PHYSICOMECHANICAL PROPERTIES OF IRON TREE SEED *(PROSOPIS AFRICANA)* FROM SOUTH EASTERN NIGERIA.

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ABSTRACT
Selected physical and mechanical properties of Iron tree seeds (Prosopis africana) were studied at three moisture content levels of 10%, 15% and 20% (db). Compression strength characteristics were conducted under quasi-static compressive force at vertical and horizontal loading positions and the rupture forces, compressive strength, modulus of deformability, toughness, stiffness and force at bio-yield point determined as the mechanical properties. Results indicated that volume (0.088 - 0.503mm^3), surface area (0.237 - 0.754mm^2), geometric mean diameter (0.273 - 0.487mm), and weight (0.185 - 0.252g) of the velvet bean seed increased linearly with increase in moisture content and bulk density and specific gravity (2.341 - 0.571g/mm) decreased linearly with increase in moisture content. These indicate that Iron tree seeds (Prosopis africana) have wide size ranges and no single sample of the grains can effectively represent the other. In the case of the force-deformation characteristics, result indicates that the force and corresponding deformation to rupture of velvet bean seeds were found to vary from 257.825N - 368.750N and 1.110mm - 1.700mm in longitudinal (vertical) loading positions and 115.75N - 310.938N, 0.475mm - 1.563mm in lateral (horizontal) loading positions at the various moisture contents. The bio-yield force, compressive strength and toughness of the velvet bean seeds varied from 125.000N - 175.000N, 0.648KN/mm - 3.470KN/mm and 1.167KJ/mm - 7.709KJ/mm respectively in longitudinal loading positions to 82.813N - 160.938N, 0.641KN/mm - 0.890KN/mm, and 1.294KJ/mm - 1.633KJ/mm respectively in lateral loading position at the various moisture contents. Generally, the compressive strength of the Iron tree seeds (Prosopis africana) is higher at lateral loading position than at the longitudinal loading position.

Keywords: Physical and Mechanical properties, *Prosopsis africana*, moisture contents.

1. INTRODUCTION
Prosopis africana is the African mesquite and it is highly represented by about 45 species of trees and shrubs native to North America, Central/South America, Africa and Asia. *Prosopis africana* belongs to the Fabaceae-Minosoidae family in the class Taub. The English name of P. Africana is a matter of controversy as some people call it iron tree while others identify iron tree as a different tree but it is popularly known all over the world as mesquite, (Akaaimo and Raji, 2006). Due to the large numbers of species, however, most research reports use the scientific name to identify the particular specie which is under study. Though the common name of *Prosopis africana*is African mesquite, (Anon, 2002), its native Nigerian names are Kiriya (Hausa), Kohi (Fulani), Sam chi lati (Nupe), Ayan (Yoruba), Kpaye (Tiv), Ogiri-Ugba (Igbo) and Okpeye (Idoma), (Ogunshe *et al.*2007). There are however some other species of *Prosopis* that are native to Africa; these include *Prosopis cineraria* and *Prosopis pallid*. *Prosopis africana* has been known to be important to mankind in various ways (Akaaimo and Raji, 2006). Almost all the parts of the tree can be used for medicinal purposes. The leaves in particular are used for the treatment of headache, toothache, as well as other head ailments. The leaves and bark are combined to treat rheumatism while fishermen use the pounded dry fruit as fish poison (Akaaimo and Raji, 2006).The young leaves and shoots are used as fodder; cattle also like to eat the pods. The wood has a high thermal value of about

1720J/kg and produces excellent charcoal and firewood. Therefore it can be used as a fuel as well.

