



Determination of Some Physical and Mechanical Properties of IARJAT2006019 *Jatropha curcas* L. Fruits, Seeds and Kernels

¹Baba Adamu Musa, ²D. D. Yusuf, ²U. S. Mohammed, ²A. M. I. El-Okene

¹Federal Polytechnic Nasarawa, Nasarawa State

²Department of Agricultural and Bio-Resources Engineering,
Ahmadu Bello University, Zaria.

ABSTRACT

Some of the physical and mechanical properties of IARJAT2006019 *Jatropha curcas* L. fruits, seeds and kernels of Zaria origin were determined. The physical dimensions, which are the length, equatorial diameter (width) and breadth (thickness) of the fruits, seeds and kernels, were determined using a digital vernier caliper, reading 0.01 mm. The results of the physical dimensions were used to calculate the geometric mean diameter, arithmetic mean diameter, sphericity of the fruits, seeds and kernels. Other physical properties of *jatropha curcas* fruits, seeds and kernels determined were the surface area, volume, 1000 - unit mass, coefficient of static friction and angle of repose. Mechanical properties of the fruits, seeds and kernels determined were the rupture force and hardness. The mean length, equatorial diameter (width) and breadth (thickness) of the *jatropha* seeds was 16.92 mm, 10.38 mm and 7.54 mm. The mean rupture force of the *jatropha* seeds was 79.95 N at 7.0% db. The mean hardness obtained was 66.87 N. The results of some physical and mechanical properties obtained were used to design a modified *jatropha* oil mechanical extraction machine. The results obtained were within the range obtained by some known researchers.

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INTRODUCTION

The depletion of crude oil reserves coupled with the awareness of environmental issues and escalating petroleum prices have stimulated the search for alternatives to reduce overdependence on conventional fossil fuels (Sharma et al., 2013 and Tobib et al., 2019). Typically, conventional diesel and petroleum fuels release harmful gases into the atmosphere, thereby causing global warming and climate change (Nurul et al., 2020). Furthermore, fossil fuels contribute to pollution through the emission of major greenhouse gases (GHG). In principle, a biofuel is cleaner than any fossil fuel, since it can reduce carbon dioxide (CO₂) emissions by 78% and carbon monoxide (CO) emissions by 50% (Sulaiman and Ramlan, 2013). Therefore, renewable energy resources such as biofuels

urgently need to be adopted as substitutes for conventional fuels.

Biodiesel derived from *jatropha curcas*, which is suitably planted in tropical and subtropical countries, could potentially reduce the use of conventional fuels. *Jatropha curcas* is considered to be the best sustainable source. It is a multipurpose, drought resistant shrub belonging to the family of Euphorbiaceae. The seeds of *J. curcas* are considered to be the good source of lipids. They contain approximately 20 to 39% of oil and this makes their use as an energy source for fuel production very attractive (Achten et al., 2007). In addition, the oil from its seeds has been found useful for manufacture of candles and soap, in cosmetic industry and also as for medicinal purposes (Gubitz et al., 1999 and Akbar et al., 2009).

Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

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Jatropha which is toxic to humans and many animals is also widely used as a source of local medicine, a demarcation or fence, erosion control vegetation, organic manure and income earning or cash crop (Reinhard, 2007).

Design related Physical Properties of Jatropha Seeds

Some of the physical properties of *Jatropha curcas* seeds applied in the design of processing equipment are moisture content, physical dimensions (length, width and breadth/thickness), geometric mean diameter, sphericity, bulk density, solid density, 1000-unit mass, porosity, coefficient of friction on various surfaces and angle of repose (Sirisomboon et al., 2007 and Karaj and Muller, 2010). A very good knowledge of these physical properties are necessary in the design of agricultural equipment for dehulling, separating fruit hulls from seeds, seed cracking, separating seed husks from kernels, drying, cleaning and oil extraction. Therefore, the aim of this research is to determine the physical and mechanical properties of IARJAT2006019 *Jatropha curcas* L. Fruits, Seeds and Kernels for the design of a modified jatropha oil mechanical extraction machine.

MATERIALS AND METHOD

Experimental Study Area

The experiment was conducted at Samaru (11° 11' N, 07° 38' E and 685 m above sea level) in Kaduna State of Nigeria. The average annual rainfall of the area is 1100 mm and is spread between May and October. Air temperature ranges between 34°C and 40°C during the cropping season of the experimental period. The soil is formed from drift minerals and its profile is sandy on the surface overlaying clay mineral. The major crops grown in the area are maize, millet, sorghum and groundnut.

Preparation of Experimental Materials of Jatropha Fruits, Seeds and Kernels

The mature fruits (plate 2.1) of IARJAT2006019 *jatropha curcas* were harvested from the experimental field of Institute for Agricultural Research (IAR), Samaru, Zaria. The

fruits were harvested manually and then pretreated. The fruit pulping was carried out in traditional way. The pulping method consisted of removing the pulp (plate 2.2) from the fruit to obtain the jatropha seeds. The equipment that was used consisted of a bag, a small pestle and dry fruits of jatropha. For the winnowing the material that was used consisted of two basins of aluminium and plastic, a large plastic bag. Finally, the seeds were sorted, dried in the sun and stored in bags.

