Research Journal of Applied Sciences, Engineering and Technology 7(2): 379-387, 2014
DOI:10.19026/rjaset.7.265
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: April 20, 2013 Accepted: May 08, 2013 Published: January 10, 2014

Research Article

Some Engineering Properties of Four African Date Palm Fruit Cultivars

[1]Ndubisi A. Aviara, [1]Abubakar A. Lawal, [2]Lawrence A.O. Ogunjimi and [1]Abdu Dauda
[1]Department of Agricultural and Environmental Resources Engineering, Faculty of Engineering, University of Maiduguri, Maiduguri, Borno State, Nigeria
[2]Department of Agricultural and Environmental Engineering, Faculty of Technology, Obafemi Awolowo University Ile-Ife, Nigeria

Abstract: This investigation was carried out to study some physical, mechanical and thermal properties of four cultivars of African date fruits and kernels namely 'digila', 'krikri', 'sukur' and 'trigal'. The properties investigated include length, width, pulp thickness, roundness, sphericity, fruit and kernel mass, true density, bulk density and porosity. Others are angle of repose, static coefficient of friction, crushing strength and specific heat. Average fruit and kernel length of digila, krikri, sukur and trigal cultivars at the moisture contents of 17.85, 11.46, 15.85 and 12.27% (d.b.), respectively, was 38.04 and 21.98 mm, 30.70 and 22.99 mm, 33.23 and 22.40 mm and 36.08 and 22.60 mm. Corresponding average width value was 15.53 and 6.35 mm, 14.80 and 6.92 mm, 17.01 and 7.59 mm and 18.00 and 8.26 mm, for fruits and kernels. Roundness of digila, krikri, sukur and trigal fruit and kernel was 46.10 and 28.78%, 37.10 and 36.78%, 44.35 and 33.10% and 44.31 and 35.84%, respectively. Sphericity of fruit and kernel was, respectively 49.64 and 33.52% (digila), 58.81 and 37.40% (krikri), 47.85 and 35.70% (sukur) and 43.25 and 32.13% (trigal). Bulk density of the fruits of the cultivars was found to be relatively lower than that of their corresponding kernels. True density of fruits was lower than the density of water, while kernels were higher. Porosity of the fruits was 34.0, 35.21, 39.0 and 50.5% for digila, krikri, sukur and trigal and the corresponding kernel porosity was 38.8, 59.5, 30.3 and 48.6%, respectively. The angle of repose of fruit and kernel was found to be 19.82 and 34.94^{o} (digila), 18.07 and 33.36^{o} (krikri), 21.93 and 29.0^{o} (sukur) and 25.49 and 20.93^{o} (trigal). The crushing strength of both fruit and kernel was 6.74 and 10.68, 2.03 and 4.35, 13.15 and 17.64 and 5.63 and 9.67 kN/m^2, for digila, krikri, sukur and trigal, respectively. Static coefficient of friction of fruit and kernel varied structural surface. Specific heat varied with cultivar and was higher for the kernel than the fruit.

Keywords: African date palm, crushing strength, digila, krikri, Nigeria, physical properties, specific heat, sukur, trigal

INTRODUCTION

Date palm (*phoenix dactylifera*) is a crop of desert oases that has an unbranch slender trunk and grows up to 10 to 15 m tall with rings of leaves at the top (Al-Suhaibani *et al*., 1988). The crop is largely cultivated in North Africa and the Middle East (Kader and Hussein, 2009). In Nigeria, date palm is mainly cultivated in the arid and semi-arid regions of the North where the four cultivars popularly known as "digila", "krikri", "sukur" and "trigal" and respectively shown in Fig. 1a, b, c and d are commonly consumed. Date palm is mainly important for its fruit, that contains pulp, embedded inside of which is a hard kernel. The pulp is rich in digestible sugar and provides energy (Chandra *et al*., 1993; Kader and Hussein, 2009). It contains minerals like iron, potassium, calcium and phosphorus and is a good source of vitamins A, B, B_2, B_6 (Chandra *et al*., 1993). Its protein content varies from 1.75 to 2.75%.

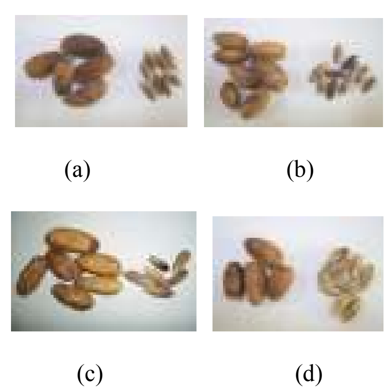

Fig. 1: Fruits and kernels of datepalm cultivars, (a) digila, (b) kri kri, (c) trigal and (d) sukur

The pulp is eaten raw (fresh or dry), or processed into various products such as cubes, pastes, spreads,

Corresponding Author: Ndubisi A. Aviara, Department of Agricultural and Environmental Resources Engineering, Faculty of Engineering, University of Maiduguri, Maiduguri, Borno State, Nigeria

powder, jam, jelly, juice and alcohol (Mahmoudi *et al*., 2008). The kernel is processed and used as coffee substitute or animal feed. The traditional methods of handling and processing date fruits as presently practiced are not only labor intensive but also time consuming. Improved methods of handling and processing the fruits and kernels using suitable machines and equipment can be developed if the engineering properties are known.

Several investigators studied the engineering properties of agricultural and food products for the above purpose. Aviara *et al*. (2007) and Mamman *et al*. (2005) investigated some physical and mechanical properties of guna fruit and balanites aegyptiaca nuts with a view to developing guna seed extractor and balanites aegyptiaca nut cracker respectively. The method utilized in determining the engineering properties of agricultural materials have been reported by investigators (Bhatia *et al*., 2009; Ahmadi *et al*., 2009; Sormez *et al*., 2007; Heidarbeigi *et al*., 2009; Abdullahi *et al*., 2011; Owolarafe *et al*., 2007; Aviara *et al*., 2005a; Naderiboldaji *et al*., 2008; Dash *et al*., 2008). The size of various fruits, nuts and seeds has been expressed using principal axial dimensions. The shape of materials has been described using roundness and sphericity. Investigators used either the gas displacement or liquid displacement methods to determine true density. Bulk density was determined using AOAC (1980) recommended method.