The bark and root can be used as tannin or dye stuff and the pod ashes are a source of potassium for making soap used to treat skin disease, fevers and as eye washes. They contain 14–16% tannin and a colouring matter that gives a reddish tint to leather. Barminas *et al.*, (1998), reported that the proximate composition of *P. africana*in terms of protein, ash and fibre is comparable to *Parkia africana* seeds (locust bean) which contain 26% protein and it is used as human and animal feed. Phosphorus, potassium and calcium are the major mineral elements of the seeds which suggest that consumption of the seed or its products could contribute partially to the overall daily intake of these elements. The pod pulp of *P. africana* contains an energy value of 1168J, 96% protein, 3% fat and 53% carbohydrate. The seeds are fermented to produce food condiments consumed by over 15 million people, (Oyeyiola, 1999), while its gum is used in the medical industry (Adikwu *et al.*, 2001). Ankyambe-Akue *et al.*, (2004), worked on the potential of powdered *P. africana* as protectant to cowpea seed against the cowpea *Bruchid* in Benue state of Nigeria. They discovered that *P. africana*powder could be adjudged as a potential botanical substitute to synthetic insecticides.Very few studies have been published on the physical and engineering properties of the seed and pod of *P. africana*. However, a few publications describe the specie, without highlighting the properties that can have engineering importance. The ripe and dry pods of *P. africana* are dark brown,cylindrical (about 15cm long and 3cm in diameter), compartmented, thick, hard and shiny with woody walls. There are about 10 loose, rattling seeds per pod with a thin, inter-marginal line around. Extraction of the seed from the hard pod can be done by crushing it. For propagation, the seeds are pre-heated in boiling water for 15min to soften the seed coat, allowed to cool and are soaked overnight, they are then sown in bags (Le Houerou, 2003). Processing the seed into food condiments involves boiling the seed in water for 10–12 hours and splitting the seed coat to release the cotyledons. The cotyledons are then washed with water and further boiled for 2hours, allowed to cool and are wrapped in leaves for fermentation (Omofuvbe *et al.*, 1999).

Most agricultural materials especially fruits and vegetables are highly susceptible to mechanical damage during harvesting, handling, transportation and storage. The damage causes them to rot quickly, reduces quality and increases loss (Xiaoyu and Wang, 1998). In order to minimize mechanical damage the handling and transportation stresses must be kept under a certain value.

Designing equipment without consideration of the physical and mechanical properties of agricultural biomaterials may yield poor results (Blewett *et al.*, 2000; Agu and Oluka, 2012; Eze and Oluka, 2014; Aydin *et al,* 2002). The objective of this research is to determine the physical and mechanical properties of iron tree seed relevant to processing.

Fig. 1: Fruits Pods and Seeds of Iron tree (*Prosopis africana)*

2.0. MATERIALS AND METHODS

2.1. Physical Properties

Prosopis africana pods were harvested from a farm in Ohodo town, Igbo-Etiti local government area of Enugu-North senatorial zone of Enugu State, Nigeria. The pods were threshed manually and winnowed to obtain the clean seeds. Immature seeds were carefully sorted out by handpicking. There was no broken seed due to the hardness of the seed coat. Thereafter the seeds were taken to the Bioprocessing Laboratory of the department of Agricultural and Bioresource Engineering, Enugu State University of Science Technology where the research was conducted to ascertain the physical properties of the iron tree seeds (*Prosopis africana*). Some of the apparatus used includes a 0-25mm range of vernier caliper used to measure the major diameter, the intermediate diameter and the minor diameters of the seeds. Also, a Mettler Toledo electronic digital weighing balance of model XP204 was used to measure the weight of the seeds. This experiment was conducted at three different moisture contents 10%, 15% & 20% dry base (d.b). The average diameter was calculated by using the arithmetic mean and geometric mean of the three axial dimensions as expressed in equations 1 and 2. The Arithmetic Mean diameter (AMD) and Geometric Mean Diameter (GMD) of the seeds were determined using equations as expressed by Mohsenin, 1986.

$$AMD = \frac{a+b+c}{3} \quad - \quad - \quad - \qquad (1)$$

$$GMD = (abc)^{\frac{1}{3}} \quad - \quad - \qquad (2)$$

where: *AMD* = arithmetic mean diameter; *GMD* = geometric mean diameter; *a* = major diameter (mm); *b* = intermediate diameter (mm); and *c* = minor diameter (mm).