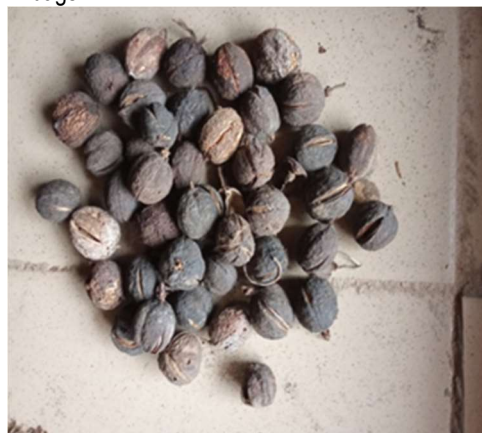


Plate 2.1: Jatropha fruits



Plate 2.2: Jatropha pulp

The IARJAT2006019 *Jatropha curcas* L. seeds were also obtained from the fruits harvested from the experimental field of the

Institute for Agricultural Research, IAR, A B U, Zaria. The broken seeds, dirt, foreign agents, bad and immature seeds were removed. The seeds (plate 2.3) were spread on traditional mat and dehulled in small quantities (30 grams), using pestle, to remove the hulls. Hulling of seeds was carried out manually by slightly, hitting the seeds

on the floor with the pestle to expose the kernel (plate 2.4). The shelled seeds were cleaned of hulls (plate 2.5) and other materials. The cleaning of the seeds and kernels was done manually, by winnowing, using two plastic basins of volume 0.3 m³ each.



Plate 2.3: Jatropha seeds



Plate 2.4: Jatropha kernels



Plate 2.5: Jatropha hulls]

Design Related Calculation of Physical and Mechanical Properties of Jatropha Curcas Seeds

For the design of the *Jatropha curcas* seed mechanical oil extraction machine, some physical properties of the *Jatropha curcas* fruits, seeds and kernel were determined. The physical properties determined were physical dimensions (length, equatorial diameter also known as width and breadth also known as thickness), arithmetic mean diameter, geometric mean diameter, sphericity, 1000-unit mass, coefficient of friction on four different surfaces (stainless steel, plywood, galvanised steel and mild steel) and angle of repose, and the mechanical properties of the *jatropha curcas* seeds determined, were the rupture force and hardness of the seeds.

Experimental Procedures

Determination of Physical dimensions of *Jatropha curcas* L. fruits, seeds and kernels

The physical dimensions are the length, equatorial diameter (width) and breadth (thickness). The length refers to the major diameter while the breadth is the minor diameter of the seed. The intermediate diameter is the equatorial diameter or width. (Omobuwajo et al.,

1999) stated that knowledge of these dimensions is useful in determining aperture sizes in the design of seed processing and handling equipment. Samples of 100 fruits, seeds and kernels were randomly taken. Each seed was measured for its (a) length, (b) equatorial diameter also known as width and (c) breadth also known as thickness, using a digital vernier caliper, reading to 0.01mm. Each seed was placed between the outside jaws of the caliper to measure the length along the major axis of the seed. The equatorial diameter or width (b) was measured such that it was perpendicular to the length of the seed while the breadth or thickness (c) was measured to be perpendicular to both the length and the equatorial diameter. The physical dimensions of 100 fruits and kernels were also measured in a similar manner as described for the seeds. The geometric mean diameter, D_g , arithmetic mean diameter, D_a , sphericity, (ϕ), surface area, A , volume, V , 1000-unit mass, coefficient of static friction (μ), angle of repose (γ) were calculated using various formulae given below; as described by Mohsenin (1986) and Sirisomboon et al. (2007).

Arithmetic Mean Diameter

The arithmetic mean diameter of the *Jatropha curcas* L. fruits, seeds and kernels were

Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

Federal Polytechnic Nasarawa, Nasarawa State

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determined using the physical dimensions obtained, after Joshi et al. (1993), Mohsenin (1986), Sirisomboon et al. (2007), by the relation in equation (1):

$$\text{Arithmetic mean diameter } D_a = \frac{a+b+c}{3} \dots\dots\dots (1)$$

Where; a, is the length, b, is equatorial diameter (width) and c, is breadth (thickness) of the fruits, seeds or kernels, in mm

Geometric Mean Diameter

The geometric mean diameter was also determined from the physical dimensions (length, width and thickness of the fruits, seeds and kernels, all in mm. It was obtained from equation 2, as reported by Joshi et al. (1993) and Sirisomboon et al. (2007):

$$\text{Geometric mean diameter } D_g = (abc)^{1/3} \dots\dots\dots (2)$$

Sphericity

Sphericity of the fruits, seeds and kernels were determined from equation 3 given below, which was used by other researchers (Mohsenin, 1986 and Sirisomboon et al., 2007).

$$\text{Sphericity, } (\phi) = \frac{D_g}{a} \text{ or } \frac{(abc)^{1/3}}{a} \dots\dots\dots (3)$$

Where; D_g is geometric mean diameter, a, is length, b is equatorial diameter and c is breadth of the fruits, seeds or kernels, in mm.

