

A COMPARATIVE ANALYSIS OF MOISTURE CONTENT VARIATION ON FLOW AND MECHANICAL PROPERTIES OF BREADFRUIT SEED

(*ARTOCARPUS ALTILIS*)

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ABSTRACT

Determination of some engineering properties of two varieties of breadfruit seed was carried out using standard procedures. The initial moisture content was 6.85% and later adjusted by rewetting to 14.85%, 21.85% and 28.85 % (wb). Angle of repose and coefficient of friction of the two varieties were also determined on three surfaces (plywood, glass and Aluminium). The mechanical properties at compressive yield were determined using universal testing machine. Data obtained were statistically analyzed using Minitab statistical software. Results showed *var. Africana* values are in the following ranges: angle of repose plywood (20.84 to 33.12⁰) on glass (17.04 to 29.56⁰) and on aluminum (16.57 to 29.06⁰). Coefficient of friction on plywood was (0.376 to 0.496), on glass (0.325 to 0.450) and on aluminum (0.368 to 0.469). While *var. inversa* have the following values for angle of repose plywood (17.04 to 22.97⁰) on glass (20.38 to 30.07) and on aluminium (20.50 to 29.32). Coefficient of friction on plywood was (0.344 to 0.459), on glass (0.279 to 0.396), and on aluminium (0.348 to 0.433). These properties increased with increase in moisture content. The fracture resistance of *var. africana* and *var. inversa* were found to decrease with increase in moisture content. The data obtained from this study will aid in the design and construction of breadfruit seed threshing machine.

Keywords; Breadfruit seed, var. Africana, var. inversa, moisture content, fracture resistance

1.0 Introduction

The breadfruit (*Artocarpus altilis*) is a native to vast areas which include amongst others, New Guinea, the Indo- Malayan Archipelago and Western Micronesia. It is largely cultivated within the rainforest belt of West, Central and East Africa as well as Madagascar (Julia, 1987). The African breadfruit seed is an important food item, popularly known as *ukwa* by the Ibo, *afon* in Yoruba, *ize* in Benin, *izea* in Ijaw and

ediang in Efik (Nwokolo, 1996). Eaten in a variety of ways, breadfruit can also be made into flour. The breadfruit flour is gluten-free and it is an excellent source of potassium, carbohydrate and fiber. The seed can be cooked as porridge or mixed with other food stuff such as sorghum (Onweluzo and Nnamuchi 2009), or roasted and sold with palm kernel as road side snacks. The flour has high potential usage for pastries (Onyekwelu and Fayose, 2007).

Recent studies have shown that the oil from breadfruit seed is economically viable as vegetable oil, yielding up to 10.23% of oil per kg of processed seeds. This value compares favourably with oils from common oil seeds like cotton seed (*gossipol*) and palm kernel which are currently used for commercial oil production. The presence of linoleic acid in the oil gives the seed a high nutritional quality as source of essential fatty acid. Breadfruit seed is highly nutritious and the diet is gaining popularity worldwide (Nwokolo, 1996). To design equipment for product handling (bins, silos, hoppers), angle of repose and coefficient of friction are important for solid flow and storage structure, the coefficient of friction between seed and wall in the prediction of seed pressure on walls (Gumble and Maina, 1990). Angle of repose of a product determines the flow ability of the product. It is a measure of the internal friction between grains and can be useful in hopper design to ensure continuous flow of the material by gravity. The coefficient of friction helps in determining the angle at which chutes should be positioned so as to achieve steady flow of the material through the chute (Ghasemi et al., 2007). In Nigeria presently there is no mechanized production and processing of the seeds at industrialized scale. The knowledge of the flow and mechanical properties of this seed is scanty making the design and fabrication of machines relevant to bulk handling, harvesting, decortications, storage and extraction of oil from seed non-existent.

The objective of this study is to investigate some selected engineering properties of two varieties of bread fruit seed (*var. Africana* and *var. inversa*) at four different moisture content levels, and to ascertain their possible contributions in terms of design considerations in the production of bread fruit processing machines.