The sphericity (s), (%) was determined using the following relationship as reported by Mohsenin, 1986;

$$S = \frac{(abc)^{1/3}}{a} = \frac{GMD}{a} \quad - \quad - \quad - \qquad (3)$$

The surface area, A (mm^2) of the seeds was obtained using the relationship given below as suggested by [19];

$$A = \frac{\lambda d^2}{4} \quad - \quad - \quad - \quad - \qquad (4)$$

$Where, A = Surface of the seeds and d = Minor Diameter.$

The unit volume of 30 seeds each was determined from the values of major, intermediate diameters and minor diameters (a, b and c respectively) from the following relationship,

$$V = \lambda\left(\frac{abc}{6}\frac{1/3}{6}\right) - \quad - \quad - \qquad (5)$$

$Where; V = Volume of the seeds (mm^2), a = major diameter (mm), and$
$b = intermediate diameter (mm) and c = minor diameter\ (mm).$

A Mettler Toledo electronic weighing balance of model XP204 and 0.001g sensitivity was used to determine the mass of the seeds. The measurements were replicated 30 times to the total mass of 30 seeds as well as the mean. The seeds were put into a container with known weight and volume from a height of 150mm at constant rate as reported by Oduma *et al,* (2013). Bulk density was calculated from the weight of the seeds divided by the volume.

$$Bulk density, eb = W/v \quad - \quad - \quad - \quad - \quad - \qquad (6)$$

$eb = bulk density, (g/mm^3), W = weight of the seeds\ (g)$, and
$V = Volume of the seeds\ (mm^3)$

Specific Gravity is the ratio of the density of a solid or liquid to the density of water at 4^{o}C. The term can also refer to the ratio of the density of a gas to the density of dry air at standard temperature and pressure.

$$SpeficGravity = \frac{Weightofthesubstance}{Weightofequalamountofwater} \quad - \quad - \quad (7)$$

or

$$SpeficGravity = \frac{Densityofthesubstance}{Densityofequalamountofwater} \quad - \quad - \quad (8)$$

The research was conducted at three (3) different moisture contents 10%, 15% and 20% (wb) respectively. The oven dry method of moisture content determination using a multi-purpose drying oven (OKH-HX-IA) was used to determine the moisture content of the seeds. The weight of the dry samples and the weight of the wet samples were determined and the moisture content evaluated from equation 9.

$$M.C = \frac{W_w - D_W}{D_W} x100\ \% \quad - \quad - \quad - \quad (9)$$

$$Where; MC = Miosturecontent(\%), Ww = Weightofwetsample(g)and$$
$$Dw = Weightofdrysample\ (g)$$

2.2. Determination of the Mechanical Properties:

The compressive test was conducted at the Agricultural and Bioresource Engineering Laboratory of the Enugu State University of Science and Technology, ESUT, Enugu. The test was carried out using the latest version of Instron Universal Testing Machine to determine the compressive strength (N/mm^2), the bio-yield force, the rupture force, the deformation at rupture, stiffness, deformation energy, modulus of deformability and toughness of iron tree seed *(Prosopis africana)* under three different moisture contents 10%, 15% and 20% (d.b) respectively. The samples were loaded in two (2) different loading positions longitudinally and laterally loading. The sample where placed in the compressive jaws making sure that the centre of the tool is in alignment with the peak of the curvature of the horse eye bean. Force was applied by turning the load arm of the testing machine with a beam of 2KN and the point of deformation and maximum break (rupture) was noted. It was observed to have a significant drop on the force –deformation graph, which was plotted automatically by the computer using Blue Hill Software thereby recording the force and the corresponding deformation. The results obtained also showed the force deformation curve; indicating bio-yield points, point of rupture which is derived at different loading positions and moisture content. The replications were taken at a maintained means temperature of 29^{o}C.The following parameters were determined from the plotted graph after the experiment; the rupture force, deformation, modulus of deformation, toughness and stiffness.