The relationship between porosity and bulk and true densities as stated by Mohsenin (1986) has been frequently utilized by investigators to evaluate the porosity of agricultural and food materials. Different methods of determining the static coefficient of friction of agricultural materials have been applied by investigators. These include the inclined plane method (Mohsenin, 1986; Naderiboldaji *et al*., 2008), the shear box equipment (Osunade and Lasisi, 1994) and moving a given surface against the material (Lawton, 1980). Different structural surfaces including galvanized metal sheet and plywood have been used. Angle of repose of fruits and nuts has been determined by investigators (Dash *et al*., 2008; Aviara *et al*., 2005b; Heidarbeigi *et al*., 2009) using a specially construction box with removable front panel. Ahmadi *et al*. (2009), Mamman *et al*. (2005) and Aviara *et al*. (2007), respectively determined the compressive strength of apricot fruit, balanite aegytiaca nuts and guna fruit using a Universal Testing Machine (UTM). Aviara and Haque (2001), Aviara *et al*. (2008) and Aviara *et al*. (2011) determined the specific heat of sheanut kernel, guna seed, moringa oleifera seed, soya bean and mucana flagellipes nuts, using the method of mixtures.

Al-Suhaibani *et al*. (1988) utilized physical measurements in establishing the specification of date palm service equipment. Some physical properties of date fruit were determined by Keramat Jahromi *et al*. (2007) but in the study, only one variety was investigated. Information on the variation of engineering properties of agricultural products with variety could be useful in the establishment of the specifications, determination of the adjustments and prediction of the performance of processing machines and equipment. The objective of this study was to determine some engineering properties of the fruits and kernels of four African date palm cultivars, namely, digila, krikri, sukur and trigal and investigate their variation with cultivar. The engineering properties studied were: size, roundness, sphericity, average mass, pulp thickness, true density, bulk density, porosity, angle of repose, static coefficient of friction, crushing strength and specific heat.

MATERIALS AND METHODS

Sample preparation: Bulk quantities of the four African cultivars of date palm fruit namely digila, trigal, krikri and sukur used in this study were purchased at the Monday market in Maiduguri, Borno State, Nigeria. The samples were manually cleaned to remove foreign materials, broken or immature fruits and kernels. Samples were spread on mat in thin layer at room temperature for 3 days after which their moisture contents were determined. Moisture content was determined following the procedure adopted by Aviara *et al*. (2005a), Fo'hat *et al*. (2011) and Kashaninejad *et al*. (2007). This involved oven drying at 105±2°C until a constant weight was reached.

Determination of physical properties: The physical properties determined in this study were size, shape, mass, true and bulk densities and porosity. A sample of 100 date fruits and kernels was randomly selected from each cultivar following the procedure described by Dutta *et al*. (1988a). For each fruit and kernel, two linear dimensions namely length and width, were measured using a vernier caliper reading to 0.01 mm. Kernel size and pulp thickness were determine by depulping each fruit in a sample and measuring the length and width of the kernel as well as the thickness of the pulp. The size distribution for the four cultivars was determined by classifying the fruits and kernels into large, medium and small after which the percentage average length, width, mass and pulp thickness in each class was determined and used to plot the frequency distribution curves. The dimensional characteristic ratios were determined using the procedure employed by Naderiboldaji *et al*. (2008). This involved computing the ratios of length and width and length and mass. The unit masses of berry and kernel of the four cultivars were measured by weighing 100 samples using an electronic weighing balance with an accuracy of 0.001 g and determining the averages.

The date fruit and kernel shapes were determined using roundness and sphericity. These parameters were determined following the procedure described by Maduako and Faborode (1990) and Oje (1994). The method involved placing the fruit or kernel of a given cultivar on a graph sheet in the natural position of rest and tracing the outline using a sharp pencil to form a shadowgraph. Largest inscribed and smallest circumscribed circles were constructed on each shadowgraph and the diameters of both circles were measured. The area of the smallest circumscribed circle was calculated and the projected area of the fruit or kernel was determined using the method of counting the squares. Thirty shadowgraphs of the fruit and kernel of each date cultivar were respectively used. Roundness was calculated using the formula stated by Mohsenin (1986) as:

$$R_a = \frac{A_P}{A_C} \quad (1)$$

where,

- R_a : Roundness
- A_p : The projected area of fruit or kernel shadowgraph in mm^2
- A_c : The area of the smallest circle circumscribing the shadowgraph in mm^2

Sphericity was determined from the ratio of diameters of inscribed to circumscribed circle as follows:

$$S_c = \frac{d_i}{d_c} \quad (2)$$

where,

- S_c : Sphericity,
- d_i : Diameter of inscribed circle in mm
- d_c : Diameter of circumscribed circle in mm

True density was obtained using the water displacement method as described by Dutta *et al*. (1988a) and Aviara *et al*. (1999). Thirty individual fruits and kernels from each date cultivar coated with a very thin layer of epoxy resin to prevent water absorption during the experiment were used. Bulk density was determined using the AOAC (1980) recommended method. This involved filling a 1500 mL cylinder with sample from a height of 15 cm and weighing its content. Porosity of samples was calculated using the relationship between true density and bulk density expressed by Jain and Bal (1997) as:

$$P = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (3)$$

where,

- P : Porosity in %
- ρ_t : True density in kg/m^3
- ρ_b : Bulk density in kg/m^3

