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Physical properties of in-shelled walnuts and kernels effected by moisture content

Tehmeena Ahad, AH Rather, SZ Hussain and Lubna Masoodi

Abstract
All the physical properties of the sample were assessed at moisture levels of 9%, 12%and 15% for whole almond and 4%, 5.5%, 7% for in shelled walnut and walnut kernel with three replications at each level. The average length, width, thickness, the geometric mean diameter, arthematic mean diameter and sphericity increased with increase in moisture content and values obtained ranged from 25.43mm-28.59 mm, 21.74mm- 24.77mm, 20.19- 22.65mm, 22.35mm – 25.22mm, 22.45mm – 25.34mm, 87.81% to 88.20% of inshell walnuts and 22.92mm-25.32mm, 19.05mm-21.45mm, 17.12mm- 18.44mm, 19.55mm 22.16, 19.70mm- 22.27mm, 85%- 87.51% for walnut kernel respectively. The values for bulk density increased from 241.25 kg/cm^3 – 275.36 kg/cm^3 at 9 to 15 % of moisture content in case of inshelled walnuts and 217.0 kg/cm^3 241.16 kg/cm^3 at 4% to 7% moisture content in walnut kernels. However porosity increased from 68.23 – 63.06 and specific gravity increased from 0.90 - 0.86. Similar case was found in the walnut kernels. The angle of repose increased from 33.42 to 35.81 in in-shelled and from to 31.52 to 33.95 in case of walnut kernels.

Keywords: Walnut, Correlative study, Kernel, physical properties

1. Introduction

Juglans regia, the Persian walnut is known to be indigenous to South-Eastern Europe, China and the Himalayan ranges, but its commercial cultivation and production are carried out in the United States of America, on a large scale as well. In commercial production of Persian, India ranks seventh after China, Iran, USA, Turkey, Romania and France (Anonymous, 2009; Martinez *et al*., 2010) [4, 11]. Out of the India's total production, the Jammu and Kashmir State of India alone accounts for >98% with an average productivity of 2.69 metric tonnes/ha from an area of 83613.80 ha and production of 224595.85 metric tonnes (Sharma *et al*., 2014) [15]. India export around 5000 metric tonnes walnut kernel of worth US $ 260-300 million annually to France, Germany, Spain, Portugal, Austria, United Kingdom, Kuwait, Bahrain, Dubai and Saudi Arabia. Besides, domestic market of worth of US $ 140-200 million for kernel and inshelled walnuts is also fulfilled by the state (Per. Com. with J and K Walnut Exporters Association in 2012).

On an average walnuts contain about 60-70% of lipids comprising of mono and polyunsaturated fats, 15.2% proteins, 13.7 per cent carbohydrates, 6.7 per cent dietary fibre and 1.8 per cent ash (Anonymous, 2004**;** Dogan and Akgul, 2005; Cosmulescu *et al*., 2009**)** [4, 6]**.** A diet supplemented with walnuts had a beneficial effect on blood lipids, lowering blood cholesterol and lowering the ratio of serum concentrations of low lipoprotein: high density lipoprotein by 12% [Gulber *et al*., 2002]. They are also good source of omega-3 oils with linoleic acid (44.2%), oleic acid (25.7%) and alfa linolenic acid (18.2%) as major components (Kuliev *et al*., 1987). Ascorbic acid, thiamine, riboflavin, niacin, pantothenic acid, vitamin B-6, foliate, vitamin A and vitamin E are the dominating vitamins and calcium, copper, iron, magnesium, manganese, phosphorous and potassium are the major minerals found in walnuts (Anonymous, 2004; Cosmulescu *et al*., 2009) [2, 6].

There is no published comprehensive literature on physical properties of walnut nuts and kernels and on physical properties of nuts and kernels of Kashmir cultivar; therefore, the aim of present study was to 1) measure three principle dimension of walnut nuts and kernels at three different moisture levels and measure various physical properties including weight, length, width, thickness, geometric diameter, arithmetic diameter, sphericity, surface area, surface volume, true density, bulk density, porosity, specific gravity, angle of repose and coefficient of friction.

