University of Maiduguri
ANNALS OF BORNO
Volume XXVI, June 2016

Engineering Properties of Palmyra Palm (*Borassusa ethiopum*) Seeds at Different Moisture Contents

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ABSTRACT
The data on the engineering properties of Palmyra palm seeds and kernels required for design of the machine are not established. The removal of the kernel from the shell is usually achieved using traditional method by roasting the seed and then break open with stone, which is time consuming and stressful. This research was carried out to determine some physical and mechanical properties of Palmyra palm seeds at three different moisture content levels of 8.09 %, 7.04 % and 5.50 %. The physical properties such as axial dimension, geometric mean diameter, surface area, static coefficient of friction, true density, bulk density and porosity were determined. The mechanical properties determined were compressive force, compressive stress and deformation both at peak and at break using Instron hydraulic universal tensile testing machine. The seed had major, intermediate, minor and geometric diameter as 10.89±1.65, 7.76±1.93, 9.14±1.84 and 9.11±1.53, respectively. While the major, intermediate, minor and geometric diameters for the kernel were 8.14±1.37, 5.08±1.19, 2.96±0.93 and 4.92±1.07 respectively. The mechanical properties of seed and kernel evaluated for force at peak, force at break, stress at peak, stress at break, deformation at peak and deformation at break were 8.03±1.87 kN, 10.82±0.23 kN, 0.46±0.07 kN/mm, 1.46±0.19 kN/mm, 3.98±0.19 mm, 4.10±0.16 mm and 17.14±1.66 kN, 36.44±8.24 kN, 0.14±1.37 kN/mm, 10.96±8.24 kN/mm, 5.21±1.28 mm and 5.53±1.33 mm respectively. The coefficient of static friction was highest on wood with 0.36±0.06 and 0.44±0.03 for seeds and kernel respectively. The results obtained from the experiment will contribute immensely to the existing knowledge aimed at solving the problems of equipment design to handle the processing of the seeds.

Keywords: coefficient of static friction, sphrecity, moisture content, Palmyra palm seed

INTRODUCTION
Palmyra palm tree (*Borassusa ethiopum*) is one of the plants of palm family that normally grows in the tropical or sub-tropical climates. Palmyra palm trees (Fig. 1) are indigenous to tropical Africa most commonly found in Senegal. It is known in Nigeria, among the Yoruba, Igbo, Hausa, and Nupe people as *Agbon-eye, Ubiri, Giginya and Gbaci* respectively. Palmyra palm is a genus of six species of palms that grows in great abundance on riverine flats and coastal plains, and also occurs in open secondary forest, dense forest borders and in savannah and drier areas where it is restricted to grassland with high ground water table and annual rainfall of 500-1000 mm (Uhl and Dransfield, 1987). It thrives in temporary flooded areas, often forming dense stands. It is irregular, but widely distributed, typically found at altitudes up to 400 m, but up to 1200 m in Africa and Asia. Growth of the Palmyra palms depends very much on soil conditions. The soil beneath the

Palmyra palm tree is very important to its growth; it thrives in sandy soil and well-drained soil, but prefers alluvial soils near watercourses with pH in the range of 5.5-7. Established plants are draught tolerant. Many species grow well in either acidic or alkaline soils. The moisture requirement of some palm species is preferably once a week and palm from desert areas may need even less (Arbonnier, 2004).

Plate 1: Palmyra palm ***(****Borassusa ethiopum)* trees

Three phases of growth are recognized. The 1st phase takes 6-8 years and involves leaf development, in which about 20 leaves grow in a wide crown (about 3 x 3 m). The 2nd phase involves rapid growth of the trunk above the ground and takes place from the 8th to about the 20th year. The 3rd phase involves flowering and shedding of leafstalks. The trunk becomes smooth and swellings appear on it. Little care is required if palms are established on a good site (Poinar, 2000). However, young leaves should be harvested only under very controlled conditions if the palm is to grow properly. Rotation periods depend on the site but can be 60 - 140 years (Arnold and Mohsenin, 1971). Palmyra palm is among the best known and most extensively cultivated plant families. Almost all its parts are useful in food production, such as: oils, timber, dyes, fibers, wine, and raw materials. The wood is very resistant to termites and fungi, and is used in carpentry, construction and also for household articles. The roots serve for the treatment of stomach parasites, bronchitis, sore throats and asthma, as well as being used for a mouthwash. The leaves are used for making thatch, mats, baskets, fans, hats, umbrellas and writing materials. When boiled in salt water with turmeric, it acts as a preservative and also serves as an aphrodisiac. The seedlings are used in cooking. The fruits are eaten as a food supplement; both the fruit pulp and seeds are edible. The fruit is made into soft drinks (Ogbuagu *et al.*, 2013). The fruits, kernel and seeds of Palmyra palm are shown in Figure 2, A, B and C.