Toughness: Is the amount of work or energy required to bring about rupture in a material. It was determined by computation of the area under the force –deformation curve before rupture as reported by Mohsenin, 1986.

$$\boldsymbol{Toughness = \frac{Ruptureenergy}{Volumeofmaterial}} \quad - \quad - \quad - \quad (10)$$

Stiffness = The stiffness was determined using equation 11.

$$\boldsymbol{Stiffness = \frac{Forceatmaterial}{Deformationatrupture}} \quad - \quad - \quad (11)$$

As reported by Agu and Oluka, 2012; Pallotino et al, 2011.

Deformation Energy was determined using equation 12.

$$Deformationenergy\ = ruptureforceXdeformationatrupture \quad - \quad (12)$$

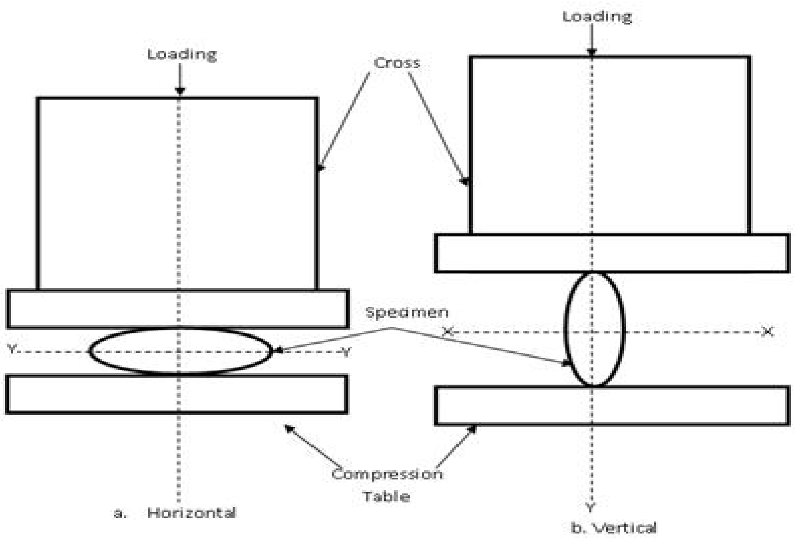

Figure 2: Block Diagram of Orientations of Iron Tree Seed *(Prosopis africana*) under Compressive Loading.

3.0 RESULTS AND DISCUSSIONS
3.1 Data Presentation/Analysis

The data collected from this study was presented and analyzed using tables with descriptive statistical methods and graphs.These data were obtained from the measurements of the Iron tree seeds, calculation of some physical properties and compression test. The results are presented in tables 1 to 2 and figures 3 to 4.

Table 1: Physical characteristics of Iron Tree Seeds (*prosopis africana)* at three different moisture content levels**.**

Moisture Content (db)	Major Diameter (mm)	Intermediate Diameter (mm)	Minor Diameter (mm)	Sphericity (mm)	GMD	AMD	Specific gravity (g/mm^3)	Sphericity	Weight (g)	Surface Area	Volume (mm^3)	Bulk density (g/mm^3)
10%	0.633	0.305	0.105	0.432	0.273	0.348	2.341	0.432	0.185	0.237	0.088	2.341
15%	0.795	0.353	0.203	0.481	0.384	0.45	1.053	0.481	0.231	0.469	0.246	1.053
20%	0.858	0.453	0.298	0.566	0.487	0.536	0.571	0.566	0.252	0.754	0.503	0.571

Table 2: Force-deformation characteristics of Iron Tree Seeds (*Prosopis africana)* at different moisture content levels under different loading positions.

Loading Positions.	Moisture Content (db)	Bio-yield Force (N)	Rupture Force (N)	Deformation at Rupture (mm)	Energy (J)	Toughness (KJ/mm^2)	Compressive Strength (KN/mm^2)
Vertical Loading	10%	175.000	368.750	1.700	546.250	7.709	3.470
	15%	157.813	293.750	1.250	435.950	3.338	1.380
	20%	125.000	257.825	1.110	286.725	1.167	0.648
Horizontal Loading	10%	160.938	310.938	1.563	483.988	1.294	0.641
	15%	131.250	262.500	1.188	317.188	1.468	0.690
	20%	82.813	115.75	0.475	54.625	1.633	0.890

