dimensions properties

For each individual almond nut, three main dimensions, namely length (*L*), width (*W*), and thickness (*T*) were measured. For measuring principal dimensions of the kernel, almond nut was broken; then length (*l*), width (*w*) and thickness (*t*) of the kernel were measured. For all measurements, a digital caliper with accuracy of 0.01mm was used. The geometric mean diameter, D_g, and sphericity, φ of the nuts and kernels were determined using the following Equation (1) and Equation (2) given by Kashaninejad et al. (2008); Perez et al. (2007); Gholami et al. (2012); Paksoy and Aydin (2004):

$$D_g = \sqrt[3]{LWT} \tag{1}$$

$$\varphi = \left(\frac{\sqrt[3]{LWT}}{L}\right) \times 100 \tag{2}$$

The volume of the nuts and kernels (*V*) can be calculated using the following Equation (3) cited by Khazaei et al. (2006); Sadeghi et al. (2010):

$$V = \left(\frac{\pi D_g^{\ 3}}{6}\right) \tag{3}$$

The surface area (*S)* of almond nuts and kernels can be calculated by obtaining the value sphere of its geometric mean diameter. This parameter was calculated using Equation (4), cited by Gupta and Das (1997); Dursan and Dursan (2005); Kabas et al. (2006); Kabas et al. (2007):

$$S = \pi D_g^{\ 2} \tag{4}$$

The projected area of the nuts and kernels (A_p) was determined by the Equation (5), cited by Khazaei et al. (2006):

$$A_p = \left(\frac{\pi WL}{4}\right) \tag{5}$$

Based on the measurements and calculations made above, for calculating statistical indices including maximum, minimum, average, standard deviation, skewness, and kurtosis for measured and calculated data, Microsoft Office Excel 2007 was used.

To study the correlation between dimensions, linear regression was used. For linear and quadratic regression, R^2 index was calculated. For calculating regression equation and R^2 index, MATLAB R2007b software package was used.

2.3 Modeling for dimensional properties

Length, width and thickness of nut and kernel distribution were modeled with four probability density functions. These functions were: (1) Normal, (2) Log normal, (3) Weibull, and (4) Generalized Extreme Value. The probability density functions ($f(x)$) for four distributions are shown in Table 1. According to the equations expressed in Table 1, for the Normal, Log normal, Weibull and Generalized Extreme Value distributions, α is location or shift parameter, β is scale parameter and γ is shape parameter. The normal distribution with α = 0 and β = 1 is called the standard normal distribution or the unit normal distribution. Whenever α is equal to zero Log normal distribution is called two parameters distribution, otherwise it is called three parameters distribution. Whenever α is equal to zero and β equals one the Log normal distribution is called standard Log normal distribution. In this study, Log normal distribution with two parameters was used.

Table 1 The Normal, Log normal, Weibull and G.E.V probability density function

Distribution	Probability distribution function
Normal	$f(x) = \left(\frac{1}{\beta\sqrt{2\pi}}\right)\exp\left(-\frac{1}{2}\left(\frac{x-\alpha}{\beta}\right)^2\right)$
Log normal	$f(x) = \left(\frac{1}{(x-\alpha)\gamma\sqrt{2\pi}}\right)\exp\left(-\frac{1}{2}\left(\frac{\ln(x-\alpha)-\beta}{\gamma}\right)^2\right)$
Weibull	$f(x) = \frac{\gamma}{\beta}\left(\frac{x-\alpha}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x-\alpha}{\beta}\right)^{\gamma}\right)$
G.E.V	$f(x) = \frac{1}{\beta}\left[1+\gamma\left(\frac{x-\alpha}{\beta}\right)\right]^{(-1/\gamma)-1}\exp\left\{-\left[1+\gamma\left(\frac{x-\alpha}{\beta}\right)\right]^{-1/\gamma}\right\}$

If α is equal to zero, the Weibull distribution is called two parameters distribution; otherwise it is called three parameters distribution. In this paper, for modeling the data, two parameters Weibull distribution was used.

Then, the four probability density functions were fitted to the empirical probability density, to estimate the parameter values. The adjustable parameters for each probability density function were estimated using the MATLAB R2007b.