2. Material and methods

Samples used in this study were walnut nuts and kernels collected in late September 2012 from a local producer in Budgam area of Kashmir. The nuts were immediately transported to laboratory and were stored at 5˚C prior to experiment. Bulk samples were selected randomly and the unwanted debrides and materials were removed from bulk sample of walnut nuts. The moisture content of shells and kernels were determined by the standard oven drying method at 105 °C for 24 h (Koyuncu *et al.*, 2004) [10]. Axial dimensions of walnut and kernel as length (*L*), width (*W*) and thickness (*T*) were measured by using a digital caliper gauge with a sensitivity of 0.01 mm. Nut and kernel masses were measured by using a digital balance with a sensitivity of 0.01 g using twenty nuts and kernels. The moisture contents for the shelled and kernel walnuts ranged between 9% to 15% and 4%.to 7%d.b. (dry basis), respectively.

The geometric mean diameter (GMD), Arthematic mean diameter (AMD) and Sphericity (ϕ) of the nuts were determined using the following Equation (1), (2) and (3)

$$\text{GMD} = 3\sqrt{\text{LWT}} \qquad (1)$$

$$\text{AMD} = \frac{\text{L} + \text{W} + \text{T}}{3} \qquad (2)$$

$$\text{Sphericity (\%)}\ \phi = \left(\frac{3\sqrt{\text{LWT}}}{\text{L}}\right) \text{x}\ 100 \qquad (3)$$

The surface area and surface volume of the nuts were calculated using the following Equation (4) and (5)

$$\text{Surface area (Sa) (mm}^2) = \lambda(\text{GMD})^2 \qquad (4)$$

$$\text{Surface volume (Sv) (mm)} = \frac{\lambda(\text{GMD})^3}{6} \qquad (5)$$

The true density of the shelled and kernel walnuts was determined by the toluene (C7H8) displacement method (Mohsenin 1970; Sitkei 1976; Sacilik *et al*. 2003) [14, 16]. The bulk density (*ρb*) 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 porosity (*ε*)of the fruits were calculated from bulk density and true density using following the Equation (6) and specific gravity were calculated from the true density and the density of toluene using equation (7)

$$\text{Porosity (\%)} \in = \left[1 - \frac{\rho b}{\rho t}\right] x\ 100 \qquad (6)$$

Specific gravity =
true density of sample/density of toulene (7)

Angle of repose was measured using pouring method, because the sphericity of almond nuts was very high (Fraczekn *et al*., 2007) [7]. The angle of repose of nuts sample was determined using a top and bottomless metallic cylinder of 250 mm height and 150 mm diameter (Mirzabe *et al*., 2013) [13]. The cylinder was placed on horizontal surface and was filled with nuts and kernels; then, the cylinder was raised very slowly. The height and radius of the cone were measured using a digital caliper. The static angle of repose was determined using the following Equation (8) reported by Milani *et al*. (2007) [12].

$$A_r = tan^{-1}\left(\frac{H}{R}\right) \qquad (8)$$

where, A_r represents angle of repose; *H,* height of the cone and *R* radius of the cone

The coefficient of friction (both static and dynamic) of the shelled and kernel walnuts was measured by a friction device at NIET, Dargah Hazratbal. The coefficient of friction (μ) is defined as the ratio between the measured friction force (F) and normal force (N).

The coefficient of friction of the shelled and kernel walnuts was measured by a friction device. The device of friction force measuring was formed by a metal box, a friction surface, and an electronic unit (Kara *et al*. 1997; Altuntas & Demirtola 2007) [9, 1]. Friction force was measured with a loadcell, converted by the ADC (Analog digital converter) card, and the data were recorded in a computer. The coefficient of friction (μ) is defined as the ratio between the measured friction force (F) and normal force (N). The maximum value of the friction force was obtained when the box started operating. This value was used to calculate the static coefficient of friction. While the box continued to slide on the friction surface at 0.02m/s velocity, the dynamic coefficient of friction (average value) was measured. The experiments were conducted using friction surfaces of chipboard and plywood.

3. Result and discussion

Dimensional properties

Length, width, thickness and dimensional properties of nuts and kernels of cultivar are shown in Table 1. The length, width, and thickness of walnut nuts at 9% and 15% ranged from 25.43 mm to 28.59mm, 21.74 mm to 24.77mm and 20.19 mm to 22.65 mm, respectively. The corresponding values for walnut kernels at 4% and 7% were found to be 22.92 mm to 25.32 mm, 19.05 mm to 21.45 mm and 17.12 mm to 20.04 mm, respectively indicating an increase with an increase in moisture content.