2.0 Materials and Methods

2.1 Experimental Design and Statistical Analysis

The experimental design was a 2×4×5 factorial design. Two varieties of bread fruit seed (*var. Africana* and *var. inversa*) were used at four different moisture content levels and each parameter determined were replicated five times.

Minitab statistical software was used in the analysis of variance (ANOVA) to determine the variation in results of all the experiments under the various independent variables and their interaction at 95% level. Furthermore, separation of means was performed using Least Significant Difference (LSD) at 95% level of significance to determine the significant difference between the moisture contents and varieties.

Regression analysis was performed to determine the relationship between the observed parameters and the treatment variables. These relationships are represented graphically and model equations generated.

2.2 Sample Collection and preparation

Seventy kilograms each of undehulled *var. Africana* and *var. Inversa* breadfruit seeds were purchased from Nsukka main market in Enugu State, Nigeria. The initial moisture content (m.c) of the sample was 6.85% (wb) for *var. Africana* and 6.02% (wb) for *var. inversa*. The samples were divided into 5 parts of 14 kg each. The moisture contents of the samples were adjusted to four different moisture content levels of 6.85, 14.85, 21.85 and 28.85% (wb) as suggested by Adindu and Williams, (2003). These moisture levels were chosen since all processing operations and storage are performed in these ranges.

2.2.1 Initial moisture content determination

The procedure for determining m.c as proposed in ASAE S352.2 (2003) was adopted. Electric oven (Gallenkamp oven 300 plus series), carrying cans, and electronic weighing balance (WENSAR PGB Series) with accuracy of 0.01g were used to determine moisture content of the two varieties of breadfruit seed. The initial average moisture content was determined by oven method. Four samples of 15 g were heated for twelve hours at $103 \pm 2^{\circ}\text{C}$ in the oven until constant weight is reached (Mahbobeh et al., 2011). The experiment was replicated five times and the average weight recorded. The moisture content was calculated using equation below

$$M.C_{(w.b)} = \frac{M_b - M_a}{M_b - M_c} \times 100\% \dots\dots\dots(1)$$

Where;

$M.C_{(w.b)}$ = moisture content (wet basis)

M_b = the weight of moisture Can plus sample weight before oven-drying (gm)

M_a = the weight of moisture Can plus sample weight after oven-drying (gm)

M_c = weight of moisture Can (gm)

2.2.2 Moisture Content Adjustment

The moisture content of the sample was adjusted to four levels, 6.85%, 14.85%, 21.85% and 28.85 % (wb) (Oluwole et al; 2007, Olatunde, 2011). Each sample weighing 14kg was sealed in separate polythene bags with the calculated amount of distilled water that changed the moisture content to the desired level. The quantity of distilled water that was added in order to adjust the moisture was calculated using equation 2; (Davies and Zibokere, 2011)

$$M = W_s \left(\frac{M_1 - M_2}{100 - M_1} \right) \dots\dots\dots(2)$$

Where;

W_s = weight of sample (kg)

M = weight of distilled water that was added (kg)

M_1 = initial moisture content (%)

M_2 = final moisture content (%)

After sealing the seed in polythene bags they were kept in the refrigerator at a temperature of 5°C for one week to create an enabling condition for uniform moisture distribution within the seeds (Davies and El- Okene, 2009)

2.3 Determination of Breadfruit Flow Properties

2.3.1 Coefficient of Friction

The static coefficient of friction (μ) of breadfruit seed was determined on three surfaces namely aluminum, plywood and glass. A topless and bottomless material box of 150 mm × 150 mm × 40 mm was filled with sample and placed on adjustable tilting table onto which the material to be tested was fastened. The box was placed on one side of the surface and raised slightly so that it was not touching the material. A screw jack was used to gently tilt the table until friction force between the seeds and the material was overcome by the gravity and moved down the slope. The angle of inclination was read from the graduated protractor attached to the tilting table. The mean value of five replicates was recorded, (Alonge and Adegbulugbe, 2005).

