Moisture dependent physical properties of sour-sop (Annona muricataL.) seeds

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Abstract: Some moisture-dependent physical properties of sour-sop seed were investigated. Results of experiments on rewetted sour-sop seed showed increasing in length, width, thickness, arithmetic and geometric mean diameter, volume, surface area, sphericity, and thousand seeds weight from 14.91-15.69, 8.71-9.24, 5.39-5.56, 9.67 - 10.16, 8.81 - 9.27 mm, 0.57 – 11.67 cm3, 244.98 - 270.89 mm2, 0.56 - 0.59 and 255.7 – 285 g, respectively within moisture range of 8 – 32.5% (d.b.). An increasing trend for bulk density and true density was observed from 0.52 – 0.59 g/cm3 and 0.47 – 0.60 g/cm3. Porosity of the seed decreased from 9.62%–4.73%. Angle of repose was increased linearly from 25.7 – 33.3 ° with increase in moisture content from 8.0 – 32.5% (d.b.).At all moisture contents, coefficient of friction was highest for mild steel (0.37) followed by galvanized steel (0.29) and stainless steel surfaces (0.29).

Keywords: Sour-sop seed, moisture content, physical properties

1　Introduction

Sour-sop (*Annona muricata* L.) is a fruit native of tropical North and South America belonging to the genus *Annona* of the family *Annonaceae* which has about 100 species of trees. Today this crop is word widely cultivated in tropical region and has many potential useful applications in chemical industries (Fasakin et al., 2008;Syahida et al., 2012).

In Nigeria, sour-sop trees yields up to 10 t/ha and the fruits weight between 0.5 to 2.0 kg, contain shiny dark brown seeds and abounds mostly in the Western part of the country; commonly cultivated in home garden and generally known as '*cha chap'* (Oyenuga, 1978; Fasakin et al., 2008). The most frequently investigated studies on the seed was the mineral content and essential oil which shown the potential importance of its oil in chemical industries (Onimawo, 2002; Fasakin et al., 2008; Kimbonguila et al., 2010).

Physical properties of sour-sop seed as a function of moisture content are to be known for design and development of relevant machines for handling and processing. Today, much data have been published on the physical properties of grains and seeds by other researchers such as(Aviaraet al., 2005) for sheanut, (Koocheki et al., 2007) for watermelon seeds, (Polat et al., 2007) forpistachio nut and kernel, (Hojat et al., 2009) for fennel seed, (Ahmadi et al., 2012) for psyllium seed, Akande et al. (2013) for locust bean seed, Milani et al. *(*2007) for cucurbit seed, Koocheki et al.(2007) for ghermez seed and Barnwal et al.(2012) for maize. However, there is scarce published literature depending on moisture variation on physical properties of the seed.

Knowing the moisture dependence is useful for further investigation in processing the seeds (Koocheki et al., 2007).Therefore, the aim of this study was to investigate some physical properties of sour-sop seeds at different moisture content

2　Materials and methods

The sour-sop seeds used for all experiment were obtained from sour-sop plants grown in Ogbomoso, Nigeria. The seeds were manually cleaned and store at room temperature (28^oC-32^oC). The initial moisture content of the samples was determined by oven drying at $103^oC\pm2^oC$ (ASAE, 2001)until a constant weight was reached. The samples of desired moisture content (8, 11.9, 15.4, 22.6 and 32.5% d.b.) were prepared by adding calculated amount of water, thoroughly mixing and then sealed in separate polythene bags. The samples were kept in a refrigerator (Thermocool, HR-170T) for at least seven days at temperature of $5^oC\pm2^oC$to enable the uniform distribution of moisture throughout the samples. The required quantities of the seed were allowed to warm to room temperature prior to each test (Aghkhani et al.,2012).