The geometric mean diameter, arithmetic mean diameter, sphericity, surface area, surface volume at 9% and 15% moisture content ranged from 22.47 mm to25.22 mm,22.45 to 25.34mm,87.81% to 88.20%, 1568.10 mm^2 to 1999.25mm^2, 5851.73mm^3 to 6189.27 mm^3 and 8421.21mm^3 at respectively (Table 1). The corresponding values for walnut kernels at 4 % and 7% moisture content were found to be 19.55mm to 22.16mm, 19.70mm to 22.27mm, 85.50% to 87.51%, 1202.21mm^2 to 1544.04mm^2, 3932.17mm^3 to 5717.81mm^3 respectively.

The bulk density at different moisture levels(9% and 15%) for the shelled and kernel walnuts varied from 241.25 $kg/m^3$to 275.36kg/m^3 and from 217.0kg/m^3 to 241.16 kg/m^3, respectively, indicating an increase in the bulk density with an increase in the moisture content. The reverse is the case with true density; it decreases with the increase in moisture content. The true density decreases from 778.41kg/m^3at 9% moisture content to 745.39 kg/m^3 at 15% moisture content. The corresponding values for walnut kernels were found to be

751.32kg/m³ at 4% moisture content to 723.41kg/m³ at 7% moisture content. The effect of the moisture content on the bulk and true density of the shelled walnuts and of the kernel walnuts was statistically significant ($P < 0.05$).

Table 1: Physical parmeters of In- shelled walnut and walnut kernel.

Parameters	In-Shelled walnut Moisture content				Walnut kernel Moisture content			
	9%	12%	15%	Regression equation	4%	5.5%	7%	Regression equation
Weight(mm)	10.45 ±0.02	12.53 ±0.02	15.26 ±0.02	Y=-2.127+0.802(X) R^2=0.988	7.54 ±0.03	9.13 ±0.03	11.76 ±0.03	Y=-0.740+1.407(X) R^2=0.960
Length(mm)	25.43 ±0.02	26.94 ±0.02	28.59 ±0.02	Y=-19.667+0.527(X) R^2=0.999	22.92 ±0.01	23.52 ±0.01	25.32 ±0.01	Y=-18.52+0.80(X) R^2=0.846
Width(mm)	21.74 ±0.01	22.87 ±0.01	24.77 ±0.01	Y=16.067+0.505(X) R^2=0.958	19.05 ±0.02	19.63 ±0.02	21.45 ±0.02	Y=14.64+0.80(X) R^2=0.837
Thickness(mm)	20.19 ±0.02	21.62 ±0.02	22.65 ±0.02	Y=15.567+0.410(X) R^2=0.958	17.12 ±0.02	18.44 ±0.02	20.04 ±0.02	Y=-12.183+0.973(X) R^2=0.997
Geometric dia(mm)	22.35 ±0.02	23.71 ±0.02	25.22 ±0.02	Y=16.998+0.479 (X) R^2=0.998	19.55 ±0.01	20.42 ±0.01	22.16 ±0.01	Y=14.925+0.87(X) R^2=0.929
Arithmetic dia(mm)	22.45 ±0.01	23.81 ±0.01	25.34 ±0.01	Y=17.087+0.482(X) R^2=0.998	19.7 ±0.01	20.53 ±0.01	22.27 ±0.01	Y=-15.12+0.857(X) R^2=0.920
Sphericity (%)	87.81 ±0.43	87.97 ±0.43	88.20 ±0.43	Y=86.690+0.70(x) R^2=0.885	85.50 ±0.44	86.80 ±0.44	87.51 ±0.44	Y=81.57+0.797(X) R^2=0.923
Surface area (mm^2)	1568.10 ±0.65	1766.10 ±0.65	1999.25 ±0.65	Y=806.738+68.54(x) R^2=0.990	1202.207 ±0.56	1311.397 ±0.56	1544.037 ±0.56	Y=626.89+108.48(X) R^2=0.916
Surface volume (mm3)	5851.73 ±1.34	6999.73 ±1.34	8421.21 ±1.34	Y=-1520.17+390.87(X) R^2=0.990	3932.17 ±1.55	4477.38 ±1.55	5717.81 ±1.55	Y=1078.43+539.2(X) R^2=0.903

Table 2: Bulk density, true density, porosity, specific gravity, angle of repose, coefficient of Static friction and coefficient of dynamic friction of In-shelled walnut and walnut kernel.

