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ORIGINAL RESEARCH ARTICLE

SOME ENGINEERING PROPERTIES OF BREADFRUIT SEED VARIETIES RELEVANT TO HANDLING

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ABSTRACT

Determination of some engineering properties of two varieties of breadfruit seeds (Var. Africana and Var. Inversa) was carried out. The initial moisture content was 6.85% and later adjusted by rewetting to 14.85%, 21.85% and 28.85% (wb). The following engineering properties, true density, bulk density, percentage porosity, specific heat capacity, terminal velocity and drag coefficient were determined. Thermal property (specific heat capacity) of the seed was determined using the calorimeter method. The aerodynamic properties (terminal velocity and drag coefficient) were also determined by using an air column made of a vertical wind tunnel in conjunction with a voltage regulator to vary the wind speed and a digital anemometer to determine the air speed. Data obtained were statistically analyzed using Minitab statistical software. The following results were obtained. The true density of Var. Africana decreased from 1033.68 kg/m^3 to 842.81 kg/m^3 which amounted to 18.5% decrease, while for var. Inversa it decreased from 948.38 kg/m^3 to 911.89 kg/m^3 amounting to 3.85% decrease as the moisture content increased from 6.85 to 28.85%. The bulk density was observed to increase linearly as the moisture content increased. It increased from 361.239 to 408.723 kg/m^3 for Var. Africana and 317.55 to 387.638 kg/m^3 for Var. Inversa. The porosity of Var. Africana ranges from 65.06% to 51.6% while for Var. Inversa it ranges from 66.5% to 57.2%. The terminal velocity increased from 5.5 to 8.0 m/s for Var. Africana and 3.89 to 6.8 m/s for Var. Inversa respectively as the moisture content increased from 6.85 to 28.85 %.

1. Introduction

The breadfruit seed is the mature ovule of *Treculia africana*, it is light brown in colour, roughly oval and spherical in shape. The seeds are contained in a pulp mass inside the fruit. When the fruits are harvested they are stored to ferment for 3-4 days, then mashed and the seeds freed by washing the solubilized pulp off the seeds in a basket with running water, and later sun dried. The dried seeds are available in the market in the undehulled state (Omobuwajo *et al.*, 1999).

When dehulled the seeds may be cooked and eaten as the main dish like rice or roasted and eaten as a snack in the same way as peanut. It could also be cooked with fresh corn into porridge. The seed is used in these food forms in several parts of West Africa and especially Southeastern Nigeria (Akande, 1998). It is used in preparing pudding, as a thickener in traditional soups and in manufacture of food products such as flour for bread, beverages and weaning food for children (Onyekwelu and Fayose, 2007).

Engineering properties of breadfruit seed are essential for the design of equipment for handling, separation, and conveying, drying, storing, aeration and processing. Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities; they can affect

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the rate of heat and mass transfer of moisture during aeration and drying processes. Rajabipour *et al.* (2006) reported that drag coefficient and terminal velocity of material are important parameters in aerodynamic and hydrodynamic behaviour which depends on acceleration due to gravity and fluid flow. These properties help in the design of equipment for separation and handling. Knowledge of specific heat capacity is important in engineering design calculations involving thermal processing of agricultural products (Mortaza *et al.*, 2008). Temperature and moisture content greatly influence the specific heat capacity of agricultural materials due to the relatively high specific heat of water.

The aim of this research work was to investigate some engineering properties of two varieties of breadfruit seed *Var. Africana* and *Var. Inversa* relevant to bulk handling. These properties include densities, porosity, aerodynamic and thermal properties as influenced by moisture content. Regression models were also generated with respect to moisture content.

2 Materials and Methods

2.1 Moisture content determination and adjustment

Standard procedures stated for ungrounded grain and seed in the ASAE S352.2 (2003) was adopted in order to obtain the different moisture content. Electric oven (Gallenkamp oven 300 plus series), carrying cans, and electronic weighing balance (WENSAR PGB Series) with accuracy of 0.01 g were used to determine moisture content of the two varieties of breadfruit seed.