A B C

Plate 2: Palmyra palm ***(****BorassusAethiopum****)*** fruits and seeds

The fruit measures about 12.25 cm in diameter, has a black husk, and is borne in clusters. The small fruit are pickled in vinegar while the shell of the fruit can be punctured with a finger and the sweetish liquid sucked out for refreshment like coconut water. The top portion of the fruit must be cut off to reveal the three sweet jelly translucent pale-white seeds socket. The jelly part of the fruit is covered with a thin, yellowish–brown skin (Sakande *et al.*, 2004). The ripened fibrous outer layer of the palm fruit can also be eaten raw, boiled, or roasted. People have perfected the art of making various sweet dishes with the yellowish viscous fluidic substance obtained from a ripe palm fruit. The pulp of mature fruit is sucked directly from the wiry fibres of roasted, peeled fruits and fresh pulp is reportedly rich in vitamins A and C (Ogbuagu *et al.*, 2013). The peeled seedlings are eaten fresh or sun-dried, raw or cooked in various ways. They also yield starch, *chilli* peppers, fish or other ingredients added. It has been proposed for commercial starch production. Within a young fruit when cut off, two or three jelly like seeds are fond and in rare cases one. The jelly like is a famous and delicious summer food (Awal *et al.*, 1995). Information on the physical and mechanical properties of Palmyra palm seed and kernel is of importance in designing processing equipment. Hence the study on the determination of the physical and mechanical properties became necessary so as to provide information to enable engineers in designing equipment for processing Palmyra palm seed and kernel which will help in reducing human drudgery.

MATERIALS AND METHODS

Preparation of the Palmyra Palm Seeds

Fresh Palmyra palm fruits were procured from Birin Kebbi central market, Kebbi State, Nigeria. The fruits were sorted out and cleaned manually before removing the cap to get to the seed by using a knife. After cleaning, the seeds and the fibre threads were manually removed with knife.

Determination of Moisture Content of Palmyra Palm Seed

The Palmyra palm seeds were manually sampled and kept in in three separate polyethylene bags. In order to achieve the desired moisture content, the samples were kept in a refrigerator at 5^{o}C for a week and two weeks for the moisture to distribute uniformly throughout the seed at the crop processing laboratory of Agricultural and Bioresources Engineering Department, Federal University of Technology, Minna, Nigeria. The seeds were tested when the target moisture contents were reached (Carman, 1996; Dauda *et al.,* 2014). The moisture content (W) was determined by oven dry method at 104 ^{o}C for 24 hours using an oven with model number PBS11TSF (ASABE, 2008; ASABE, 2012; Balami *et al*., 2016; Dauda *et al.*, 2014; Dauda *et al.*, 2015). Each test was replicated 3 times and the mean values of moisture contents were obtained as 5.5%, 7.04 %, and 8.09 % (Fadeyibi and Osunde, 2012).

It was therefore calculated using Equation 1.

$$W = \frac{(Mcws - Mcs)}{(Mcs - Mc)} \text{ X } 100 = \frac{Mw}{Ms} \text{ X } 100 \text{ \%} \qquad 1$$

where: W = Water content (%); M_{cws} = Mass of container and wet specimen (g);
Mcs = Mass of container and oven dry specimen (g); Mc = Mass of container (g);
Mw = Mass of water (g); Ms = Mass of solid particles (g)

Determination of Axial Dimensions

The axial dimensions termed as major (a), intermediate (b) and minor diameter (c) of Palmyra palm seeds of the selected samples were measured using *Mitutoyo* absolute digimaticVernier calliper of 0.010 mm sensitivity. The measurements were taken at the three different moisture contents and were replicated 3 times.