	In-Shelled walnut Moisture content				walnut kernel Moisture content			
	9%	12%	15%	Regression equation	4%	5.5%	7%	Regression equation
Bulk density(kg/m³)	241.25 ±0.75	259.39 ±0.75	275.36 ±0.75	Y=-685.38+5.503(X) R^2=0.995	217 ±0.65	228.35 ±0.65	241.16 ±0.65	Y=174.54+8.053(X) R^2=0.998
True density(kg/m³)	778.41 ±0.51	760.45 ±0.51	745.39 ±0.51	Y=180.447+5.685(X) R^2=0.997	751.3 ±0.31	737.6 ±0.31	723.41 ±0.31	Y=778.61-9.30(X) R^2=0.997
Porosity (%)	68.73 ±0.02	65.90 ±0.02	63.06 ±0.02	Y=73.09-0.513(X) R^2=0.984	71.12 ±0.01	69.05 ±0.01	66.72 ±0.01	Y=-78.61-9.3(X) R^2=0.995
Specific gravity	0.9 ±0.03	0.88 ±0.03	0.86 ±0.03	Y=0.930-0.07 (X) R^2=0.996	0.87 ±0.02	0.85 ±0.02	0.83 ±0.02	Y=0.913-0.132(X) R^2=0.991
Angle of repose	33.42 ±0.02	34.53 ±0.02	35.81 ±0.02	Y=26.87+0.405(X) R^2=0.995	31.52 ±0.03	32.73 ±0.03	33.95 ±0.03	Y=27.278+0.810(X) R^2=0.986
Coef. Of static friction	0.36 ±0.01	0.39 ±0.01	0.43 ±0.01	Y=0.047+0.012(x) R^2=0.986	0.19 ±0.01	0.23 ±0.01	0.26 ±0.01	Y=0.058+0.023(X) R^2=0.986
Coef. of dynamic friction	0.31 ±0.01	0.34 ±0.01	0.37 ±0.01	Y=0.01+0.01(x) R^2=0.998	0.15 ±0.02	0.18 ±0.02	0.21 ±0.02	Y=0.02+0.023(X) R^2=0.997

The result of the porosity for both shelled walnut and walnut kernel was found to be in increasing order similar to the true density. The porosity of shelled walnuts was recorded to be 68.73 at 9% moisture content which decreases to 63.06 as the moisture content increases to 15%.the porosity of walnut kernels was found to be 71.12 at 4% moisture content and66.72 at 7% The effect of the moisture content on porosity was statistically significant. Similar results were also reported by Gezer *et al*. (2003) [8] for apricot pit and kernel, by Aydin *et al*. (2002) [4] for Turkish mahaleb, and by Çalışır and Aydın (2004) [5] for cherry laurel.

The data obtained for the specific gravity of the shelled and kernel walnuts are presented the table. The average specific gravity of the shelled and kernel walnuts decrease with an increase in the moisture content. The specific gravity of shelled walnuts decreases from0.9 to 0.86 at 9% and 15% moisture content respectively. The specific gravity of walnut kernels decreases from 0.87 to 0.83 at 4% and 7% moisture content respectively. The effect of the moisture content on the shelled and kernel walnuts specific gravity was significant ($P < 0.05$).

The results of the coefficient of friction of walnut nuts and kernels are shown in Table (2) Value of coefficient of friction of nuts and kernels on plywood sheet is to be found more than the iron and galvanized surfaces so result of plywood were considered. The static coefficient of friction was higher at any moisture content than the dynamic coefficient of friction. A significant increase in both the friction values was recorded with the increases in moisture content from 9% to 15% in shelled walnuts and 4% to 7% moisture content in case of walnut kernels. The coeffient of static friction increases from0.36 to 0.43 in shelled walnuts and from to 0.19 to 0.26 in case of walnut kernels. The corresponding values found for coefficient of dynamic friction from 0.31 to 0.37 for shelled walnuts and 0.15 to 0.21 for walnut kernels. The effects of the moisture content and plywood friction surfaces on the static and dynamic coefficients of friction were significant for the kernel walnuts ($P < 0.05$).

As the moisture content increased, the angle of repose of the shelled and kernel walnuts increased (table 2) The angle of repose of the shelled walnut increased from 33.42 ˚C to 35.81 ˚C the increase in the moisture contents 9% and 15% respectively on plywood surface. The angle of repose of the kernel walnut increased from 31.52˚C to 33.95˚C. The effect of the moisture content on the angle of repose of the shelled and kernel walnut was statistically significant ($P < 0.01$).