The moisture content was calculated using equation 1 (Abodenyi, *et al.,* 2015)

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

Where;

$MC_{(wb)}$ = 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)

The desired moisture content were obtained by determining the required amount of water, M, as calculated from equation 2 (Davies and Zibokere, 2011),

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

Where,

W_s = weight of sample (kg)

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

M_1 = initial moisture content (%) of breadfruit seed

M_2 = desired moisture content (%) of breadfruit seed

The samples were adjusted from 6.85% to 14.85%, 21.85% and 28.85% w.b.

2.2 Determination of true density of breadfruit seeds

The seed volume and true density ρ_T as a function of moisture content was determined by water displacement method (Adejumo *et al.*, 2007, Davies and Zibokere, 2011). One hundred seeds of known average weight were dropped into a container filled with water. The net volumetric water displacement by the seed were noted and recorded. The experiment was repeated five times. The true density of breadfruit seed was then evaluated using the expression as given by equation 3;

$$\rho_T = \frac{m}{v} \quad (3)$$

Where,

ρ_T = true density (kg/m^3)

m = mass of the sample (kg) and

V = volume (m^3)

2.3 Determination of bulk density and percentage porosity

The bulk density (ρ_B) in kg/m^3 is the ratio of the mass sample of thes breadfruit seeds to its volume. Equation 4 was used to determine the bulk density using a container of 300 mm height and 200 mm diameter. The container was filled with the sample from a height of about 150 mm, (Karababa, 2006). The electronic balance was used to weigh the samples:

$$\rho_B = \frac{M_{\rho 2} - M_{\rho 1}}{V} \tag{4}$$

Where,

$M_{\rho 2}$ = mass of cylinder plus seeds (g)

$M_{\rho 1}$ = mass of empty cylinder (g)

V = volume of the cylinder (cm^3)

The porosity (ε) of the bulk seed was computed from the values of the true density (ρ_T) and bulk density (ρ_B) of the seeds by using equation 5;

$$\varepsilon = \frac{\rho_T - \rho_B}{\rho_T} \times 100 \tag{5}$$

3.1 Determination of Aerodynamic Properties

3.1.1 Determination of terminal velocity

The terminal velocity of the breadfruit seed was determined by using an air column as used by Adedeji (2012). It is made of vertical wind tunnel of diameter 44.28 mm and height of 600 mm. A voltage regulator and a digital anemometer (model AM- 4812) were used to determine the air speed. Each sample of the two varieties at the required moisture of 6.85, 14.85, 21.85 and 28.85% were dropped into the air stream from the top of the air column and the air velocity adjusted until the seed, is suspended in the air stream. The respective velocity (m/s) near the location of the seed suspension was measured with the help of the digital anemometer having accuracy of ± 0.1 m/s. The experiment was replicated five times and the readings recorded.

3.1.2 Determination of drag coefficient

The drag coefficient was calculated from equation 6 (Mohsenin, 1986)

$$CD = \frac{2Mg}{A_\rho \ \rho_A V_t} \tag{6}$$

Where,

CD = the drag coefficient

M = weight of the seed at terminal velocity (g)

g = acceleration due to gravity (m/s^2)

A_ρ = area of the particle (m^2)

ρ_A = density of air (kg/m^3)

V_t = terminal velocity of the particle (m/s)

3.2 Determination of Specific Heat Capacity

The specific heat capacities of the two varieties of the seed were determined by the method of mixture as described by Oje and Ugbor (1991) and Ogunjimi *et al.,* (2001). Hot water of known weight and temperature was poured into an adiabatic drop calorimeter containing twenty- five seeds of each variety at a time. The initial temperature of the seeds was taken. The mixture was stirred with a copper stirrer until equilibrium was reached; the final temperature of the mixture was recorded. Specific heat capacity was computed from equation 7. The experiment was replicated five times for each of the variety at the required moisture content.

$$C_S = \frac{[C_w \ M_w \ (T_{wi} - T_{wf})]}{M_s \ (T_{si} - T_{wf})} \tag{7}$$

Where,

C_s = specific heat capacity of the seed (J/kg/°C)

C_W = specific heat capacity of water (J/kg/°C)

M_W = Mass of water (g)

M_S = Mass of the seed (g)

T_{WI} = Initial water temperature (°C)

T_{WF} = Final water temperature (°C)

T_{SI} = Initial temperature of seed (°C)

4 Experimental Design and Statistical Analysis

The experimental design was a 2×4 RCBD (Randomized Complete Block Design) with replications. Two varieties of breadfruit seed (*Var. africana* and *Var. inversa)* were used at four different moisture content levels of 6.85, 14.85, 21.85 and 28.85 % and each parameter determined was replicated five times.