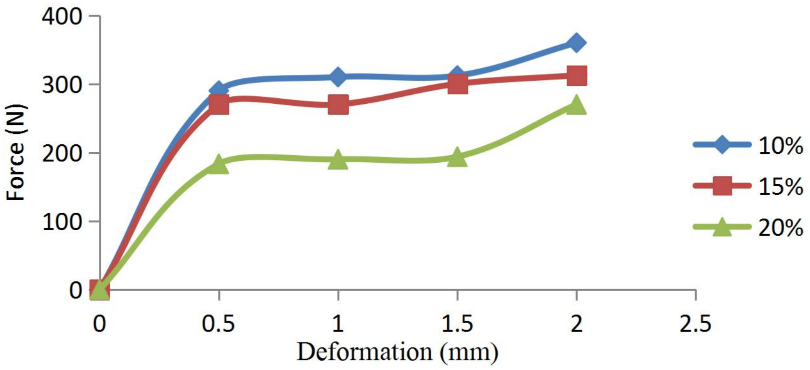

Fig. 3: Force-Deformation curves of Iron tree seeds (*Prosopis africana*) at the three different moisture contents levels under vertical loading position.

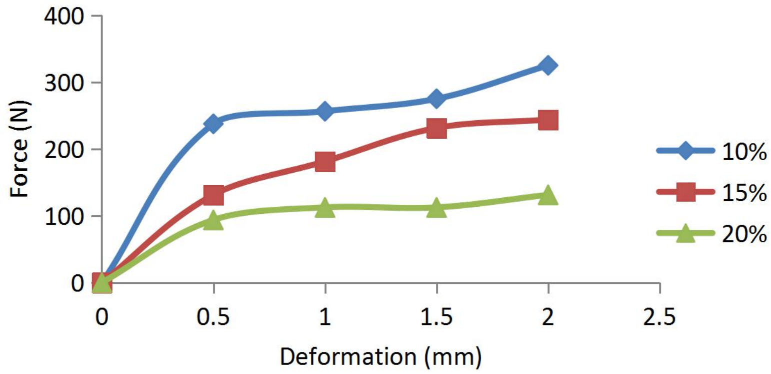

Fig. 4: Force-Deformation curves of Iron tree seeds (*Prosopis africana*) at the three different moisture contents levels under horizontal loading position.

3.2 DISCUSSION OF RESULTS.

Table 1 shows the physical characteristics of the iron tree *(Prosopis africana)*seed at different moisture contents. The dimensions increased with increase in moisture contents which contributed to expansion as a result of moisture intake within the iron tree seeds. The size observations shows that 20% m.c samples has the highest mean values for major diameter (0.858mm), intermediate diameter (0.453mm) and minor diameter (0.298mm) followed by 15% m.c samples with the values for major diameter (0.795mm), intermediate diameter (0.353mm) and minor diameter (0.203mm), and 10% m.c sample with the values for major diameter (0.633), intermediate diameter (0.305) and minor diameter (0.105). For geometric mean diameter, 20% m.c sample recorded highest mean value of 0.487mm followed by 15% m.c sample with the value of 0.384mm and 10% m.c sample with the value of 0.273mm. For arithmetic mean diameter, 20% m.c sample recorded has mean value of 0.536mm followed by 15% m.c sample with the value 0.45mm and 10% m.c sample with the value of 0.348mm. This indicates that Iron tree seeds at different moisture content levels have varying shapes and sizes.

For sphericity, 20% m.c sample has highest mean values of 0.566mm followed by 15% m.c sample with the value 0.431mm and 10% m.c sample with the value of 0.185mm. The result in table 1 also revealed that, for weight, 20% m.c sample recorded highest mean value of 0.252g followed by 15%m.c sample with the value of 0.231g and 10% m.c samples with the value 0.185g which shows that weight increases with increase in moisture content. For volume, the 20% m.c sample has the highest mean value of 0.503mm^3 followed by 15% m.c sample with the value 0.246mm^3 and 10% m.c sample with the value 0.088mm^3.