Table 3: Correlation among different dimensional and physical properties of In-shelled walnut

	WT	L	W	T	G	A	SA	SV	SP	TD	BD	POR	SG	AR	CSF	CDF
WT		0.999*	0.998*	0.985	0.999*	0.999*	1.000*	1.000**	0.986	-0.992	0.993	-1.000**	-0.997*	0.999*	1.000**	0.997*
L			0.993	0.993	1.000**	1.000**	1.000*	0.999*	0.977	-.997*	0.998*	-0.999*	-1.000*	1.000**	0.998*	1.000*
W				0.972	0.994	0.994	0.996	0.997*	0.995	-0.981	0.983	-0.997	-0.989	0.995	0.998*	0.989
T					0.992	0.992	0.989	0.986	0.944	-0.999*	0.998*	-0.987	-0.996	0.991	0.985	0.996
G						1.000**	1.000*	0.999*	0.979	-0.996	0.997*	-1.000*	-0.999*	1.000**	0.999*	0.999*
A							1.000*	0.999*	0.978	-0.996	0.998*	-1.000*	-0.999*	1.000**	0.999*	0.999*
SA								1.000*	0.982	-0.995	0.996	-1.000**	-0.999*	1.000**	1.000*	0.999*
SV									0.985	-0.993	0.994	-1.000**	-0.997*	1.000*	1.000**	0.997*
SP										-0.957	0.961	-0.984	-0.971	0.98	0.987	0.971
TD											-1.000**	0.993	0.999*	-0.996	-0.991	-0.999*
BD												-0.995	-0.999*	0.997*	0.993	0.999*
POR													0.998*	-1.000*	-1.000*	-0.998*
SG												.		-0.999*	-0.997	-1.000**
AR															0.999*	0.999*
CSF																0.997
CDF																

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Correlation among dimensional properties of In- shelled walnuts

Length exhibits positive significant correlation with width (W), geometric dia (G), Arthematic dia (A), Surface area (SA), surface volume (SV), Bulk density (BD), Angle of repose (AR), Coef. of static friction (CSF) and Coef. of dynamic friction (CDF) and negative significance with true density (TD), Porosity(POR) and Specific gravity(SG) at 0.01% level of significance. Width is positive significant correlation with Surface volume (SV) and Coef. of static friction (CSF) at 0.01% level of significance. Thickness is positive correlated with Bulk density (BD) and negative correlated with True density (TD) at 0.01% level of significance. Geometric dia is positive significant correlation with Arthematic dia (A), Surface area (SA), surface volume (SV), Bulk density (BD), Angle of repose (AR), Coef. of static friction(CSF) and Coef. of dynamic friction (CDF) and negative significance with true density (TD), Porosity(POR) and Specific gravity(SG) at 0.01% level of significance. Arthematic dia is positive significant correlation with Surface area (SA), surface volume (SV), Bulk density (BD), Angle of repose (AR), Coef. of static friction(CSF) and Coef. of dynamic friction (CDF) and negative significance with true density (TD), Porosity(POR) and Specific gravity(SG) at 0.01% level of significance. Surface area (SA) is positive significant correlation surface volume (SV) Angle of repose (AR), Coef. of static friction (CSF) and Coef. of dynamic friction (CDF) and negative significance with Porosity (POR) and Specific gravity (SG) at 0.01% level of significance. Surface volume (SV) is positive significant correlation with Angle of repose (AR), Coef. of static friction(CSF) and Coef. of dynamic friction (CDF) and negative significance with Porosity (POR) and Specific gravity(SG) at 0.01% level of significance.

Correlation among physical properties In-shelled walnuts.

Weight is positive significant correlated with length (L), width (W), Geometric dia(G), Arthematic dia(A), Surface area (SA), Surface volume, Angle of repose (AR), Coef. of static friction (CSF) and Coef. of dynamic friction (CDF) and negatively correlated with Porosity (POR), Specific gravity (SG). True density is positive significant correlated with Specific gravity (SG) and Coef. of dynamic friction (CDF) at 0.01% level of significance and negative significant with Bulk density (BD) at 0.05% level of significance. Bulk density (BD) is negative significant correlated with specific gravity (SG) and positive correlated with Angle of repose (AR), and Coef. of dynamic friction (CDF) at 0.01 level of significance. Porosity (POR) is negative significant correlated with Angle of repose (AR), Coef. of static friction(CSF) and Coef. of dynamic friction (CDF) and positive significant with specific gravity (SG) at 0.01% level of significance. Angle of repose is positive significant with Coef. Of static friction(CSF) and Coef. of dynamic friction (CDF) at0.05% level of significance. Specific gravity (SG) is negatively correlated with Angle of repose (AR), Coef. of static friction (CSF) and Coef. of dynamic friction at 0.01%level of significance.

