Physical and Mechanical Properties of Irvingia Gabonesis and Irvingia wombolu at varying Moisture Content and Temperature

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Abstract– **This study is to present the physical and mechanical properties of two species of dicotyledonous *Irvingia* species (Ogbono): *Irvingia gabonesis* (I.gab) and *Irvingia wombolu* (I.wom). In this study, some physical and mechanical properties were determined as a function of moisture content, and temperature variation under compression load. Four levels of moisture contents ranging from 10.6-43.14% d.b and 11.93-50.8%d.b for I. gab and I. wom respectively were used. The average length, width, thickness, arithmetic diameter equivalent diameter, and geometric mean diameter, seed volume and surface area were increased by 2.7, 1.0, 0.4, 1.6, 1.4, 1.3, 4.3, 2.5% for I. gab and 4.1, 0.1, 0.6, 2.2, 1.6, 1.6, 4.7, 3.3% for I. womb with increasing moisture content, respectively. The mass increased linearly from 391.5g to 416.5g for I. gab and from 442.5 to 466g for I wom. As the moisture content increased the result showed that, the bulk density decreased from 12400kgm^{-3} to 112000 kg^{m-3} and 149000 to 142000kgm^{-3} for I. gab and I. wom, respectively. Apparent porosity increased from 61.62% to 66.1% for I. gab and from 68.51% to 71.58% for I. wom. The rupture force and stress decreased under compression with increase in moisture contents. I. gab had higher rupture force and stress than I. wom in all moisture content levels. The mechanical properties of *Ogbono* were determined in terms of temperature variation on compressive strength and stress. The result showed that, the crushing force and stress decreased as the temperature is increasing. I. gab had higher crushing force and stress than I wom. Drying rate of Ogbono decreased from 10.03% to 4% M.C/hr. for I gab and from 10.04% to 4.10%M.C/hr for I. wom with increasing moisture content.**

Keywords– **Irvingia, Moisture Content, Crushing Strength and Temperature**

I. INTRODUCTION

Irvingia wombolu (I.wom.); also called Sweet bush mango because of its sweet fruit pulp, and bitter bush mango *Irvingia gabonesis* (I.gab.) which has bitter-tasting fruit, are popularly known as "Ogbono" and commonly called "African mango" or wild mango. Its high nutritional and socio-economic potential makes it stand-out amongst other food crops in Nigeria and Africa at large. Bush mango is both cultivated as both wild and domestic trees. The tree has a wide range of uses.

The most commonly observed is that both species used for processing seed cake, which is widely used in soups and stews. The nut is cracked open to release the kernel. Sweet bush mango fruit pulp is consumed fresh and the juice can be used to make jam, jellies and wine. Studies on the oil produce of the seeds and its technological application has been carried out [1]. The chemical composition of the seed, carbohydrate and energy content, ash content and dry matter inclusions were also discussed. In a similar discuss, a good report was given of the characteristics of this oil [2]. The prevalent moisture content of the seed within these studies was recorded to be 2.5g/100g, and 6.4g/100g for the defatted flour.

Moisture content of seeds ply important role in the prediction of physical and mechanical properties of seeds [3],[4]. Unarguably, one can easily accept the fact that elevated temperature will affect the majorly, the mechanical properties of seeds [5]. As the seeds are subjected to varying degree of heat, constituent materials are affected. It takes different degree for lignin, cellulose, hemicellulose and dry fibres to degenerate. Some seeds have been studied of such properties; Okro seed [6], Hemp seed [7], Water Melon Seed [7] etc.

The economic importance of the seed and the difficulty encountered at harnessing the produce has presented the unavoidable need of designing equipment for planting, harvesting, drying, separation, storage, transportation and processing of the products. The size, shape, and mechanical properties of the seeds are important in the design considerations for harvesting, drying (especially solar), separating and sizing machines. Bulk density and porosity can be useful in sizing seed hoppers and storage facilities. The drying rate of seeds is important for design of solar drying.

Abbreviation- L, Length (mm); W, Width (mm); T, Thickness (mm); S, Surface Area (mm^2); V, Volume (mm^3); $\emptyset$, spherisity (%); D_a, Arithmetic mean diameter (mm); D_p, Equivalent mean diameter (mm); D_g, Geometric mean diameter (mm); R_a, Aspect ratio; ε Apparent porosity (%); ρ_b, Bulk density(kgm^{-3}); F_r, Rupture force (KN); R_d, Drying rate(%Mc/hr); Q, Mass of added water(kg); $M_{25,}$ mass of 25 seeds(g); Irvingia gabonensis (I. gab.); Irvingia wombolu (I. wom.)