Determination of frictional and mechanical properties: The frictional and mechanical properties of date palm fruits and kernels determined in this study were angle of repose, static coefficient of friction and crushing strength of the four cultivars. Angle of repose was determined following the procedure employed by Aviara *et al*. (2005b). This involved filling an open-ended box of 150×150×150 mm in size having removable front panel with sample. The front panel was quickly removed to allow sample to slide and assumed its natural slope in bulk. The angle of repose was calculated from the depth of the free surface of the sample to the horizontal distance from the side having the free surface. Static coefficient of friction of each date cultivar fruit and kernel was determined on four structural surfaces namely, glass, galvanized iron sheet, hessian bag, plywood with wood grains perpendicular to the direction of movement and plywood with wood grains parallel direction of movement. The method used was the one due to Dutta *et al*. (1988a) and Aviara *et al*. (2005a, b). It involved the placing of an open-ended box on table with adjustable tilting surface formed with a structural surface. The box was filled with sample and the structural surface with the box and content on top was gradually raised with a screw device until the box just started to slide down. The static coefficient of friction was calculated from the angle at which sliding was initiated. Compressive strength of the fruit and kernel of the four cultivars was determined using the method employed by Owolarafe *et al*. (2007) and Mamman *et al*. (2005) that involved loading the sample until failure occurred. The resulting stress known as crushing strength, σ was calculated from the ratio of the Crushing Force (Fc) to the Projected Area (Ap) of the sample given as:

$$\sigma = \frac{F_c}{A_p} \quad (4)$$

where,

- σ : The crushing strength in N/m^2
- F_c : The crushing force in N
- A_p : The projected area of the sample in m^2

Determination of thermal property (specific heat): The specific heat of date fruits and kernels was determined following the procedure employed by Dutta *et al*. (1988b), Aviara and Haque (2001), Aviara *et al*. (2008) and Aviara *et al*. (2011) in determining the specific heat of gram, sheanut kernel, guna seed, moringa oleifera seed, soya bean and mucuna flagellipes nut using the method of mixtures. Date fruits and kernels of known mass, temperature and moisture content from each cultivar, were placed in calorimeter containing water of known mass and temperature. The mixture was stirred continuously using a stirrer and temperature was recorded at an interval of three seconds. At equilibrium, the final temperature was noted and the specific heat was calculated using the equation:

Table 1: Some physical, mechanical and thermal properties of digila, krikri, sukur and trigal cultivars of date palm fruits and kernels

	Fruit			Variety			Kernel	
Property	Digila	Krikri	Sukur	Trigal	Digila	Krikri	Sukur	Trigal
Moisture content,% (d.b) Length (mm)	17.85 38.043 (3.878)*	11.46 30.7 (3.701)	15.85 33.238 (3.423)	12.27 36.083 (3.507)	- 21.987 (2.112)	- 22.993 (2.909)	- 22.407 (2.83)	- 22.603 (2.193)
Width (mm)	15.53 (1.56)	14.8 (1.474)	17.007 (2.532)	17.973 (1.368)	6.347 (0.668)	6.92 (0.986)	7.587 (0.798)	8.257 (0.775)
Pulp thickness (mm)	3.893 (0.535)	3.893 (0.97)	3.39 (1.106)	3.08 (0.424)	-	-	-	-
Roundness (%)	46.095 (3.912)	47.1 (4.501)	44.35 (7.836)	44.31 (5.436)	28.775 (4.429)	36.775 (6.982)	33.1 (7.988)	35.84 (6.891)
Sphericity (%)	49.04 (5.294)	48.814 (7.237)	47.85 (7.021)	43.25 (3.401)	33.519 (6.074)	37.4 (5.968)	35.7 (8.685)	32.132(7.62)
Mass (g)	6.008 (1.084)	3.401 (0.58)	5.782 (1.296)	5.057 (0.917)	0.664 (0.144)	0.667 (0.167)	0.901 (0.19)	0.874 (0.29)
Bulk density (kg/m^3)	566 (0.01)	548 (0.81)	450 (0.02)	410 (0.15)	701 (0.00)	621 (0.23)	634 (1.1)	740 (0.3)
True density (kg/m^3)	858 (1.81)	846 (3.88)	738 (1.96)	828 (0.4)	1146 (0.83)	1533 (3.28)	909 (1.12)	1439 (3.18)
Porosity (%)	34.00 (2.53)	35.21 (1.24)	39.0 (1.12)	50.5 (1.46)	38.8 (1.61)	59.5 (2.46)	30.3 (1.46)	48.6 (1.41)
Angle of repose (deg.)	19.82 (0.65)	18.07 (0.86)	21.93 (0.4)	25.49 (0.48)	34.94 (0.89)	33.36 (0.99)	29.0 (0.61)	20.93 (0.47)
Crushing strength (kN/m^2)	6.74 (1.004)	2.03 (0.118)	13.15 (3.171)	5.63 (0.814)	10.678 (0.927)	4.352 (2.113)	17.638 (9.978)	9.665 (1.717)
Static coeff. of (Glass) friction	0.156 (0.009)	0.193 (0.023)	0.21 (0.014)	0.38 (0.02)	0.151 (0.009)	0.471 (0.023)	0.249 (0.013)	0.185 (0.009)
(Galvanized sheet)	0.21 (0.014)	0.229 (0.023)	0.23 (0.014)	0.243 (0.012)	0.249 (0.013)	0.559 (0.038)	0.344 (0.014)	0.26 (0.017)
(Hessian bag)	0.294 (0.017)	0.413 (0.062)	9.274 (0.017)	0.497 (0.012)	0.348 (0.016)	0.601 (0.038)	0.348 (0.016)	0.391 (0.018)
(Plywood Perpendicular)	0.398 (0.043)	0.429 (0.027)	0.422 (0.047)	0.443 (0.023)	0.506 (0.018)	0.532 (0.031)	0.497 (0.025)	0.364 (0.014)
(Plywood parallel)	0.336 (025)	0.401 (0.044)	0.356 (0.017)	0.367 (0.012)	0.441 (0.017)	0.489 (0.062)	0.441 (0.017)	0.316 (0.031)
Specific heat(kJ/°Kkg	2103.9 (570.93)	3573.9 (426.02)	6103.5 (1835.6)	1115.3 (367.85)	2544.4 (186.17)	3808.1 (218.96)	6211 (516.84)	2243 (310.14)

*: Numbers in parentheses are S.D; coeff is coefficient

$$c_s = \frac{(m_c C_c + m_w C_w)[T_w - (T_e + t'R')]}{m_s[(T_e + t'R') - T_s]} \quad (5)$$

where, C_c, C_s and C_w are the specific heat of calorimeter, sample and water, respectively in J/kgK, m_c, m_s and m_w are masses of calorimeter, sample and water in kg, respectively. R' is the rate of temperature fall of the mixture after equilibrium in K/s, T_e is the equilibrium temperature of sample and water mixture in K, T_s and T_w are the initial temperatures of sample and water, respectively in K and t' is the time in s taken for the sample and water mixture to come to equilibrium. The term t'R' accounted for the heat of hydration and heat exchange with the surroundings. This experiment was replicated five times and the average values of the specific heat of samples were recorded.