Surface area

Surface area of the fruits, seeds and kernels was calculated using equation 4, given by Mc Cabe et al. (1986);

$$\text{Surface area} = \pi D_g^2 \dots\dots\dots (4)$$

Unit volume

The relationship in equation 5 was used to calculate the unit volume of jatropha fruits, seeds and kernels, as reported by Salawu et al. (2015)

$$\text{Volume (V)} = \frac{3abc}{41000} \dots\dots\dots (5)$$

Specific surface area

The relationship in equation 6 was used to calculate the specific surface area as reported by Salawu et al. (2015).

$$\text{Specific surface area} = \frac{\text{Surface area}}{V_u} = \frac{\text{cm}^2}{\text{cm}^3} \dots\dots\dots (6)$$

1000- unit mass of fruits, seeds and kernel

Six samples of 100 jatropha fruits, seeds and kernels were weighed and their average weights determined. The average was then multiplied by 10 to obtain the 1000 - unit mass in g, for the fruits, seeds and kernels (Sirisomboon et al., 2007)

Coefficient of static friction

The coefficient of friction is defined as the ratio between the frictional force and the normal force on the surface of the material used in the wall, while coefficient of static friction is the ratio of force needed to start sliding the sample over a surface by the weight of the sample. Coefficients of static friction against stainless steel, plywood, galvanized steel and mild steel were determined for six (6) samples of fruits, seeds and kernels. An open (at both ends) PVC cylindrical pipe of diameter 100 mm and height 50 mm was placed on the inclined surface (stainless steel, plywood, galvanised steel or mild steel) whose angle of inclination was adjustable by means of a screw thread mechanism.

The sample was then placed in the pipe and the pipe raised about 5 mm from the surface in order for the sample to be in contact with the surface. The angle of inclination of the surface was increased gradually by turning a nut until the cylinder with the sample just started to slide down. This angle between the surface and the horizontal was then measured, the tangent of which gave the coefficient of friction as stated in equation 7 as given by Gupta and Das (1997).

$$\text{Coefficient of static friction } (\mu) = \tan \phi \dots\dots\dots (7)$$

Where; ϕ = angle between the surface and the horizontal at which samples just start to slide down, in degrees.

Angle of repose

The angle of repose is the characteristic of the bulk material which indicates the cohesion among the individual units of the material (Sirisomboon *et al.*, 2007). It was determined using two methods; filling and emptying methods. An apparatus consisting of a circular plate of 200 mm diameter and a hollow cylinder of 150 mm diameter and 250 mm height was used. For the emptying method seed or kernel samples were put in the cylinder which was placed on the plate. The cylinder was then lifted slowly allowing the samples to form a cone on the circular plate. The height of the cone was then measured and the angle of repose calculated from equation 8, as given by Bart-Plange and Baryeh (2003).

$$\tan y = \frac{h}{r}$$

$$\text{Angle of repose (y)} = \tan^{-1} \left(\frac{h}{r} \right) \dots \dots \dots (8)$$

Where; h is the height of the cone or heap formed and r is the radius of circular plate.

Moisture content

Moisture content of the seed refers to the amount of water contained in the seed. It affects almost all the other physical properties of the materials which in turn influence the performance of processing equipment (Gupta and Das, 1999). 3 samples of jatropha seeds of weight 1 kg was used for moisture content determination. The samples was placed in a container and weighed. After weighing the samples was oven dried at a temperature of 130 C for 15 hours and weighed again. The percentage moisture content in dry basis was calculated using equation 9 (FAO, 2010)

$$M. C = \frac{\text{Weight of wet sample} - \text{Weight of dry sample}}{\text{Weight of dry sample}} \times 100 \dots \dots \dots (9)$$

Bulk density

The bulk density, ρ_b is the ratio of the mass of the sample to its bulk volume (i.e solid volume plus void volume). It was determined using relationship given by Mohsenin (1980). The bulk density was determined by filling a known weight container with seed and weighed. The weight of

the seed was obtained by subtracting the weight of the container from the total weight of the container and seed. To achieve uniformity, the filled container was tapped 10 times for the seed to consolidate. The volume occupied was noted. The process was repeated three times and the bulk density was calculated using equation 10

$$\rho_b = \frac{M}{V_b} \dots \dots \dots (10)$$

Where;

ρ_b = Bulk density g/cm³, V_b = Bulk volume of fruits, seeds or kernels, M = Mass of the sample

True or solid density of jatropha curcas seeds

True or solid density is the ratio of mass of sample to its pure volume. For the jatropha curcas seeds true density was determined by the water displacement method as given in equation 11 (Burubai and Amber, 2014).

$$\text{True or solid density } \rho_T = \frac{\text{Mass of seeds}}{\text{Volume of seeds}} = \frac{M}{V_u} \text{ (g/cm}^3\text{) i.e. } \dots \dots \dots (11)$$

Porosity

According to Mohsenin (1986), porosity is defined as the ratio of the inter-granular void space volume and the volume of the bulk grain. Porosity, P was determined using relationship given by Mohsenin (1980) in equation (12):

$$P = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \dots \dots \dots (12)$$

Where; P = Porosity %, ρ_t = True or solid density in g/cm³, ρ_b = Bulk density in g/cm³

Determination of rupture force of jatropha curcas seeds

Jatropha curcas seeds rupture force was determined at four (4) moisture content levels as reported by Salawu *et al.* (2015). The rupture force indicates the minimum force required to break the seeds and must be exceeded to extract the oil from the seeds. A Universal Materials Testing Machine (Enerpac) with 100 k N capacity – Cat. Nr. 261 was used for the test. The test was carried out in the Strength of Materials and Heat Treatment Laboratory, Department of Mechanical



Engineering, Ahmadu Bello University, ABU, Zaria. Before carrying out the test, the seeds were inspected for cracks and any other form of damage to ensure that the best seeds were used for the test. Individual seed was loaded between two parallel plates of the machine, vertically at the preset condition until rupture occurs. Using a fixed cross head speed of 5mm/min, tests were conducted at four moisture levels of 7.0, 10.0, 13.0, and 16.0% db with each moisture level replicated 10 times. The force and deformation at rupture, was obtained from the display unit of the machine.