To determine the principal axial dimensions (length, with and thickness)of the seed, a sample of 100 seeds was randomly selected and measured using a digital caliper (GMC-20) to an accuracy of 0.01 mm. Arithmetic mean diameter (A_{md}), geometric mean diameter (G), sphericity (S) and porosity (P) were calculated according to Mohsenin (1986). To evaluate thousand seeds weight (TSW), 100 seeds were randomly selected from each moisture level then weighed using digital weighing balance (MP 1001, Gallenkamp) to an accuracy of 0.1 g and then multiplied by ten. Surface area (S_A), true density (ρ_t), volume (V) and static coefficient of friction (μ_s) with three surfaces (stainless steel (St), galvanized steel (Gv)and mild steel (Ms)) were determined using standard methods according to Aghkhaniet al. (2012), ASAE (2005) and Refik et al.(2006). Bulk density (ρ_b) and angle of repose (A_r) were determined according to Koocheki et al. (2007), Dash et al. (2008) and Sahoo et al. (2009).

2   Data analysis

Data were analyzed as per one factor analysis of variance (ANOVA) using SPSS 20 software. Regression analysis was carried out using Microsoft Excel 2010 software to determine the relationship between moisture content and the physical properties.

3   Results and discussions

All physical properties such as length, width, thickness, geometric and arithmetic mean diameter, surface area, sphericity and seed volume increased linearly with increase in moisture content from 8.0% to 32.5% (d.b.) as presented in (Table 1).The length, width, thickness of sour-sop seed increased from 14.91-15.69 mm, 8.71-9.24 mm and 5.39-5.56 mm, respectively with increase in moisture content. The values of arithmetic and geometric mean diameter, surface area, sphericity and volume increased from9.67-10.16 mm, 8.81-9.27 mm, 244.98-270.89 mm^2, 0.56-0.59 and 10.57 – 11.67 cm^3 with increase in moisture content from 8.0 to 32.5% (d.b.), respectively. Similar trend was observed for cucurbit (*Cucurbitacea specie*) seed (Milani et al.,2007), ghermez seed (Koocheki et al.,2007) and maize (Barnwal et al.,2012).

The true density, bulk density and thousand seed weight increased with increase in moisture content within the moisture range of 8.0 - 32.5% (d.b.). However, reverse trend were found for porosity. True density and bulk density increased from 0.52 – 0.59 g/cm^3 and 0.47 – 0.60g/cm^3 while thousand seed weight increased from 255.7 – 285 g, respectively (Figure 1 and Figure 2). Similar increasing trend for true density, bulk density andthous and seed weight have been reported for lima bean (Aghkhani et al., 2012) and groundnut kernel (Saeeid et al., 2009). Reverse trend was observed for maize in which the true density, bulk density and thousand seed weight decreased with increase in moisture content (Barnwal et al.,2012).Porosity of the seed was decreased significantly ($P\leq0.05$) from 9.62% to 4.73% at moisture content varied from 8.0 to 22.6% (d.b.). While at 32.5% moisture content the value of porosity was observed to be zero which shows that sour-sop seeds have low percentage air space at high moisture content above 22.6% (d.b.) (Figure 3). Similar trend for porosity have been reported for soybean (KibarandOzturk, 2008).

Table 1 Geometric properties of sour-sop seed at different moisture content

Parameters	Moisture Content, % (d.b.)			
	11.9	15.4	22.6	32.5
Length (mm)	14.91±1.73^{a}14.96±1.22^a	15.39±1.26^{ab}	15.56±1.18^b	15.69±1.04^b
Width (mm)	8.71±0.99^a	9.14±1.03^b	9.18±0.76^b 9.19±0.96^b	9.24±0.84^b
Thickness (mm)	5.39±0.71^a	5.41±0.67^a	5.42±0.53^a 5.46±0.62^a	5.56±0.71^a
Art. mean diam. (mm)	9.67±0.72^{a}9.8±0.56^b	10.0±0.51^c 10.1±0.6^c	10.16±0.52^a	
Geo. mean diam. (mm)	8.81±0.57^a 8.96±0.5^{b}9.12±0.03^{bc}	9.2±0.52^{cd}	9.27±0.48^d	
Surface area (mm^2)	245.0±31.3^{a}253.3±27.7^b	261.9±23.1^{bc}	264.2±29.7^{cd}	308.7±37.4^d
Sphericity	0.59±0.52^a	0.6±0.04^a 0.59±0.04^{ab}0.59±0.03^{ab}	0.59±0.03^b	
Volume (cm^3)	10.57±0.2^a	10.73±0.1^{a}10.8±0.2^{a}11.13±0.1^{a}11.67±0.0^a		