Data obtained on all the properties studied were subjected to Analysis Of Variance (ANOVA) using Statistix version 9, to observe the variation of the properties among the cultivars.

RESULTS AND DISCUSSION

Moisture content: The moisture contents of the cultivars of date fruit under ambient condition were 17.85(1.84)% digila, 11.46 (1.63)% krikri, 15.85 (1.4)% sukur and 12.27(1.0)% d.b trigal. It can be seen that the digila cultivar had the highest moisture content while krikri had the lowest value.

Seed and kernel dimensions and size distribution: The axial dimensions of the date palm cultivar (digila, krikri, sukur and trigal) fruits and kernels as well as their pulp thicknesses at the above moisture contents are presented in Table 1. Table 2 shows that the length of fruit differed significantly with cultivar at 5% level of significance. Digilar cultivar had the longest length and krikri cultivar had the shortest length. The length of kernels of the four cultivars did not differ significantly (Table 2). Fruit and kernel width differed significantly with cultivar at 5% level of significance (Table 2). Width of trigal fruit and kernel was highest, while that of the digila fruit and kernel was lowest. Pulp thickness of all the cultivars appeared to be of similar value. Table 3 to 6 shows the size and mass distributions of the different date cultivar fruits and kernels. From the Table, it can be seen that most of the digila fruits were of small size, whereas the highest percentage of the kernels was large. The krikri cultivar had the highest percentage of its fruits falling within the large size, while the highest percentage of its kernels was of small size. In sukur, the medium size dominated the fruits and kernels, while trigal had mainly medium sized fruits and small sized kernels. Digila cultivar had the highest fruit and kernel length/width ratio, while sukur and trigal cultivars had the lowest fruit and kernel length/width ratio. The length/width ratios of date palm cultivars are higher than those of sweet cherry

Table 2: F-ratios and P-level of some engineering properties of four African date palm cultivars

	F- Ratio		P- level	
Property	Fruit	Kernel	Fruit	Kernel
Length	5.360	0.0800	0.041	0.968
Width	6.910	3.0900	0.037	0.090
Pulp thickness	0.730	-	0.562	-
Roundness	1.520	1.0900	0.283	0.394
Sphericity	3.640	0.2300	0.0639	0.801
Mass	0.600	1.1300	0.578	0.395
True density	0.160	4.6400	0.921	0.037
Bulk Density	1.430	0.8300	0.326	0.673
Porosity	2.110	3.0800	0.044	0.013
Angle of repose	79.56	200.69	0.000	0.000
Crushing strength	4.880	3.3200	0.048	0.038
Specific heat capacity	14.07	18.290	0.002	0.001
Static coefficient of friction				
Cultivar (C)	91.26	224.11	0.000	0.000
Structural Surface (SS)	530.75	1126.55	0.000	0.000
Interaction C*SS	48.04	182.67	0.000	0.000

Table 3: Size and mass distributions of Digila cultivar of date palm fruit and kernel at the moisture content of 17.85% (d.b)

Particulars	Length (mm)	Percentage of sample (%)	Average length (mm)	Average width (mm)	Average mass (g)	Average thickness of pulp (mm)	Average length/width ratio	Average length/mass ratio
Fruit								
Ungraded	31.8 $\leq L_f \leq$48.8	100	38.04 (3.88)*	15.53 (1.56)	6.01 (1.08)	3.89 (0.54)	2.47 (0.28)	6.45 (0.76)
Large	43.2$\leq L_f \leq$ 48.8	10.0	46.53 (2.87)	17.17 (0.76)	7.64 (0.61)	4.07 (0.95)	2.71 (0.14)	6.12 (0.71)
Medium	37.5$\leq L_f \leq$ 43.1	36.7	39.46 (1.70)	15.71 (1.43)	6.43 (0.97)	3.96 (0.56)	2.53 (0.24)	6.25 (0.85)
Small	$L_f \leq$ 37.4	53.3	35.47 (1.76)	15.1 (1.6)	5.41 (0.75)	3.81 (0.45)	2.38 (0.3)	6.64 (0.7)
Kernel								
Ungraded	17.2 $\leq L_k \leq$25.9	100	22 (2.11)	6.35 (0.67)	0.66 (0.14)	-	3.49 (0.43)	34.32 (6.62)
Large	23.0$\leq L_k \leq$ 25.9	40.0	24.13 (0.85)	6.43 (0.43)	0.76 (0.11)	-	3.76 (0.23)	32.46 (3.96)
Medium	20.1$\leq L_k \leq$ 22.9	36.6	21.39 (0.62)	6.2 (0.7)	0.63 (0.15)	-	3.49 (0.36)	35.45 (8.04)
Small	$L_k \leq$ 20	23.4	19.24 (0.97)	6.43 (0.97)	0.56 (0.11)	-	3.05 (0.44)	35.72 (7.97)

*: Numbers in parentheses are standard deviations

Table 4: Size and mass distributions of Krikri cultivar of date palm fruit and kernel at the moisture content of 11.64% (d.b)