2.3.2 Angle of Repose of Breadfruit Seeds

Angle of repose (θ) was determined using an open ended cylinder of diameter 15cm and height 60cm. The cylinder was placed at the centre of a circular plate of 80 cm, and then filled with breadfruit seeds. The cylinder was lifted slowly until the seeds formed a cone on the circular plate. The diameter and height of the cone was measured and recorded and the angle of repose was calculated. This was replicated five times using the three different surfaces (plywood, glass and aluminum). These surfaces were used because they are common materials used for grain handling processes (Juana et al., 2008). Equation 1 was used to calculate the angle of repose (Dash et al., 2008)

$$\theta = \tan^{-1} \left(\frac{2H}{D} \right) \dots\dots\dots (1)$$

Where :

θ = angle of repose

H= the height of the cone (cm)

D = diameter of cone (cm)

2.4 Determination of Mechanical properties of Breadfruit Seed

Compressive test was performed on the two varieties of breadfruit seed using a Universal Testing Machine (UTM) of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State Model M500-100, 100kN, Istron Corporation USA. Seeds at different orientations (length, width and thickness) were loaded using the machine. The test result and graphs were automatically generated. The applied forces at bioyield and their corresponding deformations for each sample were read directly from the force – deformation curve. Data generated include force at yield, strain at yield, and stress at yield and compressive extension at yield. For each of the moisture content, the experiment was replicated five times.

3.0 Results and Discussions

3.1 Effect of variation of moisture content on angle of repose

Figures 1 and 2, shows the influence of moisture on the angle of repose of *var. Africana* and *var. Inversa* for three structural surfaces respectively. It was observed that increase in moisture content from 6.85% to 28.85% (wb) increased the angle of repose from 20.84⁰ to 33.2⁰ for *var. Africana* and from 22.97 to 34.34⁰ for *var. Inversa* on plywood. Table 1 shows the mean effect of moisture content on *var. Africana* and *var. inversa*.

Also on glass it increased from 17.04 to 29.56⁰ for *var africana* and 20.38 to 30.07⁰ for *var. inversa*. There was also an increase in the angle of repose on the Aluminum for *var. Africana* which ranges from 16.57 to 29.06⁰ and 20.50 to 29.32⁰ for *var inversa* as the moisture increased. These values for angle of repose for *var. africana* and *var. inversa* were found to be within the value reported for other crops (Garnayak et al (2008) for jatropha seed, and Solanki et al (2011) for neem fruit and seed).

The increase in the angle of repose for these breadfruit varieties is attributed to increase in size of the seeds as reported by Olalusi et al (2009) and Arthur (2009). The regression equation relating the angle of repose to moisture content on different surfaces are presented below

Var africana,

$$\theta_{\text{Plywood}} = 0.592mc + 17.50 \quad (R^2 = 0.937) \dots\dots\dots(2)$$

$$\theta_{\text{Glass}} = 0.561mc + 13.15 \quad (R^2 = 0.997) \dots\dots\dots(3)$$

$$\theta_{\text{Alum}} = 0.577mc + 12.81 \quad (R^2 = 0.993) \dots\dots\dots(4)$$

Var inversa,

$$\theta_{\text{Plywood}} = 0.464mc + 21.31 \quad (R^2 = 0.86) \dots\dots\dots (5)$$

$$\theta_{\text{Glass}} = 0.424mc + 18.32 \quad (R^2 = 0.930) \dots\dots\dots(6)$$

$$\theta_{\text{Alum}} = 0.398 mc + 18.60 \quad (R^2 = 0.920) \dots\dots\dots(7)$$

From the statistical analysis, the effect of moisture content on the angle of repose of the two varieties on the three surfaces was significant at 0.05 probability level (Appendix A)

3.2 Effect of Moisture Content on Coefficient of Friction of Breadfruit Varieties.

The effect of moisture on coefficient of friction for the three surfaces, plywood, glass and aluminum for *var africana* and *var. inversa* are shown in figure 3 and 4 respectively. Table 2 below shows the mean effect of moisture content and variety on breadfruit varieties. It was observed that static coefficient of friction on the three surfaces increased with increase in moisture levels. *Var. africana* increased from 0.376 to 0.496 and *var. inversa* increased from 0.344 to 0.459 on plywood respectively. On the glass, *var. Africana* increased from 0.325 to 0.450, and 0.279 to 0.396 for *var. Inversa*, while on Aluminum the increase was from 0.368 to 0.469 for *var. africana* and 0.348 to 0.433 for *var. inversa* respectively. The result showed that *var. africana* has higher coefficient of friction than *var. inversa*; this can be attributed to the cohesive force exerted by the seeds on the surface of contact at higher moisture levels. This result is similar to that obtained by Davies and Zibokere (2011) for cowpea varieties and Coskun et al (2005) for sweet corn.