Note: Mean values ±standard deviations with the same letter are not significantly different (P≤ 0.05)
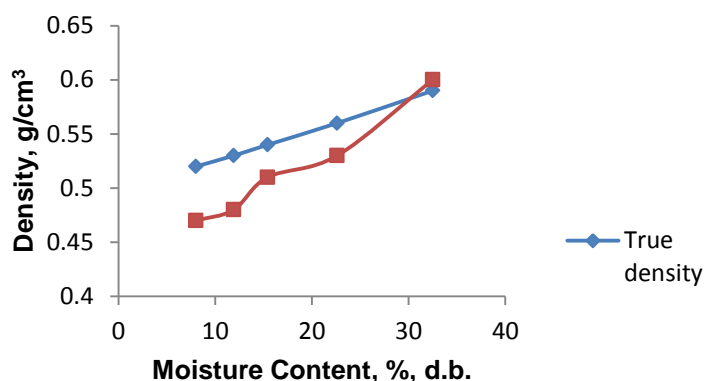

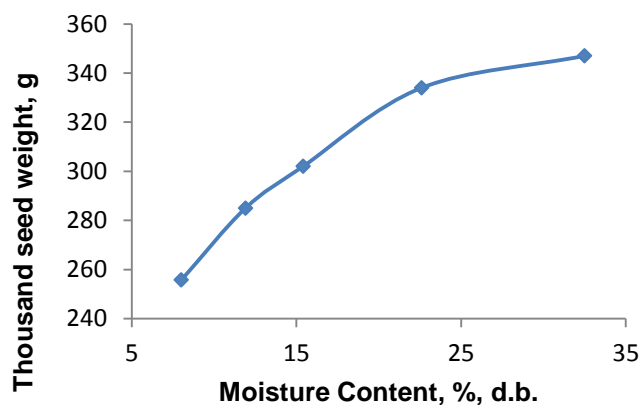Figure 1 Effect of moisture content on true and bulk density of sour-sop seed

Figure 2 Effect of moisture content on thousand seed weight of sour-sop seed
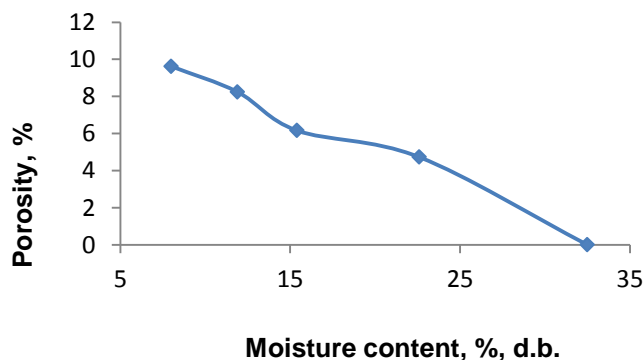

Figure 3 Effect of moisture content on the porosity of sour-sop seed

The regression equations which show the relationship between moisture content principal axial dimensions, geometric and arithmetic mean diameters, surface area, sphericity and volume of sour-sop seeds and their coefficients of determination (R^2) are presented in Table 2. Results of analysis show that the moisture content has significant difference ($P \leqslant 0.05$) on geometric properties of the seed.