There are several competing models for the same data set such as likelihood, Kolmogorov-Smirnov, Chi-squar and Anderson Darling. In this study, log likelihood was selected because MATLAB, the software used by the authors, uses this method. The test statistic (often denoted by D / Equation (6)) is twice the difference in these log likelihoods (Mirzabe et al., 2012):

$$D = -2\left(\frac{L_n}{L_a}\right) \tag{6}$$

where, L_n was the likelihood for null model; L_a was the likelihood for alternative model.

2.4 Gravimetric properties

2.4.1 Mass properties

To determine the mass of the single kernel (nut), 100 kernels (nut) from the bulk sample were selected quite randomly. The mass of the kernels (nuts) was measured by a digital balance with an accuracy of 0.01 g. For determination of one thousand kernels (nuts) mass, 500 kernels (nuts) were selected; then the kernels (nuts) were divided randomly to five bins so that in each bin 100 kernels (nuts) were placed. The weight of each bin was measured. Then the value of average of weight of bins was calculated and then multiplied by 10 to give one thousand kernels (nuts) mass.

2.4.2 Densities

The bulk density (ρ_b) is the ratio of the mass of a sample of nuts or kernels to its total volume. The bulk density was determined with a weight per hectolitre tester which was calibrated in kg per hectolitre (Aydin, 2003). The nuts and kernels were poured in the calibrated bucket up to the top from a height of about 150 mm and excess amount was removed by strike off stick. The nuts and kernels were not compacted in any way.

The true density (ρ_t) of kernels and nuts was determined using the water displacement method. Toluene (C_7H_8) was used in the place of water, because it is absorbed by seeds to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Milani et al., 2007). The porosity (ε) of the fruits was calculated using bulk density, true density and following the Equation (7) (Fathollahzadeh et al., 2009):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{7}$$

2.5 Frictional properties

2.5.1 Coefficient of friction

The coefficient of static friction, using plywood, iron sheet and galvanized iron sheet, under different moisture content, was determined. A top and bottomless metallic box was put on the surface. The box was filled by kernels (nuts). The surface was gradually raised by the screw. Both horizontal and vertical height values were measured using a ruler and digital caliper when the seeds started sliding over the surface and, the coefficient of static frication was calculated using the following Equation (8) (Burubai et al,, 2007; Mirzabe et al., 2013):

$$\mu_s = \tan(\alpha) \tag{8}$$

where: μ_s = coefficient of external static friction; α = angle of external static friction.

2.5.2 Angle of repose

Static angle of repose was measured by the use of pouring method (Fraczek et al., 2007; Mirzabe et al., 2012; Mirzabe et al., 2013). The angle of repose of kernels and nuts was determined by using a top and bottomless plastic cylinder of 250 mm height and 150 mm diameter. The cylinder was placed at horizontal surface and was filled by kernels and nuts. The cylinder was raised very slowly. The height and radius of the cone were measured using a ruler. The static angle of repose was determined using the following Equation (9) cited by Milani et al. (2007):

$$A_r = \tan^{-1}\left(\frac{H}{R}\right) \tag{9}$$

where, A_r was angle of repose; H was height of the cone; R was radius of the cone.

3 Results and Discussion

3.1 Dimensional results

Length, width, and thickness of nuts and kernels and are shown in Table 2. The length, width, and thickness of almond nuts ranged from 22.85 mm to 47.15 mm, 15.20 mm to 27.65 mm and 9.15 mm to 18.05 mm, respectively. The corresponding value for almond kernels was found to be 15.21 mm to 29.70 mm, 8.45 mm to 19.00 mm and 3.95 mm to 8.35 mm, respectively.