At all the moisture content levels the highest coefficient of friction were observed for plywood followed by aluminum while the least value was for glass. This might be due to the increase in the size of the seed at higher moisture, and rough surface of the seeds that could limit sliding. The low value of coefficient of friction for glass occurred due to the polished nature and smoothness of the structural surface. The regression equation is shown below for the range of moisture content considered.

Var africana

$$\mu_{\text{plywood}} = 0.005mc + 0.352 \quad (R^2 = 0.913) \dots\dots\dots (8)$$

$$\mu_{\text{Glass}} = 0.005mc + 0.296 \quad (R^2 = 0.964) \dots\dots\dots (9)$$

$$\mu_{\text{Alum}} = 0.004mc + 0.348 \quad (R^2 = 0.928) \dots\dots\dots (10)$$

var inversa

$$\mu_{\text{plywood}} = 0.005mc + 0.305 \quad (R^2 = 0.984) \dots\dots\dots (11)$$

$$\mu_{\text{Glass}} = 0.005mc + 0.243 \quad (R^2 = 0.948) \dots\dots\dots (12)$$

$$\mu_{\text{Alum}} = 0.004mc + 0.319 \quad (R^2 = 0.938) \dots\dots\dots (13)$$

The statistical analysis indicates that the effect is significant on plywood and aluminium at 0.05 probability level but showed not significant for glass. This property is needed in the design of agricultural machine hopper and other conveying equipment; it determines the flowability of the material in handling operations.

Table 1: Mean values for angles of repose at different surfaces

Variety	Moisture content %	Plywood	Glass	Aluminum
<i>Var.africana</i>	6.85	20.84	17.04	16.57
	14.85	26.45	21.60	21.41
	21.85	32.39	25.04	26.01
	28.85	33.20	29.56	29.06
<i>Var. inversa</i>	6.85	22.97	20.38	20.50
	14.85	29.97	25.45	25.27
	21.85	32.75	28.68	28.47
	28.85	34.34	30.07	29.32

Table 2: Mean values for coefficient of friction at different surfaces

Variety	Moisture content %	Plywood	Glass	Aluminum
<i>Var.Africana</i>	6.85	0.38	0.33	0.37
	14.85	0.45	0.39	0.43
	21.85	0.48	0.42	0.44
	28.85	0.49	0.45	0.47
<i>Var. Inversa</i>	6.85	0.34	0.28	0.35
	14.85	0.38	0.32	0.37
	21.85	0.43	0.39	0.43
	28.85	0.46	0.39	0.43

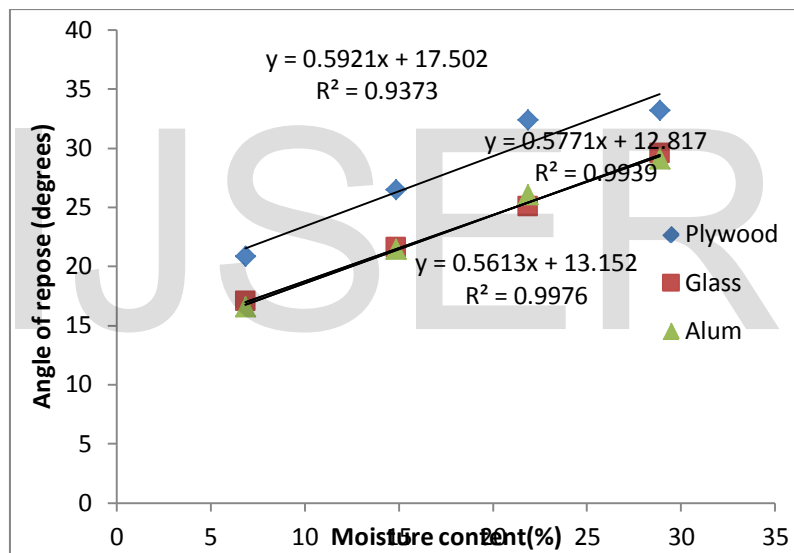


Fig. 1: Effect of moisture on angle of repose of var africana on different surfaces.