Determination of Geometric Mean Diameter

The geometric mean diameter (Dg) was calculated from average values of the axial dimensions (Yalcin *et al.,* 2007) as expressed in Equation 2.

$$\left(D_g\right) = (abc)^{\frac{1}{3}} \qquad 2$$

Where; a = major diameter, cm;b = intermediate diameter, cm; c = minor diameter, cm

Determination of Sphericity

The Sphericity (Φ) is defined as the ratio of the surface area of the sphere having the same volume as that of the seed. Likewise, it is regarded as the degree of closeness of seed to a sphere. Furthermore, it also describes the rolling ability of seed during processing, therefore it is a function of the basic dimensions (major, intermediate and minor diameter) and can be calculated using the expression in Equation 3 as given by Ghasemi *et al.*(2008).

$$\Phi = \frac{(abc)^{1/3}}{a} \qquad 3$$

where; a = major diameter, cm; b = intermediate diameter, cm and c = minor diameter, cm

Determination of Surface Area

Surface area is an important property of seed. It helps the designer in estimating the hopper, processing chamber and the chute. The surface area was found by analogy with a sphere of some geometrics mean diameter by using Equation 4 given by Khazaei(2012).

$$S = л(Dg)^2 \qquad 4$$

where: S represents surface area and Dg stands for geometric mean diameter respectively.

Determination of Static Coefficient of Friction

The static coefficient of friction was determined on three different structural surfaces (glass, metal sheet and plywood) for all samples. Single seed was placed on the surface, which was gradually tilted until the seed began to slide down the surface. The angle which the surface made with the horizontal was taken. This was replicated three times. The coefficient of friction (μ) was obtained by using Equation 5 as given by Adejumo*et al.* (2007).

$$\mu = tan\Theta \qquad 5$$

Determination of True Density

The true density of a seed is defined as the ratio of the mass of a sample of a seed to the solid volume occupied by the sample. The seed volume and true density was determined using the liquid displacement method. Toluene (C_7H_8) was used in place of water because Toluene 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. The volume of toluene displaced by nuts was recorded. The ratio of mass to volume of the nuts was treated as true density (ρ_T) and calculated using the expression in Equation 6.

$$\rho_T = \frac{M}{V} \qquad 6$$

where: ρ_T = True density M = mass of individual seed (g) and V = volume of individual seed (cm^3).

Determination of Bulk Density

The bulk density is defined as the ratio of the mass of the sample of the seeds to its total volume. Varnamkhasti *et al.*(2008) reported using the same method for other seed by filling an empty 1000 ml cylindrical container with seeds. The seeds were poured from a predetermined height, striking off the top level and weighted. Bulk density (ρ_B) was calculated by using the given expression in Equation 7.

$$\rho_B = \frac{M_B}{V_B} \qquad 7$$

where:

M_B = mass of the sample of seeds (g) and V_B = volume of container used (cm^3).

Determination of Porosity

The porosity (Ɛ) was calculated from the values of bulk and true density (Mohseni, 2011) as expressed in Equation 8.

$$\varepsilon = \left[1 - \frac{\rho_B}{\rho_B} x100\%\right] \qquad 8$$

where: (ρ_B) =bulk density and(ρ_T) = True density

Determination of Mechanical Properties

Instron hydraulic Universal material testing machine *(CARVER)* having sensitivity of 0.001 kN, maximum capacity of 240 kN and 0.001 mm deformation was used for determining some mechanical properties of the seeds and kernels (force, stress and deformation). The mechanical behaviour of the seeds and kernels was expressed in terms of the force and stress required at peak, break and deformation. The force at break was determined when the seeds and kernels under compression makes a clicking sound. The process was completed whenever the breaking point of each positioned seed was reached. The procedure was replicated for seeds and kernels (Gupta and Das, 2000).