Determination of the hardness of jatropha curcas seed at 7.0 % db moisture content

The hardness of the jatropha seeds was determined in the processing laboratory of Agric. and Bio-resources Engineering, Ahmadu Bello University, ABU, Zaria using Digital Grain Hardness Tester, Model: AGW. The seeds were placed in between two flat surfaces of the machine and then a knob located below was rotated clockwise, squeezing the seed, until a cracking sound was heard, indicating the breaking of the seed. The value of hardness of the seed was then read at the display unit of the digital tester. Fifty seeds were measured and the average of the readings was taken as the hardness of the seed.

Instrumentation and Equipment Used

The instruments used to conduct the experiment included; Digital vernier caliper, reading 0.01 mm, a digital weighing scale, an oven, roasting pan, measuring cylinders of volumes 200 ml and 500 ml, masking tape, stop watch, polythene bags, cylindrical pipe, circular plate, hollow cylinder, cylindrical container. A digital weighing scale, Mettler Instruments AG model, with span of 1200 g and 0.01 g sensitivity was used for JCS measurement. The weighing scale was also used for JCS seeds moisture content determination. An electric oven (Shermond model-2000), with a specification 201 C and 0.25 C sensitivity was used for oven drying the seeds. A measuring cylinder model polylab with a specification of 500 ml and readability of 2 ml was used for the volumetric measurement of

extracted oil. The time used for drying seeds was measured using a digital stop watch with span of 1 hr and 0.01 seconds sensitivity. Plastic and aluminium basins of volumes 0.3 m³ and 0.15 m³ were used for keeping and transfer of seeds.

RESULTS AND DISCUSSION

Physical Properties of Jatropha Curcas L. Fruits

Table 3.1 shows that the results obtained for the axial dimensions, being the length, width and thickness of Jatropha curcas L. fruits were at the range of 31.65 - 33.85 mm, 29.63 - 30.89 mm and 28.43 - 29.98 mm. The mean values of the length, width and thickness were 33.80 mm, 30.24 mm and 29.11 mm. Sirisomboon et al. (2007) reported a range of 31.78 - 34.94 mm, 30.54 - 32.48 mm and 28.97 - 31.13 mm for the length, width and thickness of jatropha curcas L. fruits, which is not quite different from what is obtained by this researcher. The geometric mean diameter, arithmetic mean diameter, sphericity and 1000 – unit mass were at the range of 30.16 - 31.24 mm, 30.20 - 31.85 mm, 90 – 96 % and 13850 – 14680 g. The mean values were 30.67 mm, 30.72 mm, 93 % and 14145 g. Sirisomboon et al. (2007) reported 30.5 - 32.7, 92 – 98 % and 12,144.6 - 16,975.4 g for geometric mean diameter, sphericity and 1000 – unit mass. The values are close except for 1000 - Unit mass. The result of sphericity which gave the range of 90 – 96 % confirmed that the shape of Jatropha fruit is elliptical as stated by Beerens et al. (2007) who stated that jatropha fruits are slightly elliptical in shape with length approximately 35 mm and contain 3 seeds on average.

Bulk density, true density, surface area and porosity were in the range of 0.45 - 0.47 g/cm³, 0.76 - 1.00 g/cm³, 28.58 - 30.62 cm² and 40.8 - 55.0 %. The mean values obtained were; 0.46 g/cm³, 0.92 g/cm³, 29.56 cm² and 49.7 %. Sirisomboon et al. (2007) reported 0.47 g/cm³, 0.93 - 0.97 g/cm³, 29.42 - 33.37 cm² and 50.53 %. Both results reported are not the same but, at the same time are not largely different. For static angle of repose, filling method and emptying method, coefficient of static friction on mild steel

Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

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sheet, plywood, stainless steel and galvanized steel, the results obtained were at the range of 39.85° - 43.27°, 38.75° - 40.28°, 0.47 - 0.49, 0.36 - 0.42, 0.42 - 0.49 and 0.31 - 0.34. The mean values were; 41.84°, 39.71°, 0.48, 0.40, 0.46 and 0.32. Sirisomboon et al. (2007) reported 51.8° - 55.25°, 42.24° - 43.58°, 0.59 - 0.69, 0.45 - 0.55

and 0.44 - 0.48. The result for galvanized steel was not reported. There was bigger difference observed in the results of static angle of repose as reported by the two researchers. This might be as a result of human or material error.

Table 3.1: Physical Properties of IARJAT2006019 *Jatropha curcas* L. Fruit at 7.0 % Moisture Content on Dry Basis

Physical property	Unit	No. of observation	Mean value	Min. Value	Max. Value	S. D	C. V
Length, L	mm	100	32.80	31.65	33.85	0.68	2.07
Width, W	mm	100	30.24	29.63	30.89	0.47	1.54
Thickness, T	mm	100	29.11	28.13	29.98	0.33	1.13
Geometric diameter, D _g	mean mm	100	30.67	30.16	31.24	0.26	0.85
Arithmetic diameter D _a	mean mm	100	30.73	30.19	31.85	0.30	0.96
Sphericity, Ø	%	100	93	90	96	0.01	1.57
1000-Unit mass, m	g	10	14145	13850	14680	35.83	0.25
Surface area, A	cm ²	100	29.56	28.58	30.66	0.50	1.71
Unit volume, V _u	cm ³	10	98.68	96.52	102.56	1.02	2.56
Bulk volume, V _b	cm ³	10	168.52	161.25	165.21	0.92	2.96
True density, ρ _t	g/cm ³	10	0.92	0.76	1.00	0.06	6.52
Bulk density, ρ _b	g/cm ³	10	0.46	0.45	0.47	0.02	0.92
Specific Surface area, A _s	cm ² /cm ³	10	3.16	3.01	3.28	0.18	1.51
Porosity, P	%	10	49.7	40.8	55.0	2.16	3.25
Static angle of repose, θ _s	Degree	10	38.26	37.95	40.36	1.58	3.91
Coefficient of static friction, μ							
Mild steel sheet	Value	6	0.48	0.47	0.49	0.01	2.08
Plywood	Value	6	0.40	0.36	0.42	0.02	5.00
Stainless steel	Value	6	0.46	0.42	0.49	0.01	2.17
Galvanized steel	Value	6	0.32	0.31	0.34	0.02	6.25