II. MATERIALS AND METHODS

Two species of the fruit I. gab and I. wom shown in Figure 1 and Figure 2 used in this research, are the prevalent species in Nigeria that were obtained from Awka, Anambra State and Etsako-West, Jattu-uzairue, Edo State, Nigeria respectively. The initial moisture content of the fresh samples before drying, were 65%d.b and 67%d.b respectively. The fresh samples were then subjected to sun drying for two months. Followed by oven drying at 110$\pm$ 1^{oc} for 72 hours (ASAE, 2006). The samples were manually cleaned to remove foreign matters such as; decayed fibre, dust, dirt, broken and immature seeds [9].

The dried samples were wet with distilled water. Then, weighed immediately and recorded as 'wet weight of sample' the wet samples were dried to a constant weight at 110$\pm$1^{0}C and allowed to cool. The cooled samples were weighed and recorded as the 'dry weight of samples'.

Fig. 1: Irvingia. Gabonensis

Fig. 2: Irvingia. Wombolu

The moisture content of the sample was calculated using the following formula:

$$MC = \left(\frac{wet\ weight\ (grams) - Oven\ dry\ weight(grame)}{Oven\ dry\ weight}\right) \times 100 \quad (1)$$

Equation 1 was used to determine the four levels of moisture contents; 10.6, 21, 32.54, 43.14% d.b for I. gab and 11.93, 24, 35.78, 50.8% d.b for I. wom and the amount of added water were calculated from a general rewetting equation [10].

A. *Apparent Porosity and Bulk Density*

The basic laboratory method was used in determining the apparent porosity. The samples were dried in an oven at 110^{0}C $\pm$1^{0}C to a constant weight (W_d) with an accuracy of 0.001g, the dried specimens were suspended in distilled water so as not to touch the bottom or side of the beaker. The samples were boiled for two hours (2hrs), and then cooled to room temperature and its weight (W_s) was noted. They were removed and the water wiped off from the surface and then weighed in air (W_a).

The apparent porosity is then calculated as:

$$\varepsilon = \frac{actual\ volume\ of\ open\ pores\ of\ specimen}{external\ volume\ of\ the\ specimen} \times 100 \quad (2)$$

B. *Rupture Force and Stress at Different Moisture Content*

To determine the crushing force and stress of Ogbono seeds, a universal compression testing machine (Tinius Olesen Compression Machine, Made in India, Maximum Load: 2000kN, Model: 317E-FA) was used with accuracy of $\pm$0.001N. The individual seed was loaded and compressed along the thickness until rupture occurred.

C. *Rupture Force and Stress at Different Temperatures*

This test was carried out to determine the effect of temperature variation on compression force and stress. Each of the samples was placed in a crucible and feed into the furnace and the temperature was raised to 50^{0}C and was held at this temperature for 20 minutes. The samples were brought out and the crushing force and stress were determined using Tinius Olsen universal compression testing Machine. The process was repeated for temperature ranges of 50^{0}C-100^{0}C, 100^{0}C-150^{0}C, 150^{0}C-200^{0}C, and 200^{0}C-250^{0}C. The result of these tests was tabulated in Table 3 and Table 4.

D. *Drying Rate*

The drying rates R_d (M.C/hr) of 'Ogbono' seeds corresponding to the different percentage moisture contents were determined using established formulae [11].

III. RESULT AND DISCUSSION

A. *Seed Dimensions*

The mean values and standard errors of the axial dimensions of the I. gab and I. wom at different moisture contents were presented in the tables 1 and 2. The three axial dimensions, arithmetic, equivalent, and geometric diameters, increased with an increase in moisture contents from (10.60% to 43.14%) and (11.93% to 50.8%) for I. Gab and I. wom respectively. These increments indicating that: upon moisture absorption, seeds expand in length, width, and thickness within the stated moisture rage. The average length, width, thickness, arithmetic, equivalent and geometric diameter of 25 seeds varied reasonably for both I. wom and I.gab as recorded in Table 1 and Table 2. The seeds dimensions were increased with increased moisture content, but it did not make significant difference between the treatments (P> 0.05).