RESULTS AND DISCUSSION

Physical Properties of Palmyra Palm Seed

The axial dimensions being the major, intermediate and the minor diameters of the Palmyra palm seeds are presented in Table1. These dimensions were important in the design of specific machine for material handling and processing and other machine members like; cracking sieve, clearance between the sieve and the drum in the cracking unit and other apertures of the cracker. The major diameter, intermediate and the minor diameters of the seeds ranged between 7.75 to 10.89 cm at 5.50 % moisture content, 7.22 to 7.76 cm at 7.04 % moisture content and 6.88 to7.14 cm at 8.09 % moisture content $w.b$ respectively. The effect of moisture variation has tremendous influence on seeds dimensions (Aydin and Ozean, 2003). Similar observation was also reported by Solomon and Zewdu (2009) on Tiger nut seeds where the dimensions increased by about 11 % with rise of moisture content from 5.60 to 31.67 %. The use of these properties has a great impact on the design of separators or cleaners as well as for determining the drag coefficients.

Table 1: Mean Value of Physical Properties of Palmyra Palm Seed

Parameter	Moisture content (%wet basis)			
	N	**5.50**	**7.04**	**8.09**
Major Diameter (cm)	20	7.75±0.73	8.65±0.69	10.89±1.66
Intermediate Diameter (cm)	20	7.22±0.79	8.00±0.80	7.76±1.93
Minor Diameter (cm)	20	6.88±0.66	7.77±0.77	9.14±1.84
Geo. Mean Diameter (cm)	20	7.25±0.67	8.16±5.04	9.11±1.53
Surface Area (cm^2)	20	167±30.30	209±79.80	270±95.90
Bulk density (c/cm^2)	20	0.35±0.11	0.24±0.06	0.33±0.14
True density (g/cm^3)	20	0.94±0.13	0.91±0.13	1.55±0.37
Porosity (%)	20	62.32±13.76	73.16±7.42	78.31±8.54
Sphericity (%)	20	0.94±0.04	0.94±0.07	0.85±0.11
Volume (cm^3)	20	134.30±16.95	137.75±16.92	141±20.08
Arithmetic mean diameter (cm)	20	7.28±0.67	8.17±0.59	9.25±1.51

N = Number of sample, Values with ± = standard deviation

The average values for the geometric mean diameters, surface area and sphericity are also presented in Table 1. The results of the experiment indicated significant influence of moisture content when increased from 5.50 to 8.09 %. These values sequentially increased from 7.25 to 9.11 cm and 167 to 270 cm^2 for geometric mean diameter and surface area respectively. Sphericity indicated a decreased from 94 % to 85 % as the moisture content increased from 5.50 to 8.09 %$w.b$. The lower sphericity is an indication that the seed cannot roll on its side but can slide (Sessiz *et al.,* 2007). This is very useful in the design of handling equipment for the seed. Similar trends of decrease were reported by Idowu *et al.* (2012) for sandbox seed at moisture content of 9.3 to 52.5 % $w.b$. Means and Standard Deviation of coefficient of static friction of Palmyra palm seeds and kernels on three types of structural surface at the same moisture content of 8.09 % were 0.36 ±0.06, on wood, 0.25±0.02 on glass, 0.34±0.05 on metal for seeds and 0.44±0.03 on wood, 0.31±0.03 on glass and 0.36±0.04 on metal for kernel respectively. It was found that the seed had the highest coefficient of static friction on metal and wood followed by glass and kernels is higher on glass as shown in Table 2. This property is of paramount importance in determining the steepness of the storage container, hopper or any other loading and unloading device. This result is within the results of Idowu *et al.* (2012) for sandbox seed at 9.30 % moisture content and Oje and Ugbor (1991) for oilseed bean.

Table 2: Mean Values of Coefficients of Friction of Palmyra Palm Seed and its Kernel

Properties	Mean of Seed	Max. seed	Min. seed	Mean of kernel	Max. kernel	Min. kernel
Plywood	0.36 ±0.06	0.44	0.23	0.44 ±0.03	0.51	0.38
Glass	0.25 ±0.02	0.29	0.22	0.31 ±0.03	0.36	0.26
Metal	0.34 ±0.05	0.39	0.26	0.36 ±0.04	0.43	0.26