Physical Properties of *Jatropha Curcas* L. Seeds

Table 3.2 shows that the results obtained for the length, width and thickness of *Jatropha curcas* L. seeds were at the range of 14.99 - 18.96 mm, 9.36 - 11.20 mm and 6.30 - 8.90 mm. The mean values obtained were 16.92 mm, 10.38 mm, and 7.54 mm. Salawu et al. (2015)

reported 15.13 - 18.89 mm, 10.02 - 11.95 mm and 5.58 - 9.20 mm for the length, width and thickness of *Jatropha curcas* L. seeds. The values reported for the length, width and thickness by Garnayak et al. (2008) were 18.83 mm, 11.47 mm and 9.01 mm. Sirisomboon et al. (2007) reported 19.99 - 22.05 mm, 11.67 - 12.27 mm and 9.3 - 9.86 mm for length, width and thickness of *Jatropha curcas*

Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

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L. seeds. Pradhan et al. (2010) reported 14.18 - 19.56 mm, 9.12 - 10.85 mm and 7.09 - 10.89 mm as the length, width and thickness of *Jatropha curcas* L. seeds. Francis et al. (2012) reported a range of 17.23 - 18.99 mm, 10.98 - 11.96 mm and 8.48 - 9.30 mm for the length, width and thickness of *Jatropha curcas* L. seeds. Beerens et al. (2007) reported a range of 11 - 30 mm and 7 - 12 mm for the length and width for *Jatropha curcas* L. seeds. The length, width and thickness of the *Jatropha* obtained by this researcher were close to the one reported by Salawu et al. (2015). This might be because the seeds were from the same environment (Zaria).

The results obtained for geometric mean diameter, arithmetic mean diameter, Sphericity and 1000 - Unit mass were at the range of 9.67 - 12.21 mm, 10.59 - 12.90 mm, 56.29 - 75.38 % and 572.00 - 643.00 g. The mean values obtained were 10.97 mm, 11.62 mm, 64.95 % and 601.83 g, respectively. Salawu et al. (2015) reported the range of 10.46 - 12.62 mm, 56.15 - 72.37 % and 535.30 - 611.90 g for geometric mean diameter, sphericity and 1000 - Unit mass. The mean values were 11.62 mm, 66.22 %, and 578.04. Karaj and Muller (2010) reported 11.92 mm, 67.0 %, 610.0 g for geometric mean diameter, sphericity and 1000 - Unit mass. Sirisomboon et al. (2007) reported the range of 13.04 - 13.76 mm, 61.00 - 67.00 % and 1307.8 - 1337.0 g for geometric mean diameter, sphericity and 1000 mass. Pradhan et al. (2010) reported the range of 1300 - 1321g for the 1000 - Unit mass. The mean was 1310.5 g. Francis et al. (2012) reported 11.82 - 12.70 mm, 12.37 - 13.31 mm, 66 - 70 %, 540.84 - 541.82 g for the geometric mean diameter, arithmetic mean diameter, sphericity and 1000 - Unit mass. The mean values of 1000 - Unit mass obtained, 601.83 g, was a little different from the value of 578.04g reported by Salawu et al. (2015). However, these findings were widely different from the results of 1310.5 g and 1307.8 - 1337.0 g reported by Pradhan et al. (2010) and Sirisomboon et al. (2007).

The reason might be due to the denser nature of the seeds in those regions. The result reported by Francis et al. (2012), of 540.84 - 541.82 g was close to this researcher's findings.

The results obtained for bulk density, true density and surface area were at the range of 0.39 - 0.45 g/cm³, 0.71 - 0.93 g/cm³ and 2.94 - 4.68cm². The mean values obtained were 0.42 g/cm³, 0.88 g/cm³ and 3.79 cm². Salawu et al. (2015) reported the range of 0.37 - 0.42 g/cm³, 0.67 - 0.73 g/cm³ and 3.44 - 5.01 cm² for bulk density, true density and surface area. The mean values reported were 0.40 g/cm³, 0.70 g/cm³ and 4.25 cm². Sirisomboon et al. (2007) reported the range of 0.44 - 0.46 g/cm³, 1.00 - 1.08 g/cm³ and 5.02 - 5.66 cm² for bulk density, true density and surface area. Karaj and Muller (2010) reported bulk density and true density (for seed fractions with unit mass of 0.61 g) to be 0.373 g/cm³ and 0.662 g/cm³ which is close to the result of this research. Francis et al. (2012) reported the range of 3.71 - 4.26 cm² for the surface area. The mean of this result is in line with the one obtained by this researcher and Salawu et al., (2015).