Particulars	Length (mm)	Percentage of Sample (%)	Average length (mm)	Average width (mm)	Average mass (g)	Average thickness of pulp (mm)	Average length/width ratio	Average length/mass ratio
Fruit								
Ungraded	25.5 $\leq L_f \leq$39.9	100	30.70 (3.70)*	14.80 (1.47)	3.40 (0.58)	3.89 (0.97)	2.09 (0.27)	9.33 (2.16)
Large	35.2 $\leq L_f \leq$39.9	6.6	39.40 (0.57)	14.55 (0.21)	6.30 (0.57)	3.65 (0.07)	2.71 (0.00)	11.07 (1.58)
Medium	30.4 $\leq L_f \leq$35.1	36.7	33.33 (1.06)	15.58 (1.25)	3.29 (0.68)	4.64 (0.91)	2.15 (0.15)	10.58 (2.36)
Small	$L_f \leq$30.3	56.7	27.98 (1.41)	14.29 (1.51)	3.45 (0.54)	3.44 (0.76)	1.98 (0.22)	8.31 (1.52)
Kernel								
Ungraded	18.1$\leq L_k \leq$ 29.7	100	23 (2.91)	6.92 (0.99)	0.68 (0.17)	-	3.38 (0.6)	36.55 (12.44)
Large	25.9 $\leq L_k \leq$29.7	16.6	28.30 (1.31)	6.82 (0.65)	0.73 (0.06)	-	4.18 (0.47)	39.19 (3.71)
Medium	22$\leq L_k \leq$ 25.8	36.7	23.264 (1.15)	6.96 (0.93)	0.59 (0.17)	-	3.40 (0.49)	43.76 (16.58)
Small	$L_k \leq$ 21.9	46.7	20.89 (1.29)	6.92 (1.17)	0.73 (0.16)	-	3.08 (0.44)	29.94 (6.00)

*: Numbers in parentheses are standard deviations

Table 5: Size and mass distributions of Sukur cultivar of date palm fruit and kernel at the moisture content of 15.85% (d.b)

Particulars	Length (mm)	Percentage of sample (%)	Average length (mm)	Average width (mm)	Average mass (g)	Average thickness of pulp (mm)	Average length/width ratio	Average length/mass ratio
Fruit								
Ungraded	26.4$\leq L_f \leq$ 41.9	100	33.24 (3.42)*	17.01 (2.53)	5.78 (1.3)	3.39 (1.15)	1.98 (0.33)	5.84 (0.82)
Large	36.8$\leq L_f \leq$ 41.9	10.4	39.77 (1.94)	17.67 (0.46)	7.57 (1.38)	4.5 (0.87)	2.25 (0.06)	5.36 (0.9)
Medium	31.6$\leq L_f \leq$ 36.7	58.6	34.03 (1.33)	17.72 (2.67)	6.2 (0.86)	3.56 (1.11)	1.97 (0.36)	5.58 (0.66)
Small	$L_f \leq$ 31.5	31	29.57 (2.01)	15.81 (2.15)	4.63 (0.77)	2.8 (0.87)	1.91(0.28)	6.49 (0.77)
Kernel								
Ungraded	16.8$\leq L_k \leq$ 28.1	100	22.41 (2.83)	7.59 (0.8)	0.90 (0.19)	-	3.00 (0.44)	25.82 (6.01)
Large	24.4 $\leq L_k \leq$28.1	16.7	26.68 (1.25)	7.54 (0.9)	1.048 (0.1)	-	3.59(0.57)	25.61 (2.06)
Medium	20.6$\leq L_k \leq$ 24.3	60	22.71 (1.09)	7.86 (0.62)	0.92 (0.19)	-	2.91 (0.3)	25.91 (7.11)
Small	$L_k \leq$ 20.5	23.3	18.37 (1.27)	6.77 (0.8)	0.74 (0.15)	-	2.73(0.21)	25.73 (5.17)

*: Numbers in parentheses are standard deviations

Table 6: Size and mass distributions of Trigal cultivar of date palm fruit and kernel at the moisture content of 12.27% (d.b)

Particulars	Length (mm)	Percentage of Sample (%)	Average length (mm)	Average width (mm)	Average mass (g)	Average thickness of pulp (mm)	Average length/width ratio	Average length/mass ratio
Fruit								
Ungraded	30.2 $\leq L_f \leq$42.1	100	36.08 (3.51)*	17.97 (1.37)	5.06 (0.92)	3.08 (0.42)	2.02 (0.26)	7.25 (0.83)
Large	38.2$\leq L_f \leq$ 42.1	33.3	40.12 (1.24)	18.22 (2.23)	5.84 (1.00)	3.30 (0.35)	2.24 (0.32)	7.03 (1.12)
Medium	34.2$\leq L_f \leq$ 38.1	40	35.66 (0.82)	17.98 (0.75)	4.86 (0.58)	3.03 (0.41)	1.99 (0.10)	7.41 (0.72)
Small	$L_f \leq$ 34.1	26.7	31.67 (1.43)	17.71 (0.59)	4.37 (0.43)	2.89 (0.46)	1.79 (0.07)	7.29 (0.57)
Kernel								
Ungraded	20.1$\leq L_k \leq$ 27.2	100	22.60 (2.19)	8.26 (0.78)	0.87 (0.29)	-	2.76 (0.34)	28.44 (8.88)
Large	24.9$\leq L_k \leq$ 27.2	23.4	26.09 (1.02)	8.56 (1.03)	1.04 (0.32)	-	3.08 (0.35)	27.63 (1.02)
Medium	22.5$\leq L_k \leq$ 24.8	13.3	23.10 (0.32)	8.00 (0.81)	0.85 (0.26)	-	2.91 (0.32)	29.302 (9.08)
Small	$L_k \leq$ 22.4	63.3	21.22 (0.76)	8.20 (0.67)	0.82 (0.27)	-	2.61 (0.25)	28.55 (8.86)

*: Numbers in parentheses are standard deviations

(Naderiboldaji *et al*., 2008) and rose (Demir and Ozcan, 2001).