5 Results and Discussion

5.1.1 True and bulk densities

The result of the effect of moisture variation on true density is presented in Table 1. The true density of *Var. africana* decreased from 1033.68 kg/m^3 to 842.81 kg/m^3 which amounted to 18.5% decrease, while for *var. Inverse* it decreased from 948.38 kg/m^3 to 911.89 kg/m^3 amounting to 3.85% decrease as the moisture content increased from 6.85 to 28.88%.

The regression equations, 8 and 9 indicates a negative linear correlation which is to say that as the moisture content increased the true density decreased. Taheri *et al*., (2012) observed the same result for hemp seed, and Bagherpour *et al* (2010) also found true density to decrease with increase in moisture content from 1330 to 1194 kg/m^3 and moisture content from 8 to 20% wb.

$$\rho_{TA} = -10.25MC + 1140 \qquad R^2 = 0.856 \qquad (8)$$

$$\rho_{TIN} = -2.055MC + 979.8 \qquad R^2 = 0.812 \qquad (9)$$

This result revealed that the relative increase in the weight of breadfruit seed due to moisture absorption is lower than the corresponding volumetric increase. This finding agrees with Tunde-Akintunde and Akintunde (2007) for beniseed and Davies and Zibokere (2011) for three varieties of Cowpea, and Solanki *et al* (2011) for neem fruit and seed. The ANOVA (Table 2) result indicated that the moisture content had significant effect on true density at P≤0.05 probability. Also the interaction effect between moisture content and variety was significant.

The bulk density was observed to increase linearly as the moisture content increased. It increased from 361.239 to 408.723 kg/m^3 for *Var. Africana* and 317.55 to 387.638 kg/m^3 for *Var. Inversa*. The increase in bulk density for neem seed indicated increase in mass owing to moisture in the seed. This result agrees with the result of Solanki *et al.* (2011) on neem fruit and seed, Adedeji (2012) on neem seed and kernel and Dursun and Dursun (2005) caper seed. The ANOVA of the effect of moisture content on bulk density of breadfruit varieties indicates that the effect was significant at P≤0.05 probability and also significant for the interactive effect of moisture content and variety. The coefficient of determination R^2 obtained from the regression models gave values of 0.983 for *Var. africana* and 0.996 for *Var. inversa* on the effect of moisture content on bulk density of the two breadfruit seed varieties.

$$\beta\,\rho_{A} = 2.122MC + 349.0 \qquad R^2 = 0.983 \qquad (10)$$

$$\beta\,\rho_{IN} = 3.196MC + 293.9 \qquad R^2 = 0.996 \qquad (11)$$

Asoegwu *et al,* (2011) found the R^2 value for African breadfruit seed to be 0.984. The mean separation between the varieties and moisture content is presented in Table 1. There is a significant difference between all the moisture content levels for both varieties which tallies with the ANOVA result in Table 2. Bulk density and true density are useful in the design of hoppers and storage facilities.