Table 4: Correlation among different dimensional and physical properties of walnut kernel

	WT	L	W	T	G	A	SA	SV	SP	TD	BD	POR	SG	AR	CSF	CDF
WT		0.99	0.989	0.996	0.999*	0.998*	0.998*	0.997	0.943	-0.991	0.994	-0.995	-0.99	0.99	0.975	0.99
L			1.000**	0.975	0.996	0.997	0.997*	0.998*	0.887	-0.963	0.97	-0.971	-0.961	0.961	0.935	0.961
W				0.973	0.995	0.996	0.997	0.998*	0.883	-0.961	0.968	-0.969	-0.958	0.959	0.932	0.958
T					0.991	0.989	0.989	0.986	0.968	-0.999*	1.000*	-1.000**	-0.998*	0.999*	0.991	0.998*
G						1.000**	1.000*	0.999*	0.926	-0.984	0.988	-0.989	-0.982	0.982	0.963	0.982
A							1.000**	1.000*	0.921	-0.982	0.986	-0.987	-0.98	0.98	0.96	0.98
SA								1.000*	0.919	-0.981	0.985	-0.986	-0.979	0.979	0.959	0.979
SV									0.913	-0.978	0.983	-0.983	-0.975	0.976	0.954	0.975
SP										-0.979	0.973	-0.972	-0.98	0.98	0.993	0.98
TD											-1.000*	1.000*	1.000**	-1.000**	-0.996	-1.000**
BD												-1.000**	-0.999*	0.999*	0.993	0.999*
POR													0.999*	-0.999*	-0.993	-0.999*
SG														-1.000**	-0.997	-1.000**
AR															0.996	1.000**
CSF																0.997
CDF																

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Correlation among dimensional properties of walnut kernel

Length exhibits positive significant correlation with width (W) at 0.05% level of significance and Surface area (SA), surface volume (SV) at 0.01% level of significance. Width is positive significant correlation with Surface volume (SV) at 0.01% level of significance. Thickness is positive correlated with bulk density (BD), Angle of repose (AR), and Coef. of dynamic friction (CDF) and negative significant with True density(TD), and Porosity(POR) at 0.01% level of significance. Geometric dia is positive significant correlation with Arthematic dia (A) at 0.05% level of significance and Surface area (SA), surface volume (SV) at 0.01% level of significance. Arthematic dia is positive significant correlation with Surface area (SA), surface volume (SV) at 0.05% and 0.01% level of significance. Surface area (SA) is positive significant correlation with surface volume (SV) at 0.01% level of significance.

Correlation among physical properties of walnut kernel.

Weight is positive significant correlated with length (L), width (W), Geometric dia (G), Arthematic dia(A),Surface area (SA), Surface volume, Angle of repose (AR), Coef. of static friction (CSF) and Coef. of dynamic friction (CDF) and negatively correlated with Porosity (POR), Specific gravity (SG). True density is positive significant correlated with Specific gravity (SG) and Porosity (POR) at 0.01% level of significance and negative significant with Bulk density (BD), Angle of repose (AR) and Coef. of dynamic friction (CDF). Bulk density (BD) is negative significant correlated with Porosity (POR) specific gravity (SG) and positive correlated with Angle of repose (AR), and Coef. of dynamic friction (CDF) at 0.01 level of significance. Porosity (POR) is negative significant correlated with Angle of repose(AR), Coef. of static friction (CSF) and Coef. of dynamic friction (CDF) and positive significant with specific gravity (SG) at 0.01% level of significance. Angle of repose is positive significant with Coef. of dynamic friction (CDF) at0.05% level of significance. Specific gravity(SG) is negatively correlated with Angle of repose(AR), and Coef. of dynamic friction at 0.05% level of significance.

Conclusion

The size dimensions, unit mass, geometric mean diameter, arthematic diameter, sphericity, bulk density, surface area, specific gravity, angle of repose of the in- shelled and kernel walnuts increased. The true density and porosity linearly decreased with an increase in the moisture content.The static and dynamic friction coefficients and angle of repose of the shelled and kernel walnuts on plywood surfaces increased with an increase in the moisture content.

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