The frequency distribution curves for the dimensions, pulp thickness and mass of various date palm cultivars are presented in Fig. 2. The trend of the curves tended towards normal distribution. The length of trigal and width of sukur exhibited bimodal distribution. The peak of all the curves corresponded to the mean values of the parameters. Similar results were reported by Makanjuola (1972), Ige (1977), Joshi *et al*. (1993), Carman (1996), Suthar and Das (1996), Aviara *et al*. (2000) and Irtwange and Igbeka (2002), for melon seeds, cowpea varieties, pumpkin seeds, lentils seeds, karingda seeds, sheanut and African yam bean accessions respectively. The average mass of each cultivar fruit (Table 1) was higher than that of the

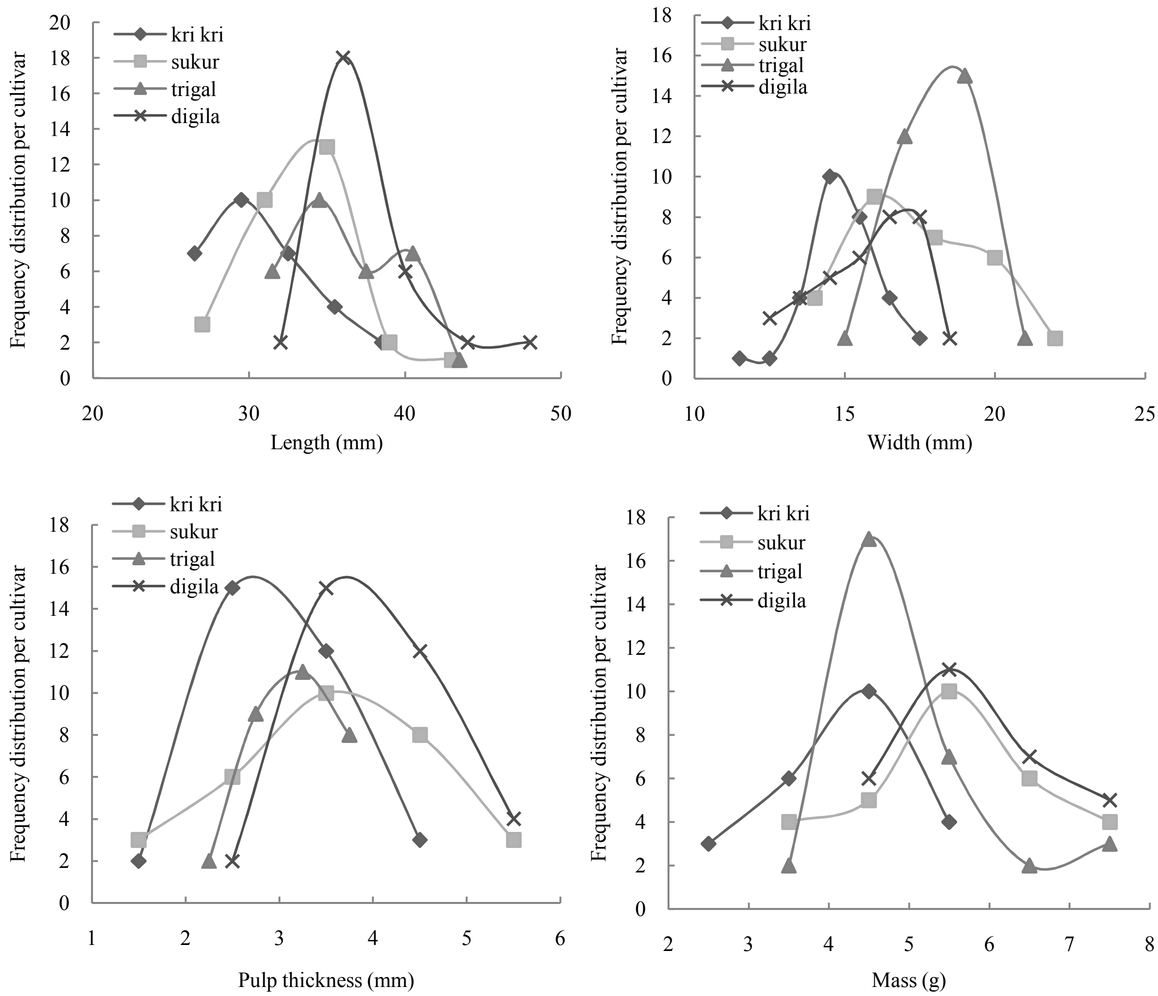

Fig. 2: Frequency distribution curves of the dimensions and mass of different date palm cultivar fruits: length, pulp thickness, width and mass

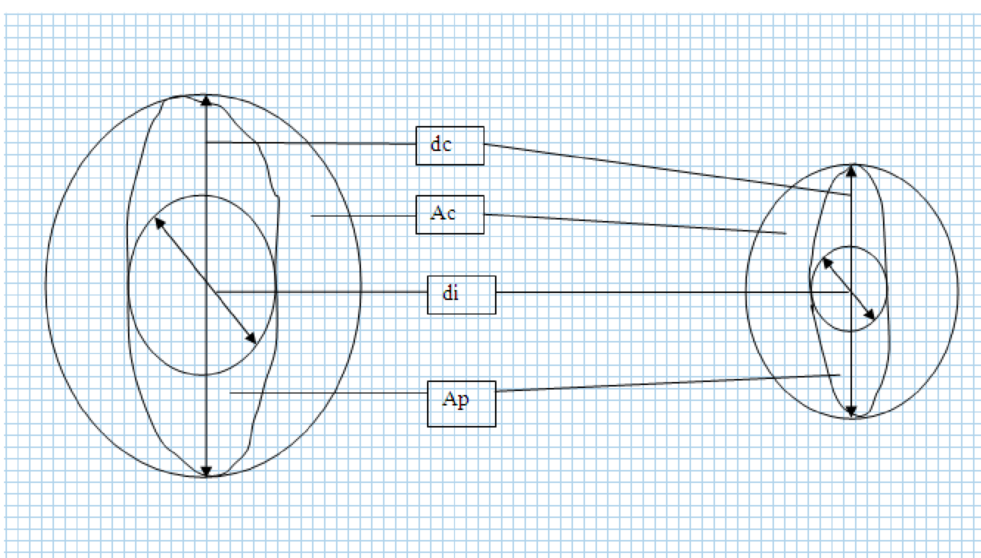

Fig. 3: Typical shadowgraphs of datepalm fruit and kernel, dc-diameter of circumscribed circle, Ac-area of circumscribed circle, di-diameter of inscribed circle, Ap-projected area

kernel. The mass of digila fruit and sukur kernel was, respectively of the highest value. Large fruits and kernels of all the cultivars (Table 3 to 6) were heaviest, while the small size fruits were lightest. For kernels, the small sized digila, sukur and trigal cultivars were lightest. Medium size kernel of the krikri cultivar was of lower mass than the small size kernels. Krikri cultivar had the highest fruit and kernel length/mass ratio (Table 1), while sukur cultivar had the lowest fruit and kernel length/mass ratio. Typical shadowgraphs of date palm fruit and kernel are presented in Fig. 3. Table 1 shows that the roundness and sphericity of the fruits and kenels were less than 50% indicating that they should not be treated as spheroidal objects in the analytical determination of their behavior when subjected to thermal processing. Krikri and digila fruits had the highest values of roundness and sphericity respectively, while krikri had the highest roundness and sphericity among kernels.