Table 2 Calculated statistical indices of dimensional parameters of almond nuts and kernels

Parameter	Mean	Min	Max	Std	Skewness	Kurtosis
L/ mm	32.4018	22.85	47.15	4.9956	0.4437	0.4238
W/ mm	19.0877	15.20	27.65	2.2292	0.8295	1.1529
T/ mm	13.4209	9.15	18.05	1.3296	0.3409	1.7620
l/ mm	22.6098	15.21	29.70	2.9906	-0.2053	-0.5597
w/ mm	11.7058	8.45	19.00	1.6039	1.5054	4.6508
t/ mm	6.1176	3.95	8.35	0.8747	-0.1728	-0.4094

The dimensional properties of nut and kernels of almond are shown in Table 3. The geometric mean diameter, sphericity, volume, surface area and projected area of almond nuts ranged from 16.17 mm to 26.36 mm, 52.08% to 76.47%, 2,212 mm^3 to 9,586 mm^3, 821 mm^2 to 2,182 mm^2 and 278 mm^2 to 861 mm^2 respectively. Corresponding value for almond kernels were found to be 9.00 mm to 14.29 mm, 43.08% to 67.11%, 382 mm^3 to 1,527 mm^3, 255 mm^2 to 641 mm^2 and 113 mm^2 to 388 mm^2 respectively. Comparison between the results in this paper and Aydin's results (Aydin, 2003) shows mean value of length, width, geometric mean diameter, and volume of kernels to be greater, and value of thickness and sphericity lower than the value cited by Aydin. Mean value of length, width, thickness, geometric mean diameter, and volume of nuts are also greater and value of sphericity is lower than the value cited by Aydin.

Result of linear and quadratic regression analysis is shown in Table 4. That result indicated that using linear and quadratic regression, no correlation between dimensions of kernels or dimensions of nuts could be found. For most almond nuts it cannot be said that if the width of a nut was large, so the width of its kernel is also large, and the same goes for their thickness. But for most almond nuts it can be said that if the length of a nut was bigger, so is the length of its kernel.

Table 3 Calculated statistical indices for shape parameters of almond nuts and kernels

	Parameter	Max	Min	Mean	Std	Skewness	Kurtosis
Nuts	D_g / mm	26.356	16.167	20.198	2.092	0.394	-0.121
	φ/ %	76.473	52.084	62.960	5.347	0.423	-0.556
	V/ mm^3	9586.070	2212.301	4454.064	1420.296	0.942	1.067
	S/ mm^2	9586.070	2212.301	4454.064	1420.296	0.942	1.067
	A_p / mm^2	861.024	278.160	490.914	120.494	0.767	0.747
Kernels	D_g / mm	14.289	9.004	11.678	1.017	-0.237	0.106
	φ/ %	67.110	43.086	52.137	4.899	0.770	0.289
	V/ mm^3	1527.532	382.259	852.519	216.788	0.297	0.299
	S/ mm^2	641.416	254.713	431.636	74.023	0.030	0.100
	A_p /mm^2	387.677	113.483	209.289	46.238	0.453	0.650

Table 4 Linear and quadratic regression equations of nuts and kernels dimensions

Linear Regression Equation	R^2	Quadratic Regression Equation	R^2
$L = 1.338W + 6.865$	0.3564	$L = -0.1239W^2 + 6.331W - 42.35$	0.3930
$T = 0.3981W + 5.823$	0.4454	$T = 0.0099W^2 + 0.0024W + 5.823$	0.4487
$L = 1.576T + 11.250$	0.170	$L = -0.1161T^2 + 4.748T - 10.180$	0.1819
$l = 0.7116w + 14.280$	0.1457	$l = -0.2135w^2 + 6.216w - 20.360$	0.2864
$t = -0.0467w + 6.664$	0.0073	$t = -0.0122w^2 + 0.2678w + 4.685$	0.0127
$l = 0.1256t + 21.840$	0.0013	$l = -0.5631t^2 + 6.334t + 3.476$	0.0275
$L = 1.497l - 1.449$	0.8033	$L = 0.4139l^2 - 34.960l + 18.780$	0.8108
$W = 0.9323w + 8.174$	0.4500	$W = -0.1464w^2 + 4.708w - 15.59$	0.5691
$T = 0.4372t + 10.75$	0.0827	$T = 0.1809t^2 - 1.750t + 17.22$	0.0992

3.2 Modeling results

The three main dimensions and physical properties of nuts and kernels were modeled using the Normal, log-normal, Weibull and Generalized Extreme Value probability density functions distribution. The result for modeling of three dimensions distributions of almond nuts is shown in Table 5. For length, width and thickness of almond nuts distribution skewness have positive value, which is less than 1. For length distribution, value of kurtosis was between 0 and 1; in this case Log-normal had best prediction and Weibull had worst prediction. For width and thickness distribution, value of kurtosis was more than 1; in this case Log-normal and Generalized Extreme Value had best prediction and Weibull had worst prediction. Therefore, modeling dimensions of almond nuts Log-normal and Generalized Extreme Value have good performances and Weibull has a bad performance.