5.1.2 Porosity of breadfruit varieties

Figure 3 shows the effect of moisture content on percentage porosity of *Var. Africana* and *Var. Inversa*. Increase in moisture content decreased the porosity of the seeds. The porosity of *Var. Africana* ranges from 65.06% to 51.6% while for *Var. Inversa* it ranges from 66.5% to 57.2%. This shows that a pack of *Var. Inversa* is more porous than *Var. Africana*. This property is required in the aeration process in agricultural material handling; from this result *Var. Inversa* might dry faster than *Var. Africana* during air drying process. This result agrees with Aydin *et al.* (2002), for Turkish Marhleb, Irtwange and Igbeka (2002b) for two African yam bean accessions TSs 137 and TSs 138 and Alonge and Adegbalugbe (2005) for groundnut. The result in Table 1 and the ANOVA (Table 2) indicate that there is a significant difference between all the moisture content levels for both varieties at $P \leq 0.05$ alpha level. Regression equations 12 and 13 shows that the coefficient of determination are significant for the two varieties at $p \leq 0.05$.

$$\varepsilon_A = -0.676MC + 70.74 \qquad R^2 = 0.912 \tag{12}$$

$$\varepsilon_{IN} = -0.418MC + 70.14 \qquad R^2 = 0.945 \tag{13}$$

The coefficient of determination (R^2) tended towards unity (1) indicates that the interaction of the independent variable has a very strong effect on the dependent variable.

5.2 Effect of Moisture Content on Thermal Properties of Breadfruit Seed Varieties

5.2.1 Specific heat capacity of breadfruit seed varieties

The influence of moisture variation on specific heat capacity of *Var. Africana* and *Var. Inversa* is presented in Figure 4. Increase in moisture content resulted to increase in specific heat capacity of the two varieties. *Var. Africana* increased from 2869.70 J/kg/^{O}C to 3909.63 J/kg/^{O}C while, *Var. Inversa* increased from 2811.35 to 3777.30 J/kg/^{O}C as the moisture increased from 6.85 to 28.85%. The mean effect of moisture content on breadfruit varieties is shown in Table 1. Regression analysis from equations 14 and 15 showed that there is a linear relationship between *Var. Inversa* and the moisture content while *Var. Africana* had a polynomial relationship as evident in Figure 4.

$$C_A = -2.663MC^2 + 141.9MC + 2026 \qquad R^2 = 0.999 \tag{14}$$

$$C_{IN} = 47.67MC + 2500 \qquad R^2 = 0.929 \tag{15}$$

The R^2 value for *Var. Africana* is higher than that for *Var. Inversa*, so the model for the *Var. Africana* is recommended. The increase in specific heat capacity of breadfruit varieties is in agreement with findings of some previous researchers. The specific heat of hard red spring wheat was found to increase linearly from 1054 to 2521 J/kg/°C with moisture content in the range of 10 to 23 % db by Muir and Viranvanichai (1992) and Mirzaee *et al.* (2008) for Apricot fruit.

The specific heat of shea nut kernel as a function of moisture content was determined by Aviara and Haque (2001). They found that the specific heat increase linearly from 1792 to 3172 J//kg/°C as moisture was increased from 3.32% to 20.7% (db). This property can be used to determine the amount of heat required in the processing of the seed. It can also be used to design equipment and facilities for drying, preservation and processing of breadfruit seed, for making industrial products such as beverages, snacks pastas, flours, and cosmetics and in the pharmaceuticals, the knowledge of the specific heat capacity is important. The ANOVA (Table 2) showed that moisture content has a significant effect on the specific heat capacity of breadfruit seed. But there was no significant effect on the interaction between moisture and variety at 0.05 probability level.

5.3 Effect of Moisture Content on the Aerodynamic properties of Breadfruit Seed Varieties

5.3.1 Terminal Velocity of Breadfruit Seed Varieties

The mean effect of moisture content on terminal velocity is shown in Table 1. As moisture content increased from 6.85 to 28.85% (wb) the terminal velocity also increased from 5.5 to 8.0 m/s for *Var. africana* and 3.89 to 6.8 m/s for *Var. inversa* respectively. The result is in agreement with the report of Simonyan *et al.* (2008), Gursoy and Guzel (2010) and Adedeji (2012). The increase in terminal velocity with increase in moisture content can be attributed to the increase in the weight of an individual breadfruit seed per unit frontal area presented to the air stream. The regression equations and correlation between the moisture content and terminal velocity are shown in equations 16 and 17 and Figure 5.