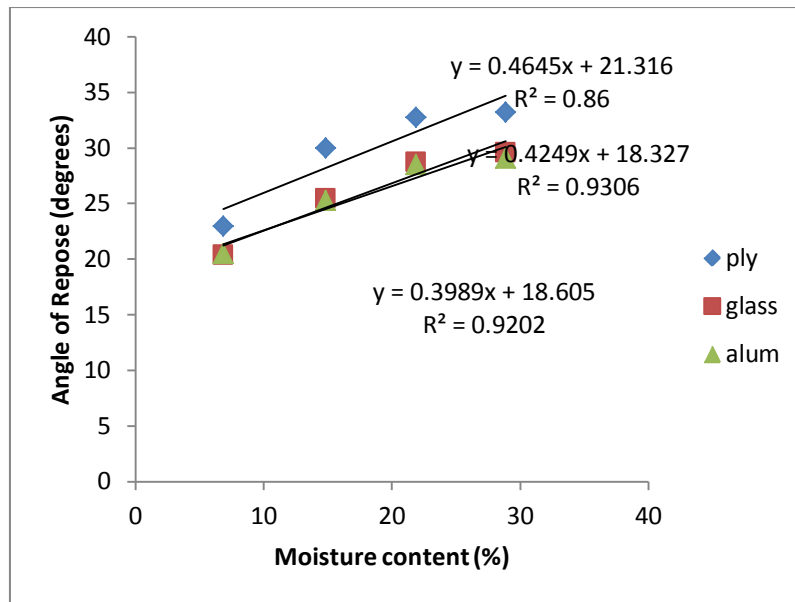


Fig.2: Effect of moisture content on angle of repose of var inversa

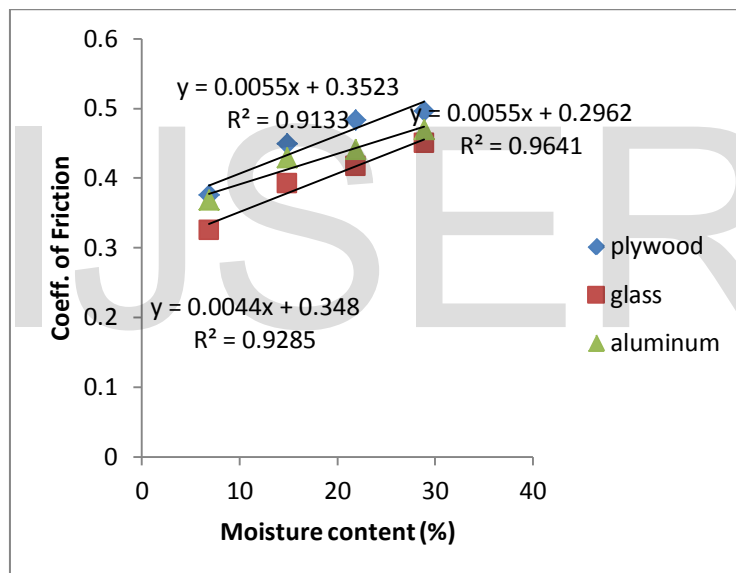


Fig. 3: Effect of moisture content on coefficient of friction of var Africana

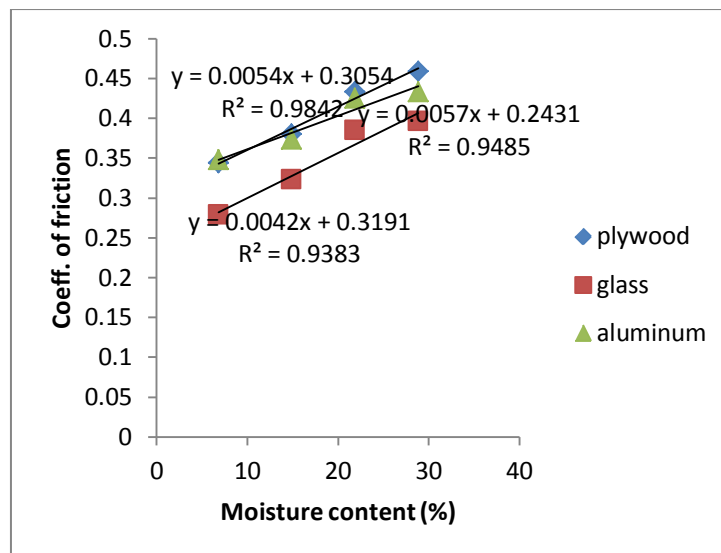


Fig. 4: Effect of moisture content on coefficient of friction of *var. inversa*

3.3 Effect of Moisture Content Variation on Force at Yield

The crushing strength was found to reduce from 6.07N to 4.086N and then increased as the moisture increased there after reduced to 4.672N as the moisture increased from 6.85% to 28.85% for *var. Africana*. The rupture force for *var. Inversa* decreased with increase in moisture content. The result agrees with the earlier findings of Owolerafe et al (2007) for fresh oil palm fruit, Adedeji (2012) for neem seed and Kernel and Solanki et al (2007) for neem fruit.

This rupture force at higher moisture content might have resulted from the fact that the seed tended to be very brittle at high moisture content. The correlation between rupture strength and moisture content is represented by the equations below,

$$\text{Force at yld}_{\text{Afr}} = -0.036mc + 5.806 \quad (R^2 = 0.135) \dots\dots(14)$$

$$\text{Force at yld}_{\text{Inv}} = -0.435mc + 18.1 \quad (R^2 = 0.751) \dots\dots (15)$$

Statistical analysis of the effect of moisture on the crushing force (Appendix B) shows that there is significant difference for the range of moisture content levels at ($P < 0.05$). Experimental result shows a reduction in the force required for initiating seed rupture as the moisture content increased.

3.4 Effect of Moisture Variation on Compressive Strain at yield

As the moisture increased from 14.85 to 28.85% wb the compressive strain at yield decreased from 2.437% to 0.172% for *var. invera* and from 0.219 to 0.193 for *var. africana*. The ratio of the size of the seed under pressure is important in deciding the screen size in the design of a decorticator and cleaner.