The results obtained for porosity, static angle of repose (filling method and emptying method) and coefficient of static friction (on mild steel sheet, plywood, stainless steel, galvanized sheet) were at the range of 36.62 - 58.06 %, 35.21 - 38.45°, 35.12 - 38.00°, 0.49 - 0.51, 0.34 - 0.42, 0.42 - 0.49, 0.31 - 0.34. The mean results obtained were; 51.28 %, 37.09°, 36.69°, 0.50, 0.39, 0.46 and 0.32. Salawu et al. (2015) reported a range of 40.58 - 45.59 %, 24.44 - 27.57°, 0.235 - 0.244, 0.415 - 0.455, 0.450 - 0.465, 0.361 - 0.375 for porosity, static angle of repose and coefficient of static friction on steel sheet, plywood, rubber and aluminum. The mean values reported were 43.43 %, 25.61°, 0.24, 0.44, 0.46 and 0.37.

The range of the results reported by Salawu et al. (2015) did not vary significantly with result of this research. This, as stated earlier might be because the area and method of research were almost similar. Karaj and Muller (2010) obtained 42.30 % for porosity which is at the range of the values obtained by this research. They also obtained 0.23, 0.44 and 0.35 for coefficient of static friction against the surfaces of stainless steel sheet, rubber and aluminum, respectively. Here, there were some variations as the values obtained by Karaj and Muller (2010) for coefficient of static friction on stainless steel was 0.23, while

this researcher obtained 0.46. This might be as a result of moisture content or unnatural surface or human error. The results obtained also showed that the highest coefficient of static friction was recorded on the surface of mild steel sheet, while the lowest was on galvanized sheet.

Sirisomboon et al. (2007) reported the range of 0.46 - 0.52, 0.45 - 0.47, 0.45 - 0.53 as the coefficient of static friction on plywood, steel and stainless steel. The range for stainless steel (0.45 - 0.53) fell within what was obtained by this research (0.46), while others were either slightly higher or lower. Francis et al. (2012) reported the

range of 0.37 - 0.41, 0.31 - 0.33, 0.44 - 0.52, as coefficient of static friction on plywood, galvanized steel and mild steel. Here the results on plywood (0.37 - 0.41) fell within the same range with the result of this research (0.34 - 0.42), while others were either slightly higher or lower than the one of this research. Pradhan et al. (2010) reported the range of 0.49 - 0.59 as the coefficient of friction without mentioning a particular surface. The mean value was 0.54 which was higher than the value obtained on all the surfaces by this research.

Table 3.2: Physical Properties of *IARJAT2006019 Jatropha curcas* L. Seeds at 7.0 % Moisture Content on Dry Basis

Table								
Physical property	Unit	No. of observation	Mean value	Min. value	Max. Value	S. D	C. V	
Length, L	mm	100	16.92	14.99	18.96	1.02	6.05	
Width, W	mm	100	10.38	9.36	11.20	0.53	5.07	
Thickness, T	mm	100	7.54	6.22	8.94	0.76	10.05	
Geometric mean diameter, D _g	mm	100	10.97	9.67	12.21	0.60	5.46	
Arithmetic mean diameter D _a	mm	100	11.62	10.35	12.90	0.58	4.95	
Sphericity, Ø	%	100	64.95	56.29	75.38	3.64	5.60	
1000- Unit mass, m	g	10	601.83	572.0	643.00	2.52	4.19	
Surface area, A	cm ²	100	3.79	2.94	4.68	0.41	10.90	
Unit volume, V _u	cm ³	10	85.20	83.50	87.50	1.36	3.51	
Bulk volume, V _b	cm ³	10	146.86	143.21	149.36	1.82	2.68	
True density, ρ _t	g/cm ³	10	0.88	0.71	0.93	0.07	7.90	
Bulk density, ρ _b	g/cm ³	10	0.42	0.39	0.45	0.02	5.24	
Specific surface area, A _s	cm ² /cm ³	10	2.64	2.29	3.00	0.68	2.89	
Porosity, P	%	10	51.28	36.62	58.06	5.83	11.36	
Static angle of repose, θ _s	Degree	Filling method	10	37.09	35.21	38.45	1.41	3.80
		Emptying method	10	36.69	35.12	38.00	1.19	3.23
Coefficient of static friction, μ								
Mild Steel sheet	Value	6	0.50	0.49	0.51	0.01	2.00	
Plywood	Value	6	0.39	0.34	0.42	0.03	7.69	
Stainless steel	Value	6	0.46	0.42	0.49	0.03	6.52	
Galvanized steel	Value	6	0.32	0.31	0.34	0.01	3.13	

Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

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Physical Properties of *Jatropha Curcas* L. Kernels

Table 3.3 shows that the results obtained for the length, width and thickness of *Jatropha curcas* L. Kernels were at the range of 14.91 - 15.08 mm, 8.96 - 9.35 mm, 6.31 - 6.50 mm. The mean values were 15.00 mm, 9.06 mm and 6.41 mm. Sirisomboon et al. (2007) reported the range of 14.91 - 15.99 mm, 9.89 - 10.61 mm and 7.09 - 7.75 mm. Francis et al. (2012) reported the range of 14.37 - 15.73 mm, 8.45 - 9.65 mm and 6.88 - 7.80 mm. Judging by what was obtained, it could be said that the results of this research were very close to the results reported by Francis et al. (2012) and Sirisomboon et al. (2007). The range for geometric mean diameter, arithmetic mean diameter, sphericity and 1000 - Unit mass were; 9.46 - 9.68 mm, 10.08 - 10.24 mm, 63 - 65 % and 586 - 598 g. The mean values were; 9.55 mm, 10.15 mm, 64 % and 592 g.