The results for modeling of dimensions of almond kernels distributions are shown in Table 6. For length and thickness of almond kernels distribution skewness and kurtosis have negative value and which are more than -1. In these cases, Generalized Extreme Value had best prediction and Weibull had worst prediction. For width distribution, skewness and kurtosis have positive value, which are more than 1. In these cases Generalized Extreme Value had best prediction and Log-normal had worst prediction. Therefore modeling dimensions of almond nuts and kernels show that Generalized Extreme

Value has best performance and Weibull has worst performance.

Table 5 Calculated parameter values of the different probability density functions for length, width and thickness of almond nuts

Dimension	Distribution	Mean	Variance	Location parameter	Scale parameter	Shape parameter	Log likelihood	Rank
Length /mm	Normal	32.402	24.956	32.4018	4.9956	–	−377.937	3
	Log-normal	32.405	25.039	0	3.4665	0.1535	−375.935	1
	Weibull	32.230	32.883	0	34.5665	6.5809	−385.604	4
	G.E.V	32.409	24.937	30.4735	4.5757	−0.1523	−376.048	2
Width /mm	Normal	19.088	4.9695	19.0877	2.2292	–	−277.075	3
	Log-normal	19.086	4.7167	0	2.9425	0.1134	−272.605	2
	Weibull	18.938	7.8897	0	20.1096	8.0031	−291.509	4
	G.E.V	19.086	4.9352	18.1141	1.8528	−0.0556	−270.289	1
Thickness /mm	Normal	13.421	1.7678	13.4209	1.3296	–	−212.475	2
	Log-normal	13.422	1.7852	0	2.5919	0.0993	−212.165	1
	Weibull	13.326	2.7460	0	14.0288	2.6560	−224.89	4
	G.E.V	13.447	1.9087	12.9037	1.3031	−0.1889	−213.872	3

Table 6 Calculated parameter values of the different probability density functions for length, width and thickness of almond kernels

Dimension	Distribution	Mean	Variance	Location parameter	Scale parameter	Shape parameter	Log likelihood	Rank
Length /mm	Normal	22.610	8.9435	22.6098	2.9906	–	−313.800	3
	Log-normal	22.616	9.6104	0	3.1094	0.1364	−316.547	4
	Weibull	22.593	9.6847	0	23.9003	8.6608	−313.683	2
	G.E.V	22.607	8.8858	21.6209	3.0589	−0.3314	−312.805	1
Width /mm	Normal	11.706	2.5725	11.7058	1.6039	–	−235.922	3
	Log-normal	11.703	2.2935	0	2.4516	0.1289	−227.19	2
	Weibull	11.560	4.6011	0	12.4308	6.2664	−255.796	4
	G.E.	11.722	2.4818	11.0234	1.2764	−0.0306	−223.963	1
Thickness /mm	Normal	6.1176	0.7650	6.1176	0.8747	–	−160.128	2
	Log-normal	6.1198	0.8297	0	1.8006	0.1480	−163.143	4
	Weibull	6.1114	0.8336	0	6.4918	7.9411	−160.517	3
	G.E.V	6.1173	0.7654	5.8189	0.8886	− 0.3094	−159.611	1

For an easy comparison between dimensions of almond kernels together, probability density functions are shown in Figure 2. For all modeling in Figure 1, Generalized Extreme Value was used, because it had best prediction of probability density functions of length, width and thickness of kernels. For length and thickness of kernels, skewness and kurtosis have negative value and for width, skewness and kurtosis have positive value; which is shown in Figure 1. This figure shows that there is little overlap between the PDF of length and width, and even lesser overlap between the PDF of width and thickness. There is no overlap between length and thickness. It means that the greatest measured thickness of kernel is lower than the lowest measured length.