$$V_{tA} = 0.120MC + 4.668 \qquad R^2 = 0.970 \qquad (16)$$

$$V_{tIN} = 0.132MC + 2.989 \qquad R^2 = 0.999 \qquad (17)$$

The terminal velocity for *Var. africana* was found to be higher than that of *Var. inversa*. This is a good parameter for effective separation. The ANOVA indicates that the effect of moisture content on the breadfruit variety is significant at 0.05 level of probability, but not significant for interaction effect of variety and moisture content. This result indicates that in the design of a cleaning chamber for breadfruit seed decorticator the terminal velocity should not be more than 8.0 m/s but higher than 3.89 m/s. Terminal velocity has practical application in calculating volume of air stream for seed and chaff separation, such as fan and sieve arrangement of the thresher.

5.3.2 Drag coefficient of breadfruit seed varieties

From Table 1 it was observed that as the moisture content increased the drag coefficient for *Var. africana* reduced from 0.01 to 0.0029, for *Var. inversa* it reduced from 0.005 to 0.0018. Drag coefficient is resistance of a seed in a flow environment. This property is required in the design of cleaning and sorting machine. The result obtained agrees with McCormick (1989) findings that less drag coefficient of an object the higher the moisture content.

The ANOVA shows that there is no significant effect at $p \leq 0.05$ for the two varieties. The regression analysis indicates a polynomial correlation as shown in Figure 6 and equations 18 and 19

$$CD_A = 0.005MC^2 - 0.003MC + 0.014 \quad R^2 = 0.999 \qquad (18)$$

$$CD_{IN} = 0.006MC^2 - 0.002MC + 0.007 \quad R^2 = 0.981 \qquad (19)$$

Conclusion

1. The bulk density increased from 361.239 kg/m^3 to 408.723 kg/m^3 as the moisture content increased from 6.85% to 28.85 % wb for *Var. africana*, and from and 317.55 to 387.64 kg/m^3 for *Var. inversa*
2. The following properties for *Var. africana* decreased with increase in moisture; true density and porosity; ranging from 1033.68 kg/m^3 to 842.81 kg/m^3 and 65.06 to 51.58% respectively. While for *Var. inversa* the decrease ranged from 948.38 to 911.89 kg/m^3 for true density and 66.51% to 54.24 % for porosity.
3. The specific heat capacity was found to increase from 2869.70 to 3909.63 J/kg/^{o}C for *Var. africana* while for *Var. inversa* it increased from 2811.35 to 3777.30 J /kg/ ^{o}C as the moisture content increased from 6.85 to 28 85%.
4. The terminal velocity for *Var. africana* and *Var. inversa* increased from 5.50 to 8.0 m/s and 3.89 to 6.8 m/s, respectively as moisture content increased from 6.85 to 28.85%
5. The drag coefficient was observed to decrease with increase in moisture content for *Var. africana* from 0.010 to 0.0029, while for *Var. inversa* it deceased from 0.005 to 0.0018 for moisture range of 6.85 to 28.85 %.

Table 1: Mean Separation for Some Engineering Properties of Breadfruit Seed Varieties Using LSD at 0.05

Variety	MC (%)	True Density (kg/m^3)	Bulk density (kg/m^3)	Porosity (%)	Terminal velocity (m/s)	Drag coefficient	Specific heat capacity(J/Kg/ ^{o}C)
Africana	6.85	1033.68^a	361.24^a	65.06^a	5.50^a	0.010^a	2869.70^a
	14.85	1047.71^b	383.9^b	63.31^b	6.30^b	0.0059^a	3560.13^b
	21.85	863.38^c	395.82^c	54.06^c	7.75^c	0.0038^a	3842.32^c
	28.85	842.81^d	408.72^d	51.58^d	8.01^d	0.0029^a	3909.63^c
LSD $_{0.05}$		13.554	2.1673	0.6009	0.2192	0.0582	348.08
Inversa	6.85	948.38^a	317.55^a	66.51^a	3.89^a	0.005^a	2811.35^a
	14.85	962.13^b	339.30^b	64.80^b	4.96^b	0.0035^a	3142.60^b
	21.85	948.34^c	362.85^c	61.82^c	5.90^c	0.0020^a	3720.74^c
	28.85	911.89^d	387.64^d	54.24^d	6.80^d	0.0018^a	3777.30^c
LSD $_{0.05}$		13.554	2.1673	0.6009	0.2192	0.0582	348.08

Means having the same letter in the same column are not Means having the same letter in the same column are not statistically different from each other at $p \leq 0.05$.