Bulk density, true density and porosity: The bulk density, true density and porosity of date palm cultivars are presented in Table 1. Digila and krikri fruits had higher bulk density than sukur and trigal, while digila and trigal kernels had higher bulk density than krikri and sukur kernels. This indicates that the fruits and kernels of digila cultivar would require lesser space for storage per unit weight than those of the other cultivars. The fruits of trigal and sukur and kernels of krikri and sukur would require more spaces for storage per unit wt compared to those of the other cultivars. The true density of the four date fruit cultivars showed that digila fruit had the highest value, while sukur had the lowest average value. Krikri kernel had the highest true density, while that of sukur had the lowest value. From the values of true density it can be seen that the date fruits would float on water surface, while the kernels would sink. The exception is the kernel of sukur that would be partially submerged. Table 1 shows that the porosity of date fruits and kernels varied with cultivar. Trigal fruit had the highest porosity, while digila fruit had the lowest value. From Table 1, it can be seen that krikri kernel had the highest porosity while sukur kernel had the lowest value. This indicates that trigal fruit and krikri kernel had more void spaces than the other cultivars. Table 2 shows that the variation of date palm fruit and kernel porosity with cultivar was significant at 5% level of significance.

Mechanical properties: The angle of repose of fruits and kernels for different cultivars of date palm is presented in Table 1. From the Table, it can be seen that the angle of repose of the fruit was lower than that of the kernel for various cultivars with the exception of trigal. Trigal fruit had the highest angle of repose value, followed by sukur, digila and krikri fruits. Digila kernel had the highest angle of repose, while trigal kernel had the lowest value. Table 2 shows that the variation of fruit and kernel angle of repose with cultivar was significant at 1% level of significance. These values of angle of repose of fruit and kernel reveal that the fruits have more tendencies to flow than kernel. Trigal fruit would be the least flowable, while its kernel would be the most flowable among the date cultivars.

The static coefficient of friction of the four date cultivars fruits and kernels on different structural surfaces is presented in Table 1. The static coefficient of friction of fruit and kernel varied with cultivar and structural surface. Trigal and digila fruits had the highest and lowest static coefficient of friction, respectively, on all surfaces, except on hessian bag and plywood with grain parallel to the direction of sliding where krikri and sukur fruits the highest and lowest coefficients, respectively. Kernel of krikri had the highest static coefficient of friction on all the structural surfaces used. Table 2 shows that the variation of fruit and kernel coefficients of friction with cultivar and structural surface was significant at 1% level of significance.

The crushing strength of different cultivars of date palm fruits and kernels is respectively presented in Table 1. Sukur fruit and kernel had the highest crushing strength respectively, followed by those of digila and trigal with those of krikri having the lowest values. Table 2 shows that the variation of fruit and kernel crushing strength with date palm cultivar was significant at 5% level of significance.

Thermal property: The variation of specific heat for date palm fruit and kernel with cultivar is presented in Table 1. The Table shows that sukur fruit and kernel had the highest specific heat, while trigal had the lowest values. Table 2 shows that the variation of date palm fruit and kernel specific heat with cultivar was significant at 1% level of significance.

CONCLUSION

- Some engineering properties of the fruits and kernels of four African date palm cultivars namely digila, krikri, sukur and trigal were determined at the moisture level of 17.85, 11.46, 15.85 and 12.27% (d.b.), respectively.
- Geometric properties of the fruits were significantly affected by cultivar, while those of the kernels were not significantly affected.
- Gravimetric properties of the fruits and kernels were not significantly affected by cultivar, with the exception of kernel true density that varied significantly with date cultivar.

- Porosity of the fruits and kernels varied significantly with cultivar.
- Angle of repose, static coefficient of friction on five structural surfaces and crushing strength of fruits and kernels significantly varied with cultivar.
- Specific heat of date fruit and kernel varied significantly with cultivar.

REFERENCES

Abdullahi, M.H.R.O., P.E. Ch'ng and T.H. Lim, 2011. Some physical properties of Parkia speciosa seeds. Proceeding of the 6th International Conference on Food Engineering and Biotechnology, Retrieved from: http//www.ipcbee.com/vol9/9-Bo21.pdf, /04/2012.

Ahmadi, H., H. Fathollahzadeh and H. Mobli, 2009. Post harvest physical and mechanical properties of Apricot fruits, pits and kernels (C.V. Sonnati Salmas) cultivated in Iran. Pak. J. Nutr., 8(3): 264-268.

Al-Suhaibani, S.A., A.S. Babeir, J. Kilgour and J.C. Flynn, 1988. The design of a date palm service machine. J. Agric. Eng. Res., 40: 143-157.

AOAC, 1980. Official Methods of Analysis. Association of Official Analytical Chemists Press, Washington, D.C.

Aviara, N.A. and M.A. Haque, 2001. Moisture dependence of thermal properties of sheanut kernel. J. Food Eng., 47: 109-113.

Aviara, N.A., M.A. Haque and I.A. Izge, 2000. Physical and frictional properties of sheanut. Agroscience, 1(2): 19-34.

Aviara, N.A., E. Mamman and B. Umar, 2005a. Some physical properties of balanites aegyptiaca nuts. Biosyst. Eng., 92(3): 325-334.

Aviara, N.A., F.A. Oluwole and M.A. Haque, 2005b. Effect of moisture content on some physical properties of sheanut (Butyrospernum Paradoxum). Int. Agrophys., 19: 193-198.