The regression analysis shows the relationship between strain and moisture content.

$$\text{Comp strain}_{\text{Afr}} = -0.018mc + 0.311 \quad (R^2 = 0.519) \dots\dots(17)$$

$$\text{Comp strain}_{\text{Inv}} = -0.455mc + 75.009 \quad (R^2 = 0.959) \dots\dots (18)$$

The result of the statistical analysis on the effect of moisture on the compressive strain shows that the effect was highly significant for the two varieties at 0.05 significant level.

Also the mean comparison using LSD at 0.05 confidence interval shows significant effect between the treatment means.

3.5 Effect of Moisture Content on Compressive Stress of Breadfruit varieties

The compressive stress at yield reduced as moisture increased from 14.85% to 28.85% wb as shown in table 6, the compressive stress decreased from 5.026 N/mm² to 2.999 N/mm² for *var. Inversa* and from 2.303 to 1.259N/mm² for *var Africana*. The regression equation relating moisture content and compressive stress at yield is presented below

$$\text{Comp stress}_{\text{Afi}} = -0.039mc + 2.230 \quad (R^2 = 0.464) \dots\dots (19)$$

$$\text{Comp stress}_{\text{Inv}} = 0.026mc + 2.563 \quad (R^2 = 0.031) \dots\dots (20)$$

The result of the statistical analysis shows that the effect was not significant at 0.05 significant level.

3.6 Effect of Moisture and Variety on Young's Modulus of Var. Africana and Var. Inversa.

The mean values of the young's modulus decreased from 1032.76 to 954.86N/mm² at 2.5mm/min loading as the moisture content increased from 6.85 to 14.85% it later increased as the moisture content increased to 28.85%, while for *var. Inversa* the young's modulus was 81.235N/mm² at 6.85% moisture content, then an increase was observed at 14.85% to 2540.21N/mm² followed by reduction in the value of the young's modulus as the moisture increases to 28.85%.