The porosity mean values of Palmyra palm seed increased from 62.32±13.76 to 78.31±8.54 % with increase in moisture content from 5.50 to 8.09 % $w.b$ as shown in Table 1. This could be attributed to the expansion and swelling of seeds that might have resulted in more voids space between the seeds and increased bulk volume. This also is experienced in the reduction of bulk density with increase in moisture content. Investigation carried out by Gupta and Das (2000) for sunflower seeds stated that as the moisture content increased so the porosity value increased. The bulk density decreased from 0.35±0.11 to 0.33±0.14 g/cm^3 as the moisture content increased from 5.5 to 8.09 %$w.b$ Table 1. The decrease in bulk density with increase in moisture content indicates that the increase in mass resulting from the moisture gain of the sample is lower than the accompanying volumetric expansion of the bulk. The negative in linear relationship of bulk density with moisture content has been investigated with other products by various research workers (Bart-Plange and Baryeh, 2003). The true density varied from 0.94 to 1.55 g/cm^3 when the moisture level increased from 5.50 to 8.09 % $w.b$ (Table 1). The results were similar to those reported by Ozarslan (2002) for cottonseed. The static coefficient of friction decreased with increase in moisture content on all surfaces (wood, glass and metal) as shown in Table 2. The analysis of static friction of particular structural surface can be used to design, handling structures, hoppers and bunker silos. The coefficient of mobility represents the freedom of motion of a substance is inversely related to coefficient of friction (tangent of angle of internal friction) (Irtwange and Igbeka, 2002). The higher the coefficient of friction the lower the mobility coefficient hence requiring larger hopper opening, larger hopper side wall slope and steeper angle of inclination in inclined grain transporting equipment like chutes (Elaskar *et al.,* 2001).

Mechanical Properties of Palmyra Palm Seed

The variation of compression force of Palmyra palm seed with moisture content is shown in Table 3. The force increase from 6.29 kN to 8.03 kN at peak and 7.73 kN to 10.82 kN at break with increase in moisture content, probably due to fibre content of the seed coat. The variation of compressive stress of Palmyra palm seed with moisture content indicated in Table 3shows an increase in compressive stress from 0.29 kN/mm to 0.46 kN/mm and 1.16 kN/mm to 1.46 kN/mm at break and at peak respectively with increase in moisture content up to 8.09 % $w.b$. The deformation increases from 2.82 mm to 3.98 mm and 3.93 mm to 4.10 mm at peak and break respectively with increase in moisture content from 5.50 % to 8.09 % $w.b$.

Table 3: Mean Values of Mechanical properties of Palmyra palm seed

	Moisture content (% wb)		
Parameter	**5.50**	**7.04**	**8.09**
F at peak (kN)	6.29±0.49	6.67±0.48	8.03±1.87
δ at peak (kN/mm	0.29±0.05	0.41±0.05	0.46±0.07
F at break (kN)	7.73±0.87	8.80±0.54	10.82±0.23
δ at break (kN/mm	1.16±0.08	1.22±0.14	1.46±0.19
Deformation at peak (mm)	2.82 ±0.20	3.49±0.36	3.98±0.19
Deformation at break (mm)	3.93±0.17	3.61±0.35	4.10±0.16

F = Force, δ = Stress, Value of Standard Deviation

CONCLUSION

Having carried out investigation on some physical properties of Palmyra palm seed, it was observed that; Major, intermediate and the minor diameters of the seeds ranges between 7.75±0.73 - 10.89±1.66 cm, 7.22±0.79 - 7.76±1.93 cm, 6.88±0.66 - 9.14±1.84 cm these is due to difference in moisture content range from 5.50 - 8.09 % $w.b$ indicating increase with increase in moisture content. The bulk density decreased from 0.35±0.11- 0.33±0.14 g/cm^3 with increase in moisture content. The static coefficient of friction decreased on three structural surfaces namely, plywood 0.46±0.02 to 0.36±0.06, metal 0.46±0.04 to 0.34±0.05, and glass 0.26±0.03 to 0.25±0.02 range of 5.50 to 8.09 % $w.b$ moisture content. The findings from the mechanical properties show that; force at peak, stress at peak, force at break, stress at break deformation at peak and deformation at stress of Palmyra palm seed increased with increase in moisture contents. The Palmyra palm seed require more stress to deform at higher moisture content as was observed. This research showed good agreement with some of the general trend and ranges obtained for other similar crops like rubber seed (Haque *et al.*, 2009).

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