The values reported by Sirisomboon et al. (2007) were 10.21 - 10.89 mm, 67 - 69 %, and 682.40 - 693.80 g for geometric mean diameter, sphericity and 1000 - Unit mass. The result of sphericity obtained in this research (63 - 65%) is close to the one reported by Sirisomboon et al. (2007), (67 - 69 %). However, the result of 1000 Unit - mass is high. Whereas this researcher obtained 586 - 598 g, Sirisomboon et al. (2007) reported 682.40 - 693.80 g. This might be as a result of environmental factors as the kernel might have been denser, resulting to heavier mass. Francis et al. (2012) reported a range of 9.53 - 10.45 mm, 10.02 - 10.94 mm, 64 - 68 %, and 401.74 - 402.26 g for geometric mean diameter, arithmetic mean diameter, sphericity and 1000 - Unit mass. The range of arithmetic mean diameter (10.08 - 10.24) mm and sphericity (63 - 65 %) reported in this investigation was close to the one reported by Francis et al. (2012) which is 10.02 - 10.94 mm and 64 - 68 %. However, the value of 1000 - Unit mass obtained in this research (586 - 598 g) was higher compared to the one obtained by Francis (401.74 - 402.26 g).

The results obtained for bulk density, true density, surface area and porosity were at the

range of 0.35 - 0.40 g/cm³, 0.83 - 0.86 g/cm³, 2.81 - 2.93 cm² and 51.16 - 57.83 %. The mean values obtained were 0.38 g/cm³, 0.85 g/cm³, 2.86 cm² and 54.83 %. Sirisomboon et al. (2007) reported the range of 0.41 - 0.43 g/cm³, 0.97 - 1.07 g/cm³, 2.84 - 3.29 cm², 58.82 % for bulk density, true density, surface area and porosity. Francis et al. (2012) reported the range of 2.41 - 2.89 cm² as the surface area. Pradhan et al. (2010) reported a range of 0.36 - 0.39 g/cm³ for bulk density with mean value of 0.37 g/cm³. The bulk density reported in this investigation (0.35 - 0.40) g/cm³ showed that it is in the same range with the one reported by Sirisomboon et al. (2007), (0.41 - 0.43)g/cm³ and Pradhan et al. (2010), (0.36 - 0.39g/cm³).

The result of surface area is also close for all those reported. This research obtained 2.81 - 2.93 cm². Sirisomboon et al. (2007) reported 2.84 - 3.29 cm² and Francis et al. (2012) reported 2.41 - 2.89 cm². The results obtained for static angle of repose by filling method and emptying method, and coefficient of static friction over mild steel sheet, plywood, stainless steel and galvanized steel gave a range of 42.36 - 45.23°, 41.36 - 44.65°, 0.51 - 0.53, 0.53 - 0.58, 0.42 - 0.49, 0.34 - 0.36. The mean values were; 43.93°, 43.09°, 0.52, 0.55, 0.47 and 0.35. Sirisomboon et al. (2007) reported the range of 54.07° - 66.39°, 42.10° - 43.74°, 0.66 - 0.78, 0.70 - 0.76, 0.63 - 0.67 for static angle of repose by filling method and emptying method, and coefficient of static friction on plywood, steel and stainless steel. The values reported by Sirisomboon et al. (2007) are higher than the one obtained in this investigation. Francis et al. (2012) reported a range of 40.86° - 43.90°, 37.13° - 40.15°, 0.41 - 0.43, 0.38 - 0.44 and 0.52 - 0.54 for static angle of repose, filling method and emptying method, coefficient of static friction over plywood, galvanized steel and mild steel. Pradhan et al. (2010) reported the range of 26.3° - 20.5° and 0.49 - 0.59 for static angle of repose and coefficient of static friction without mentioning any specific material.



Table 3.3: Physical Properties of *IARJAT2006019 Jatropha curcas* L. Kernel at 7.0 % Moisture Content on Dry Basis

Physical property	Unit	No. of observation	Mean value	Min. value	Max. Value	S. D	C. V
Length, L	mm	100	15.00	14.91	15.08	0.05	0.36
Width, W	mm	100	9.06	8.96	9.35	0.10	1.16
Thickness, T	mm	100	6.41	6.31	6.50	0.07	1.07
Geometric mean diameter, D_g	mm	100	9.55	9.46	9.68	0.05	0.56
Arithmetic mean diameter, D_a	mm	100	10.15	10.08	10.26	0.04	0.44
Sphericity, ϕ	%	100	64	63	65	0.005	0.81
1000 mass, m	g	10	592	586	598	2.38	0.40
Surface area, A	cm ²	100	2.86	2.81	2.93	3.11	1.09
Unit volume, V_u	cm ³	10	66.21	68.35	71.52	0.36	1.01
Bulk volume, V_b	cm ³	10	132.21	129.61	135.68	0.68	0.98
True density, ρ_t	g/cm ³	10	0.85	0.83	0.86	0.08	8.01
Bulk density, ρ_b	g/cm ³	10	0.38	0.35	0.40	0.02	5.10
Specific Surface area, A_s	cm ² /cm ³	10	1.89	1.68	2.05	1.01	2.51
Porosity, P	%	10	54.83	51.16	57.83	6.23	12.15
Static angle of repose, θ_s	Degree	10					
Coefficient of static friction, μ							
Mild steel sheet	Value	6	0.52	0.51	0.53	0.01	2.02
Plywood	Value	6	0.55	0.53	0.58	0.03	6.88
Stainless steel	Value	6	0.47	0.42	0.49	0.02	6.75
Galvanized steel	Value	6	0.35	0.34	0.36	0.02	3.56

Mechanical Properties of *Jatropha Curcas* L. Seeds

The mechanical properties of the *Jatropha curcas* L. seeds determined were; the rupture force and hardness.