The relationships between the axial dimension, average diameters (D_a, D_p, D_g) and moisture contents (MC) are linear. This is common with some other seeds like corn [12]. The following equations showed the relationship of physical properties. for I. Gab.

Table 1: Physical and Mechanical Properties of I. Gab at Different Moisture Contents

MC(% d.b)	10.6	21	32.54	43.14
L(mm)	41.8±0.9	42.7±1.35	42.9±1.45	42.91±1.46
W(mm)	32.8±.05	33.12±0.21	33.13±0.22	33.14±0.22
T(mm)	22.0±0.05	22.02±0.06	22.08±0.09	22.9±0.10
D_a(mm)	32.2±0.34	32.61±0.54	32.7±0.59	32.71±0.59
D_p(mm)	31.54±0.27	31.9±0.45	31.98±0.49	31.99±0.49
D_g(mm)	31.13±0.26	31.46±0.12	31.54±0.04	31.55±0.01
S_p(%)	74.47±1.01	73.68±1.41	73.52±1.49	73.53±1.49
V(mm^3)	16431±411.00	16994±692.50	17117±754.00	17134±762.50
S(mm2)	2598±36.00	2650±62.00	2662±68.00	2664±69.00
R_a(%)	78.47±1.64	77.56±2.09	77.23±2.26	77.23±2.26
ε(%)	61.62±1.81	64.15±3.08	65.7±3.50	66.1±4.05
P_g(kgm^{-3})	124500±500	117000±400	114000±550	112000±650
M25(g)	391.5±59	405±65.75	410±68.25	416.5±71.5
F_r	8.6±0.3	8.01±0.45	6.7±1.00	6.0±1.19
σ_r (Mpa)	2.24±0.01	2.0±0.17	1.91±0.3	1.83±0.32
R_d(%MC/hr)	10.03±0.01	8.1±0.82	6.2±.30	4.0±0.23

Table 2: Physical and Mechanical Properties of I. Wom at Different Moisture Contents

MC(% d.b)	11.93	24	35.78	50.8
L(mm)	46.5±0.45	47.3±0.85	48.4±1.40	48.41±1.41
W(mm)	31.01±0.01	31.02±0.01	31.03±0.02	31.04±0.02
T(mm)	16.39±0.05	16.43±0.07	16.48±0.09	16.49±0.10
D_a(mm)	31.30±0.17	31.60±0.32	31.97±0.5	31.98±0.51
D_p(mm)	29.67±0.12	29.86±0.21	30.12±0.34	30.13±0.35
D_g(mm)	28.7±0.13	28.89±0.23	29.14±0.37	29.15±0.37
S_p(%)	61.72±0.35	61.08±0.67	60.21±1.1	60.21±1.1
V(mm^3)	13676±161	13940±293	14301±473.5	14316±481
S(mm^2)	2173±18	2204±33.5	2243±53	2244±53.5
R_a(%)	66.69±0.64	65.58±1.2	64.11±1,94	64.12±1.93
ε(%)	68.51±1.76	70.1±2.55	71.16±3.08	71.58±3.29
P_g(kgm^{-3})	149000±500	142000±400	136000±700	135000±750
Weight(g)	442.5±74.5	454±80.25	462.5±84.5	466±86.25
F_r	7.30±0.07	6.30±0.50	5.70±0.08	4.80±1.10
σ_r (Mpa)	2.1±0.01	1.92±0.12	1.82±0.19	1.63±0.26
R_d(%MC/hr)	10.04±0.09	8.30±1.34	6.23±2.34	4.10±2.7

$L = 0.0032(MC) + 41.71 \quad R^2 = 0.733$ (3)
$W = 0.009(MC) + 32.79 \quad R^2 = 0.632$
$T = 0.003(MC) + 21.966 \quad R^2 = 0.9356$ (5)
$D_a = 0.0148(MC) + 32.16 \quad R^2 = 0.7458$ (6)

$D_p = 0.013(MC) + 31.503 \quad R^2 = 0.7491$ (7)

$D_g = 0.0122(MC) + 31.092 \quad R^2 = 0.7598$ (8)

And for I. Wom

$L = 0.052(MC) + 46.059 \quad R^2 = 0.8656$ (9)

$W = 0.008(MC) + 31.001 \quad R^2 = 0.9966$ (10)

$T = 0.0027(MC) + 16.365 \quad R^2 = 0.917$ (11)

$D_a = 0.0184 + (MC) + 31.15 \quad R^2 = 0.869$ (12)

$D_p = 0.0125(MC) + 29.562 \quad R^2 = 0.8751$ (13)
$D_g = 0.0122(MC) + 28.596 \quad R^2 = 0.8748$ (14)

From the relationship as it could easily be seen that there is a remarkable effect of moisture content on T and W than on any other parameter.