Generalized Extreme Value for modeling physical parameters of almond nuts and kernels was used. Modeling results of Generalized Extreme Value are shown in Table 7. According to the obtained results, Generalized Extreme Value for modeling spheiricity of kernels compared to other physical properties has good performance and for modeling volume of nuts has bad performance.

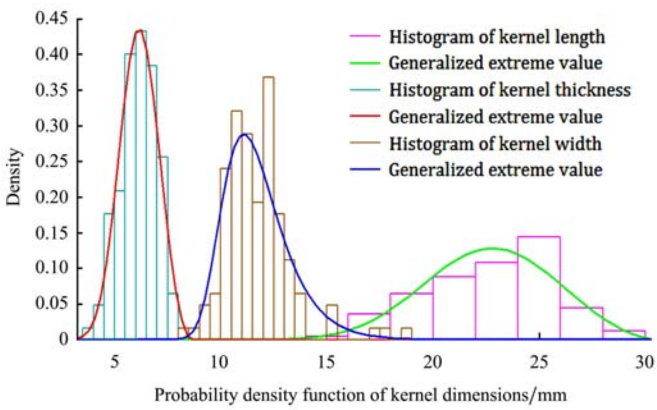

Figure 1 Probability density functions of measured and predictive length, width and thickness distribution of almond kernels

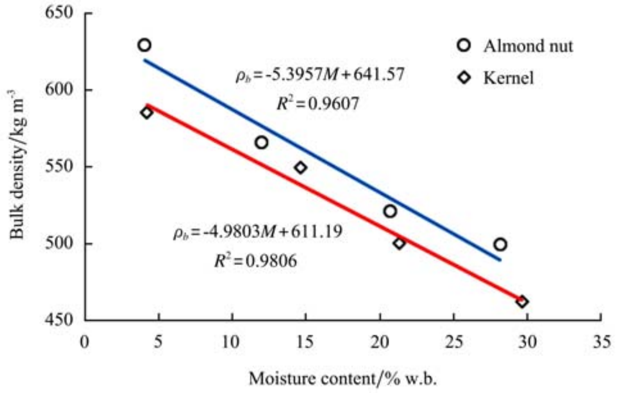

Figure 2 Variation of bulk density of almond nuts and kernels with moisture content

Table 7 Calculated parameter values of the Generalized Extreme Value distribution for physical properties of almond nuts and kernels

Particle	Dimensional properties	Mean of distribution	Variance of distribution	Location parameter	Scale parameter	Shape parameter
Nut	D_g / mm	20.1903	4.2929	19.3464	1.8988	−0.1525
	φ/ %	62.9168	27.479	60.7519	4.7385	−0.1366
	V/ mm^3	4451	2078840	3797.66	1096.97	0.0182
	S/ mm^2	1294.2	73225.2	1176.68	228.87	−0.0684
	A_p /mm^2	490.685	14433.7	438.162	100.42	−0.0577
kernel	D_g / mm	11.6822	1.0611	11.3291	1.0445	−0.3060
	φ/ %	52.1239	23.492	50.0027	4.0436	−0.0559
	V/ mm^3	853.263	47516.2	767.18	205.0	−0.1854
	S/ mm^2	431.952	5591.55	404.293	73.33	−0.2458
	A_p /mm^2	209.416	2179.22	190.100	42.11	−0.1343

3.3 Gravimetric properties

3.3.1 Mass properties

The mass, volume and surface area of almond nuts and kernels ranged from 2.13 g to 3.12 g and 0.44 g to 0.86 g, 2,212 mm^3 to 9,586 mm^3, 821 mm^2 to 2,182 mm^2 and 278 mm^2 to 861 mm^2 respectively. Mean value of nuts and kernels mass measured to be 2.80 g and 0.79 g respectively; these values were more than the value cited by Aydin (2003). Thousand nuts mass was found to be 2.782 kg. Corresponding value for almond kernels was found to be 791 g.