Aviara, N.A., M.A. Haque and L.A.O. Ogunjimi, 2008. Therma properties of guna seed. Int. Agrophys., 22: 291-297.

Aviara, N.A., M.I. Gwandzang and M.A. Haque, 1999. Physical properties of guna seeds. J. Agric. Eng. Res., 73(2): 105-111.

Aviara, N.A., S.E. Ehiabhi, O.O. Ajibola, S.A. Oni, P.P. Power, T. Abbas and O.A. Onuh, 2011. Effect moisture content and temperature on the specific heat of soya bean, moringa oleifera seed and mucuna flagellipes nut. Int. J. Agric. Biol. Eng., 4(1): 87-92.

Aviara, N.A., S.K. Shittu and M.A. Haque, 2007. Physical properties of guna fruits relevant in bulk handling and mechanical processing. Int. Agrophysics, 21: 7-16.

Bhatia, T., R.K. Sharma, K.K. Prasad and K. Prasad, 2009. Studies on some properties of protein-rich legume (Lens esculantus) splits. Asian J. Chem., 21(10): 103-107.

Carman, K., 1996. Somephysical properties of Lentil seed. J. Agric. Eng. Res., 63: 87-92.

Chandra, A., A. Chandra and I.C. Gupta, 1993. Arid Fruit Research, Chapter 7: Date Palm. Scientific Publishers, Jodhpur, India.

Dash, A.K., R.C. Pradhan, L.M. Das and S.N. Naik, 2008. Some physical properties of simarouba fruit and kernel. Int. Agrophys., 22: 111-116.

Demir, F. and M. Ozcan, 2001. Chemical and technological properties of rose (Roscanina L.) fruits grown wild in Turkey. J. Food Eng., 47: 333-336.

Dutta, S.K., V.K. Nema and R.K. Bhardwaj, 1988a. Physical properties of gram. J. Agric. Eng. Res., 39: 259-268.

Dutta, S.K., V.K. Nema and R.K. Bhardwaj, 1988b. Thermal properties of gram. J. Agric. Eng. Res., 39: 269-275.

Fo'hat, M., V. Etemad, S.M.T. Gharibzahedi and M. Ghahderijani, 2011. Physical, mechanical and aerodynamic properties of Acorn (*Quercus suber* L.) as potentials for development of processing machines. Aust. J. Crop Sci., 5(4): 473-378.

Heidarbeigi, K., H. Ahmadi, K. Kheiralipour and A. Tabatabaeefar, 2009. Some physical and mechanical properties of Khinjuk. Pak. J. Nutr., 8(1): 74-77.

Ige, M.T., 1977. Measurement of some parameters affecting the handling losses of some varieties of cowpea. J. Agric. Eng. Res., 34: 75-81.

Irtwange, S.V. and J.C. Igbeka, 2002. Some physical properties of two African yam bean (Sphenostylis stenocarpa) accessions and their interrelation with moisture content. Appl. Eng. Agric., 18(5): 567-576.

Jain, R.K. and S. Bal, 1997. Physical properties of pearl millet. J. Agric. Eng. Res., 66: 85-91.

Joshi, D.C., S.K. Das and R.K. Mukherjee, 1993. Physical properties of pumpkin seeds. J. Agric. Eng. Res., 54(3): 219-229.

Kader, A.A. and A.M. Hussein, 2009. Harvesting and post-harvest handling of dates. International Center for Agricultural Research in the Dry Areas, Aleppo, Syria, 15: 15.

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

Keramat Jahromi, M., A. Jafari, S. Rafiee, A.R. Keyhani, R. Mirasheh and S.S. Mohtasebi, 2007. Some physical properties of date fruit (cv. Lasht). Agricuitural Engineering International: the CIGR Ejournal. Manuscript FP 07 019. Vol. 9. Retrieved from: www.cigrjournal.org.

Lawton, P.J., 1980. Coefficient of friction between cereal grain and various silo wall materials. J. Agric. Eng. Res., 25: 75-86.

Maduako, J.N. and M.O. Faborode, 1990. Some physical properties of cocoa pods in relation to primary processing. Ife J. Technol., 2(1): 1-7.

Mahmoudi, H., G. Hosseininia, H. Azadi and M. Fatemi, 2008. Enhancing date palm processing, marketing and pest control through organic culture. J. Organ. Syst., 3(2): 29-39.

Makanjuola, N.N., 1972. A study of some of the physical properties of melon seeds. J. Agric. Eng. Res., 17: 128-137.

Mamman, E., B. Umar and N.A. Aviara, 2005. Effect of moisture content and loading orientation on the mechanical properties of Balanites Aegyptiaca nuts. Agric. Eng. Int. CIGR E-J., FP04 015, VII. Retrieved from: www.cigrjournal.org.

Mohsenin, N.N., 1986. Physical Properties of Plant and Animal Materials. 2nd Edn., Gordon and Breach Science Publishers, New York.

Naderiboldaji, M., A. Khadivi khub, A. Tabatabaeefar, V.M. Ghasemi and Z. Zamani, 2008. Some physical properties of sweet cherry (prunus avium L.) fruit. Am-Eurasian J. Agric. Environ. Sci., 3(4): 513-520.

Oje, K., 1994. Moisture dependence of some physical properties of cowpea. Ife J. Technol., 4(2): 23-27.

Osunade, J.A. and F. Lasisi, 1994. Coefficient of friction of maize and sorghum grains on laterized concrete wall. NSE Tech. Transact., 29: 50-57.

Owolarafe, O.K., M.T. Olabige and M.O. Faborode, 2007. Physical and mechanical properties of two varieties of fresh oil palm fruit. J. Food Eng., 78(4): 228-1232.

Sormez, N., H.H.A. Alizadeh, R. Ozturk, A.I. Acar and G. Tarihi, 2007. Some physical properties of gilaburu seed. Tarim Bilimleri Dergisi, 13(3): 308-311.

Suthar, S.H. and S.K. Das, 1996. Some physical properties of karingda [citrullus lanatus (Thumb) Mansf] seeds. J. Agric. Eng. Res., 65: 15-22.