B. Rupture Force

The graph of rupture force against moisture content is presented in Fig 3. The rupture force decreased from 8.6 KN to 6 KN for I. Gabo and from 7.3KN to 4.8KN for I. Wom. This result proved both I. gab and I. Wom's rupture force(s) as being highly dependent on moisture content. It is also clear from the curve and table that greater force was necessary to rupture the seeds at low moisture content. The smaller rupturing force required at higher moisture content is due to the fact that the seed might have soft texture at high moisture content [13].

The relationship between moisture content and rupture force of seeds can be written as follows:

For I. Gab: $F_r = -0.0837(MC) + 9.5714 \quad R^2 = 0.9837$ (15)

For I. Wom: $F_r = -0.0629(MC) + 7.9526 \quad R^2 = 0.9904$ (16)

C. Rupture Stress

The rupture stress value ranged from 2.24 to1.83Mpa and from 2.1 to 1.63Mpa for I. gab and I. wom, respectively. This is shown in figure 4 as a polynomial relationship was found between both rupture stress values and moisture content.

The highest rupture stresses were at the moisture contents of 10.6% and 11.93%, while the lowest were at a moisture content of 43.14% and 50.8% for both I. Gab and I. wom respectively. The reason may be due to the fact that the seed might have soft moisture content and required greater rupture stress. I. wom was more correlated than I. gab [4]. The relationship between the moisture content (MC) and rupture stress (σ_r) of seeds can be represented by the following equations:

For I. Gab

$\sigma_r = 0.0003(MC)^2 - 0.0309(MC) + 2.5188 \quad R^2 = 0.9851$ (17)

For I. Wom $\sigma_r = 3E - 5(MC)^2 - 0.0137(MC) + 2.2518 \quad R^2 = 0.9925$ (18)

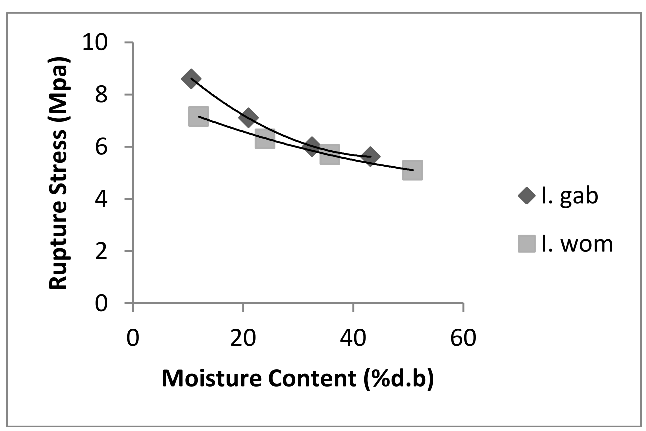

Fig. 4: Effect of moisture content on rupture stress

D. Crushing Force and Stress versus Temperature

The physical and mechanical properties of Irvinga seed do not only depend on their moisture contents but also their temperature. It was observed that as the temperature was increasing, the crushing force decreased from 10.5KN to 6.9KN and from 2.6 to 1.7mpa for I. gab and for I. wom, on the other hand, the crushing force decreases from 7.1 to 6.3KN and 2.4 to 1.40Mpa as shown in Figure 5 and Figure 6 and in Table 3 and Table 4. A linear relationship was found for the crushing force and stress for both species [14].

The following equations show the relationship between crushing force and stress respectively.