Table 2: Summary of ANOVA Results for Some Engineering Properties of Two Breadfruit Seed Varieties

Parameters	Sources of Variations	DF	F	P
True density	Variety	1	1.18	0.286^{ns}
	M.C	3	90.75	0.000*
	Interaction	3	51.54	0.000*
Bulk Density	Variety	1	1137.14	0.000*
	M.C	3	544.64	0.000*
	Interaction	3	32.20	0.000*
Porosity	Variety	1	186.45	0.000*
	M.C	3	320.08	0.000*
	Interaction	3	24.91	0.000*
Terminal vel.	Variety	1	180.65	0.000*
	M.C	3	127.51	0.000*
	Interaction	3	1.13	0.354 ^{ns}
Drag coefficient	Variety	1	160.42	0.068^{ns}
	M.C	3	119.26	0.070^{ns}
	Interaction	3	3.14	0.069^{ns}
Specific heat capacity	Variety	1	1.15	0.292 ^{ns}
	M.C	3	7.45	0.001*
	Interaction	3	0.22	0.880 ^{ns}

*= significant at $p \leq 0.05$, ns = not significant at $p \leq 0.05$

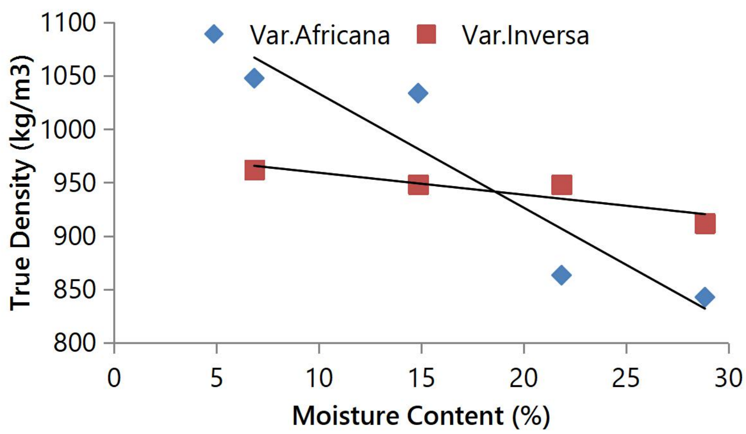

Figure 1: Effect of Moisture Content on True Density of *Var.Africana* and *Var. Inversa*

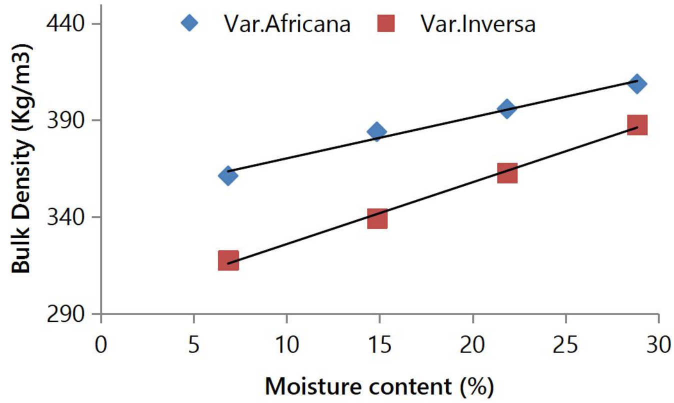

Figure 2: Effect of Moisture Content on Bulk Density of Breadfruit Seed Varieties