3.3.2 Densities

The values of bulk density of almond nuts at different moisture content levels (4.03%, 11.98%, 20.70% and 28.13%) ranged from 629.81 kg m^{-3} to 499.533 kg m^{-3}. Also the bulk density of almond kernels at different moisture content levels (4.2%, 14.6%, 21.35% and 29.64%) ranged from 585.35 kg m^{-3} to 462.343 kg m^{-3} (Figure 2). Results indicated that bulk density was decreased when the moisture content increased. The negative linear relationship of bulk density with moisture content was also observed by Aydin (2003).

Result indicated that, the true density of almond nut at different moisture levels ranged from 1,025.124 kg m^{-3} to 1,149.7 kg m^{-3}. The effect of moisture content on true density of almond nut showed an increase with moisture content. Effect of moisture content on true density of kernel showed an increase with moisture content from 939.629 kg m^{-3} to 1,077.428 kg m^{-3} (Figure 3). The effect of moisture content on true density of kernel showed an increase with moisture content. Similar results for correlation between nuts and kernels densities moisture content was mentioned by Aydin (2003).

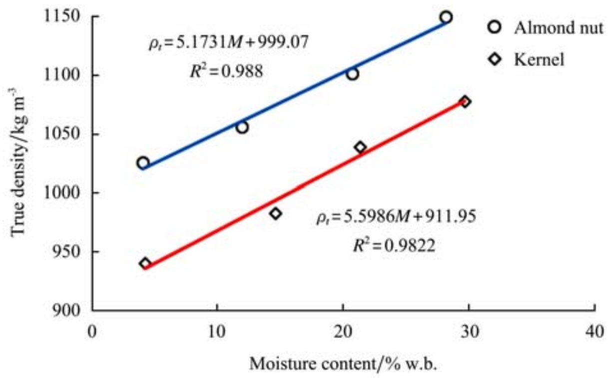

Figure 3 Variation of true density of almond nuts and kernels with moisture content

The porosity depends on the bulk and true density or kernel densities. The porosity of almond nut it was found to slightly increase with increase in moisture content from 4.03% to 28.13% (w.b.). The porosity of kernel was found to increase with increase in moisture content from 4.2% to 29.64% (w.b.) (Figure 4). In all

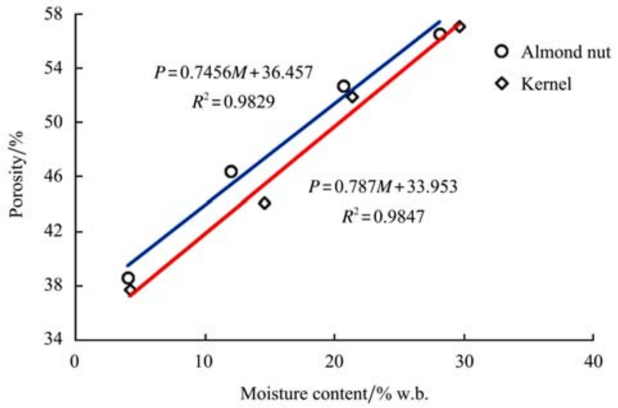

Figure 4 Variation of porosity of almond nuts and kernels with moisture content

moisture levels value of the porosity of nuts more than the kernels porosity. The form of the plot is similar to that for almond nuts and kernels as found by Aydin (2003).

3.4 Frictional properties

3.4.1 Friction of coefficient

The static coefficient of friction for almond kernel determined with respect to iron sheet metal, plywood and galvanized sheet metal surfaces are presented in Figure 5. When kernel moisture content increased, the friction coefficient increases. At all moisture contents, the static coefficients of friction were biggest for almond kernel, against iron and least for galvanized sheet metal, with plywood in between. Aydin (2003) reported a similar result.