Determination of rupture force of *jatropha curcas* L. seeds

Rupture force at four (4) moisture levels on dry basis, are presented in Table 3.4. The results showed that the ranges of rupture force are; 76.39 - 87.62 N, 91.56 - 102.59 N, 102.18 N - 126.52 N and 123.68 - 145.63 N, for moisture content levels of 7.0 %, 10.0 %, 13.0 % and 16.0 %. The results showed that the rupture force for *Jatropha curcas* L seeds increases as moisture content increases for the range of moisture content investigated. The same trend was also

observed by Makanjuola (1972) for melon seeds. Bay et al. (1996) reported an increase in compressive strength (rupture force) for snap bean (*Phaseolus vulgaris* L.) when moisture level was increased. Similar increasing trend for rupture force was reported by Karaj et al. (2010) for *jatropha curcas*. Salawu et al. (2015) also reported that similar trend of increase in force to initiate seed rupture, as moisture content is increased (from 1.8 to 14.5%wb). This trend can be attributed to the fact that at reduced (lower) moisture level the outer coating (hull) becomes hard and brittle so that the hull resistance decreases and consequently, reduced the force required to initiate seed rupture.

Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

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Table 3.4: Rupture Force of *Jatropha curcas* L. Seeds at Four (4) Moisture Content Levels

Moisture content	No. of Observation	Mean value	Min. value	Max. value	S. D	C. V
7.0	10	79.95	76.39	87.62	3.13	3.91
10.0	10	97.65	91.56	102.59	3.91	4.00
13.0	10	115.56	102.18	126.52	8.68	7.51
16.0	10	135.33	123.68	145.63	8.15	6.02

Analysis of variance for seed rupture force

Table 3.5 shows the analysis of variance for seed rupture force, which indicates that moisture

content, has significant effect on the rupture force of *jatropha curcas* seed.

Table 3.5: ANOVA for Seed Rupture Force

Source	Df	SS	MS	F-value	Pr > F
M.C (%)	3	16947	5648.97	135.49**	0.0001
Error	36	1501	41.69		
Total	39	18448			

Ns = not significant, * significant at 5% level, ** significant at 1% level

Ranking of the effect of moisture content on the rupture force of *jatropha curcas* seeds

Table 3.6 indicates the ranking of the effect of different levels of moisture content, which clearly shows that the higher is the moisture content, the

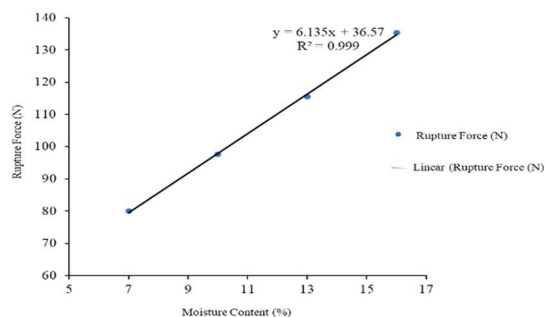
higher is the rupture force required to break the *jatropha* seeds. It also shows that the various levels of moisture content are significantly different.

Table 3.6: LSD for Means of Seed Rupture Force

Treatment	Means of seed rupture force [N]	LSD
M4	135.33	a
M3	115.56	b
M2	97.65	c
M1	79.95	d

Means in the same line with the same letter are not significantly different at $P < 0.05$ using DMRT. The relationship between rupture force and moisture content can be expressed in regression equation as:

$y = 6.135x + 36.57$ ($R^2 = 0.9993$)
Where; x and y represent moisture content and rupture force, respectively.



Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

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Determination of hardness of *Jatropha curcas* L. seeds at 7.0 %dry basis

Results of measurement in the laboratory indicated that the mean of hardness of *Jatropha* seeds is 66.87 N, which is similar to the result reported by Karaj and Muller (2010) and Salawu et al. (2015)

CONCLUSION

Design – related physical and mechanical properties of *Jatropha* fruits, seeds and kernels were determined. The properties include; the physical dimensions of *Jatropha* fruits, seeds and kernels, geometric mean diameter, arithmetic mean diameter, sphericity, surface area, volume, 1000-unit mass, coefficient of static friction, angle of repose. The mean length, width and thickness of *Jatropha* fruits are 33.08 mm, 30.24 mm and 29.11 mm. The mean length, width and thickness of *Jatropha* seeds are 16.92 mm, 10.38 mm and 7.54 mm. The mean length, width and thickness of *Jatropha* kernels are 15.00 mm, 9.06 mm and 6.41 mm. The mean length, width and thickness, geometric mean diameter, arithmetic mean diameter, sphericity, surface area, unit volume, specific surface area, 1000-unit mass, coefficient of static friction, angle of repose, moisture content, bulk density, true density, porosity of *Jatropha* fruits, seeds and kernels obtained are all within the range of results reported by other researchers such as Pradhan et al. (2010), Francis et al., (2012) and Salawu et al. (2015).

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Corresponding author: Baba Adamu Musa

✉ babaadamum50@gmail.com

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