For bulk density, 10% m.c sample has highest mean value of 2.341g/mm^3 followed by 15% m.c sample with the value of 1.053g/mm^3 and 20% m.c sample with the value of 0.571g/mm^3 because decrease in moisture content increases bulk density of the seeds. For surface area, 20% m.c sample recorded the highest mean value of 0.754mm^2 followed by 15% m.c sample with the value 0.469mm^2 and 10% m.c sample with the value 0.237mm^2.These indicate that Velvet beans have wide size ranges and no single sample of the grains can effectively represent the other. Table 2 and figures 3 and 4, represent the force-deformation characterization of iron tree seeds at 10%, 15% and 20% moisture contents for two loading positions; vertical and horizontal. The data as recorded in the table 3 and figures 3 and 4 showed significant effect on the force-deformation properties of iron tree seeds. At vertical loading position, 10% m.c samples has highest mean value for bio-yield force of 175N followed by 15% and 20% m.c samples with values of 157.813N and 125N respectively. For rupture force, 10% m.c sample has highest value of 368.75 followed by 15% and 20% samples with values of 293.75N and 257.825N respectively. For deformation at rupture, 10% m.c sample has highest mean value of 1.7mm followed by 15% and 20% m.c samples with values of 1.25mm and 1.11mm respectively. For energy, 10% m.c sample recorded highest mean value of 546.25J followed 15% and 20% m.c samples with values of 435.95J and 286.725J respectively. At horizontal loading position, 10% m.c samples has highest mean value for bio-yield force of 160.938N followed by 15% and 20% m.c samples with values of 131.25N and 82.813N respectively.

For rupture force, 10% sample has highest value of 310.938 followed by 15% and 20% samples with values of 262.5N and 115.75N respectively. For deformation at rupture, 10% m.c sample has highest mean value of 1.563mm followed by 15% and 20% m.c samples with values of 1.188mm and 0.475mm respectively. For energy, 10% m.c sample recorded highest mean value of 483.988J followed by 15% and 20% m.c samples with values of 317.188J and 54.625J respectively.

From the force-deformation graph, it can be observed that force-deformation characteristization of samples at vertical loading positions were higher than that of horizontal loading. The deformations experienced by these samples were lower than that of horizontal loading. This is in order and inline as reported by Agu and Oluka, 2012; Calisir and Aydin, 2004; Dursun and Guner, 2003, as the samples tend to have more capacity to deform when force (stress) is applied horizontally. The hard lateral lining of the seed tends to resist stress more in the vertical position but once it is overcome, yield and rupture points are reached within a short time.

CONCLUSIONS

This study has identified some of the physical and mechanical properties that contribute to the force-deformation of iron tree seeds. It can be seen that the major, intermediate and minor diameters of the sample seeds increased with increase in moisture content. The increments though small, can be attributed to the fact that as water is added to the samples during conditioning, the cell walls of the seed expand as it absorbs the water. This can also be said to be responsible for the increase in volume as moisture content increased from 10% to 20% (w.b). These indicate that Iron tree seeds (*Propsis africana*) have wide size ranges and no single sample of the grains can effectively represent the other.

The distinctive shapes and sizes of the seeds as identified by the values of sphericity and then size distribution pattern can be effectively utilized for the selection of sizes and shapes of screens that can be employed in mechanical separation of seeds and hence will make the process of mechanization in size reduction, separation and cleaning very easy.

It is also evident that the mean compressive force required initiating the seed kernel rupture decreases as the moisture content increases. Energy at rupture increased as moisture content increased with respect to the horizontal loading position. Energy at rupture decreased as the moisture content increased at the vertical loading position. The rate of increase was more pronounced in the vertical loading position than the horizontal. Toughness increased with increase in moisture content but varied with loading positions.

Compressive strength increased with increase in moisture content which also varied depending on the loading positions. The seed being very hard and non-porous indicates that there is a need forpre-treatment before processing and handling especially dehulling. These properties are also good data source useful in the design and development of the necessary processing machines for the seeds. This will help in using appropriate data rather than using properties of similar crops in machine and process design for Iron tree seeds (*Prosopis africana)* seed.

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