For I. Gab:

$$F_r = -0.013(Toc) + 9.942 \quad R^2 = 0.769 \quad (19)$$

For I. Wom:

$$F_r = -0.003(Toc) + 7.126 \quad R^2 = 0.977 \quad (20)$$

For I. Gab:

$$F_r = -0.003(Toc) + 2.478 \quad R^2 = 0.841 \quad (21)$$

For I. Wom:

$$F_r = -0.003(Toc) + 2.118 \quad R^2 = 0.565 \quad (22)$$

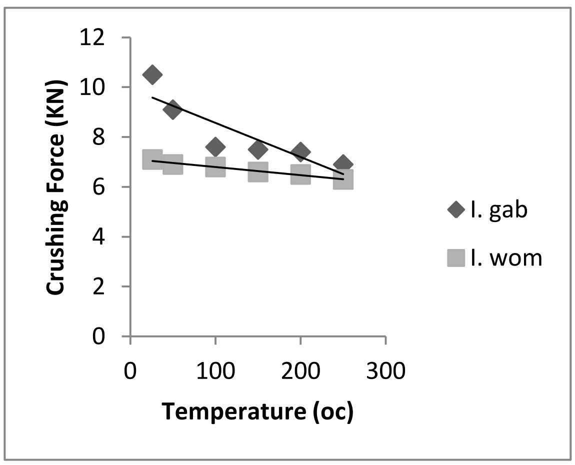

Fig. 5: Effect of temperature on crushing strength

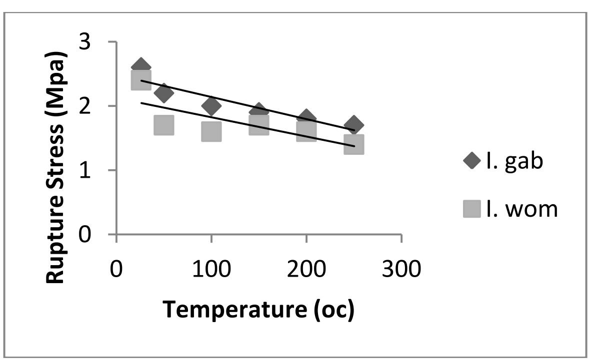

Fig. 6: Effect of temperature on rupture stress

Table 3: Effect of Temperature Variation on Compression Force and Stress for I. gab

Temperature (°c)	Crushing Force (KN)	Stress (Mpa)
Ambient	10.50	2.60
50	9.10	2.20
100	7.60	2.00
150	7.50	1.90
200	7.40	1.80
250	6.90	1.70

Table 4: Effect of Temperature Variation on Compression Force and Stress for I. wom

Temperature (°c)	Crushing Force (KN)	Stress (Mpa)
Ambient	7.10	2.40
50	6.90	1.70
100	6.80	1.60
150	6.60	1.70
200	6.50	1.60
250	6.30	1.40

All the studied physical and mechanical properties of Irvinga seed depends on their moisture contents. The following conclusions are drawn of the two species: for moisture content, a range from 10.6% to 43.14%db was established. The average length, width, thickness, arithmetic mean diameter, equivalent mean diameter and geometric mean diameter, sphericity, volume, surface area, aspect ratio, porosity, bulk density, twenty five mass, rupture force, rupture stress and drying rate, ranged from (in the order, I . gab, I. wom) 41.8 to 42.91mm,32.8 to 33.14mm, 22 to 22.09mm, 32.2 to 32.17mm, 31.54 to 31.99mm, 31.13 to 31.55mm,74.47 to73.53%, 16431 to 17134mm3, 2598 to 2664mm2, 78.47 to 77.23% 442 to 466g, 7.30 to 4.80KN, 2.1 to 1.63Mpa, 10.04 to 4.1MC%/hr

The mechanical properties for temperature ranges, from ambient to 250^{0}C were studied. For I. gab, their crushing force as well as their crushing stress is found in table 3, the crushing force ranges from 10.05 to 6.90KN and 2.6 to 1.70Mpa respectively. For I. wom, the temperature ranges from ambient to 250oc and their corresponding crushing forces and stresses ranges from 7.10 to 6.30KN and from 2.40 to 1.40Mpa.

The parameters used for the analysis of the seed's mechanical properties were dependent on the moisture content along the as the load acted longitudinally to the axis of the samples. As the moisture content increased, the rupture force value ranged from 8.6 to 6KN and 7.3 to 4.8KN for I. gab and I. wom, respectively. The rupture stress values ranged from 2.24 to 1.83Mpa and 2.1 to 1.63Mpa, as moisture content increased from 10.6 to 43.14% for I. gab and from 11.93 to 50.8% for I. wom respectively.

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