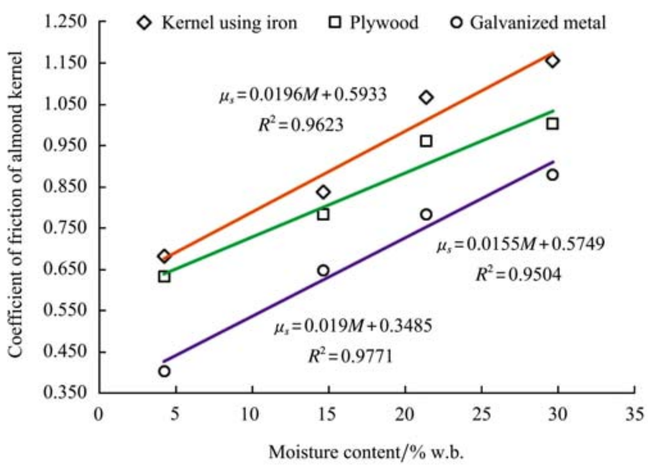

Figure 5 Effect of moisture content on static coefficient of friction

The static coefficient of friction for almond nut determined with respect to iron sheet metal, plywood and galvanized sheet metal surfaces are presented in Figure 6. When kernel moisture content increased, the friction coefficient increases. At all moisture contents, the static coefficients of friction were greatest for almond kernel, against iron and least for galvanized sheet metal, with plywood in between. Aydin (2003) reported a similar result.

A comparison between friction coefficient of kernel and nut indicated that, value of friction coefficient of kernel in same moisture content, more than the nuts friction coefficient. Aydin (2003) reported a similar result.

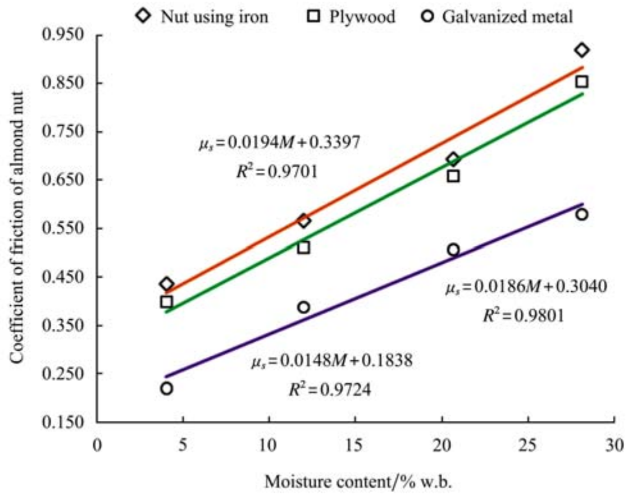

Figure 6 Effect of moisture content on static coefficient of friction

3.4.2 Angle of repose

The results of the pouring angle of repose (A_r) of nut with green shell, nut without green shell and kernels are shown in Table 8. Values of moisture content for nut with green shell, nut without green shell and kernels, 55.70%, 28.53% and 38.67% (w.b.) were measured, respectively. In all ceases value of angle of repose on iron sheet was more than the plywood and galvanized surfaces because value of friction coefficient on iron sheet was more than the plywood and galvanized surfaces. Also on all surfaces value of angle of repose of nut with green shell was more than the nut without green shell and kernel.

Table 8 Values of angle of repose of nuts and kernels on different surfaces

Material	Nut with green shell	Almond nut	Almond kernel
Iron steel	39.487	37.305	36.429
Plywood	38.271	36.818	36.211
Galvanized	35.484	33.5857	32.127

4 Conclusions

Results of linear and quadratic regression analysis show that there is no correlation between dimensions of kernels or dimensions of nuts. But for most almond nuts it can be said that increasing length of nut the kernel length also increased and vice-versa.

It can be said that whenever skewness value is between 0 and 1 and kurtosis value is between 0 and 1, log-normal distribution is the best and Weibull distribution has the worst function for predicting data. However, skwness and kurtosis have a small and negative value. Generalized Extreme Value distribution has the best prediction and Log-normal distribution has the worst prediction.

With increasing moisture content value of porosity and true density of kernels and nuts were increased and value of bulk density was decreased.

When kernels and nuts moisture content increased, the friction coefficient increases. At all moisture contents, the static coefficients of friction were greatest for almond kernel and nut, against iron and least for galvanized sheet metal, with plywood in between

Value of angle of repose of nut with green shell was more than the nut without green shell and kernel. Also value of angle of repose on iron sheet was more than the plywood and galvanized surfaces.

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