Haddad et al (2010) reported a decreasing trend in this property in their work on wheat Kernel. This could be attributed to the fact that as the moisture content increased the molecules become softer and consequently mobile thus the decrease in the mean values. Bamgboye and Adejumo (2011) also reported a similar trend for roselle seeds.

The regression equation relating young's modulus with moisture content is shown in the equation below. The statistical analysis showed that there was no significant effect for moisture and also for interactive effect of moisture and variety on young's modules at 0.05 probability level.

$$Y.\text{mod}_{\text{Afi}} = 10.62mc + 870.8 \quad (R^2 = 0.403) \dots\dots (21)$$

$$Y.\text{mod}_{\text{Afi}} = 84.64mc + 184.1 \quad (R^2 = 0.513) \dots\dots (22)$$

Table 3: Mean values of Compressive Strength properties at different moisture content

Variety	Moisture Content (%)	Force at Yield (N)	Strain at Yield (%)	Stress at Yield (N/mm ²)	Young Modulus (N/mm ²)
<i>Var.Africana</i>	6.85	6.07	0.219	2.303	1032.76
	14.85	4.09	0.115	1.078	954.86
	21.85	5.77	0.190	1.449	970.80
	28.85	4.67	0.193	1.259	1294.51
<i>Var.Inversa</i>	6.85	14.84	2.437	1.626	81.24
	14.85	13.68	0.212	5.026	2540.21
	21.85	5.37	0.144	2.546	1980.86
	28.85	6.99	0.172	2.999	2262.27

Conclusion

The effects of variety and moisture content on the flow properties were significant. The effect of moisture content on variety on the mechanical property tested has significant effect except for stress at yield that moisture showed no significant effect.

The angle of repose on plywood, glass and aluminium increased from 22.97 to 34.34⁰, 20.38 to 30.07⁰ and 20.50 to 29.32⁰ for *Var Africana* on the three structural surfaces while for *var. inversa* it increased from 20.84 to 33.2⁰, 17.04 to 29.56⁰ and 16.57 to 29.06⁰ respectively as the moisture content increased from 6.85 to 28.85% wb.

The coefficient of friction on plywood, glass and aluminium increased from 0.376 to 0.496, 0.325 to 0.450 and 0.368 to 0.469 for *Var. Africana* while for *Var Inversa* on the same structural surfaces increased from 0.344 to 0.459, 0.279 to 0.396 and 0.348 to 0.433 respectively as the moisture increased. The information will be useful in designing hopper for the necessary processing machines for the breadfruit varieties. The fracture resistance of *var. Africana* and *Var Inversa* were found to decrease with increase in moisture content.

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Appendix A: Mean Comparison of angle of repose and static coefficient of friction on breadfruit varieties as affected by structural surface material and moisture content

Variety	C of F. plywood	C of F. glass	C of F. Aluminum	A of repose ply.	A. of repose Glass	A. of repose Alum.
Africana	0.45125	0.39605	0.42670	28.212	23.309	23.262
Inversa	0.40275	0.34590	0.39450	30.009	26.146	25.889
LSD	0.0077	0.0102	0.0086	0.439	0.5078	0.4889
M.C(%)						
6.85	0.36020	0.30230	0.35810	21.905	18.708	18.535
14.85	0.41470	0.35780	0.40060	28.195	23.527	23.336
21.85	0.45820	0.44060	0.43290	32.570	26.863	27.242
28.85	0.47490	0.42320	0.45080	33.772	29.812	29.188
LSD	0.0111	0.0147	0.0124	0.6321	0.7308	0.6914



Appendix B: Mean Comparison of Compressive test on breadfruit Seed varieties

Variety	Force at yield	Strain at yield	Stress at yield	Young modulus
Africana	5.149	0.17920	1.5223	1063.2
Inversa	10.223	0.74125	3.0492	1716.1
LSD	1.788	0.2099	0.6396	708.37(NS)
M.C(%)				
6.85	10.455	1.3281	1.9643	557.0
14.85	8.883	0.1633	3.0517	1747.5
21.85	5.572	0.1669	1.9975	1475.8
28.85	5.833	0.1826	2.1294	1778.4
LSD	2.529	0.2969	0.9046	NS