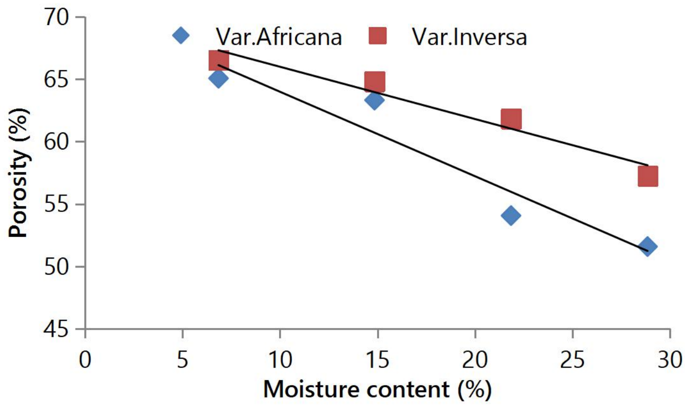

Figure 3: Effect of Moisture Content on Porosity of Breadfruit Seed Varieties

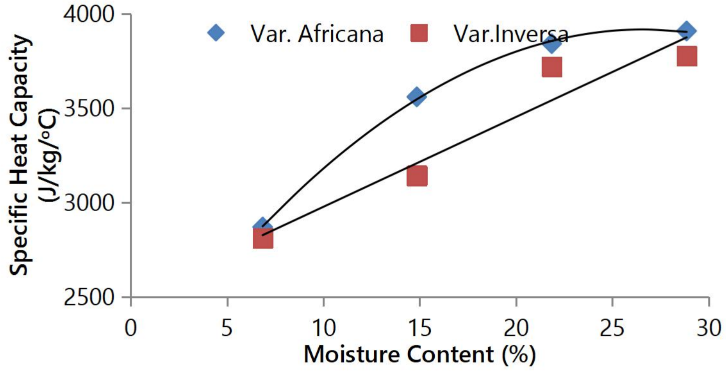

Figure 4: Effect of Moisture Content on Specific Heat Capacity of Breadfruit Seed Varieties

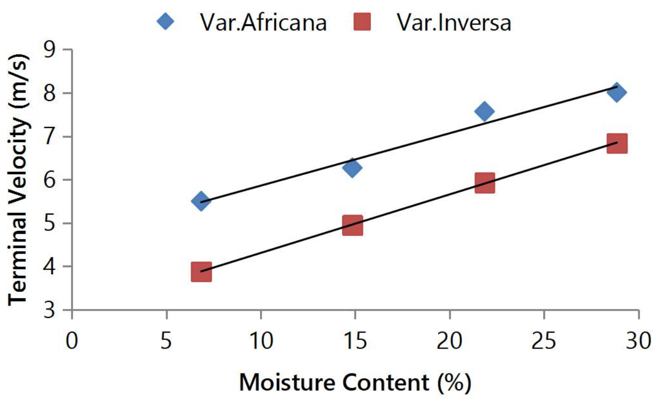

Figure 5: Effect of Moisture Content on Terminal Velocity of Breadfruit Seed Varieties

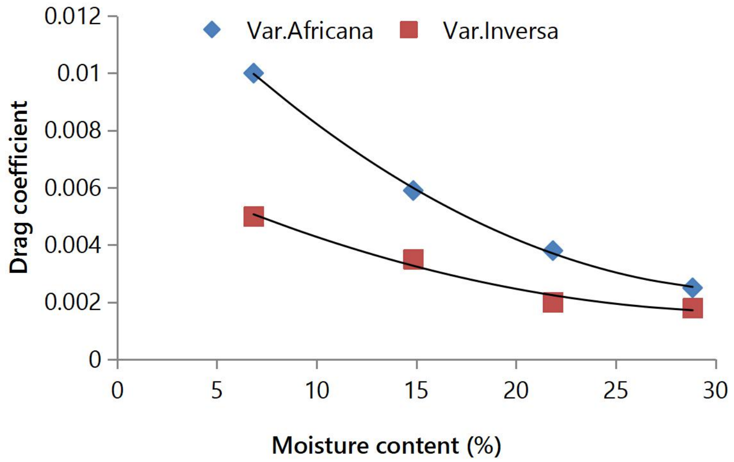

Figure 6: Effect of Moisture Content on Drag Coefficient of *Var. Africana* and *Var. Inversa*

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