Table 2 Relationship between geometric properties of sour-sop seed

Moisture content, %,d.b.	Equations	R^2
$L = 0.0834$	$MC + 14.033$	0.982
$W = 0.0472$	$MC + 8.383$	0.858
$T = 0.0144$	$MC + 5.194$	0.979
$8.0 - 32.5\ A_{md} = 0.0474$	$MC + 9.22$	0.998
$G_{md} = 0.0416$	$MC + 8.47$	0.998
$S_A = 2.6069$	$MC + 221.89$	0.992
$S = -0.007$	$MC + 0.771$	0.370

The result of analysis for the relationship between moisture content, true density, bulk density and thousand seed weight has significant difference ($P \leqslant 0.05$). The regression equations for the data showed that thousand seed weight increased logarithmically with moisture content while positive linear increase was observed for true and bulk density with high correlation coefficient (R^2).

$\rho t = 0.0029MC + 0.4962$ $R^2 = 0.999$

$\rho_b = 0.005MC + 0.4228$ $R^2 = 0.975$

$TSW = 67.172ln(MC) + 118.14$ $R^2 = 0.987$

Negative linear relationship for porosity (P) of the seed based on moisture content (*MC*)was obtained and can be represented by the following Equation 1:

$(P) = -0.381MC + 12.64$ $R^2 = 0.983$ (1)

The R^2 values obtained for both geometric and gravimetric properties of sour-sop seeds shown that there is a strong correlation between seed moisture contents, geometric and gravimetric properties of the seed, except for the sphericity.

Angle of repose was increased linearly from 25.7 – 33.3° with increase in moisture content from 8.0 – 32.5% (d.b.) (Figure 4). Similar trend was reported for maize by Barnwal et al. (2012). The increase in the angle of repose with moisture content may be due to an increase in the internal friction with the seed moisture content.
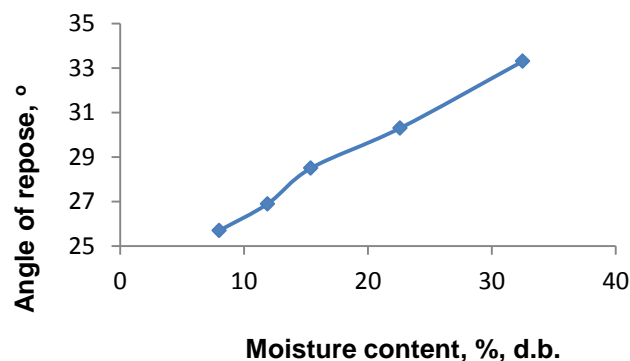

Figure 4 Effect of moisture content on the angle of repose of sour-sop seed

The coefficients of static friction were experimentally obtained against three surfaces namely stainless steel, galvanized steel and mild steel. For stainless steel, the coefficient of static friction was higher at moisture level of 15.4% (d.b.) with 0.33 values. While decreased in static coefficient of frictions was obtained from 0.24 – 0.18 and 0.33 – 0.23 between moisture content from 8.0 to 11.9% (d.b.) and 15.4 to 32.5% (d.b.).So, coefficient of static friction decreased initially and drastically increased before decreases back on stainless steel surface (Figure 4). However, reverse trend was observed on galvanised and mild steel surfaces where the coefficient of static friction increases from 0.25 – 0.3 and 0.27 – 0.4 within the moisture content level from 8.0 to 22.6% (d.b.) and however decreased to 0.34 on both

surfaces at moisture level of 32.5% (d.b.) (Figure 5).So, the highest coefficient of static friction was obtained on mild steel followed by galvanized metal while the lowest coefficient of static friction was obtained against stainless steel surface. This trend may be due to the roughness of the surfaces, as exemplified by the case of stainless steel which, with its smooth and polished surface, revealed the minimum friction value.

It was observed that material surface has greater impact on coefficient of static friction than the moisture content (see Figure 5 please). Reverse trend was reported for coefficient of static friction of cucurbit seeds (Milani et al., 2007), sesame seeds (Hosain, 2012) and maize (Barnwalet al., 2012).
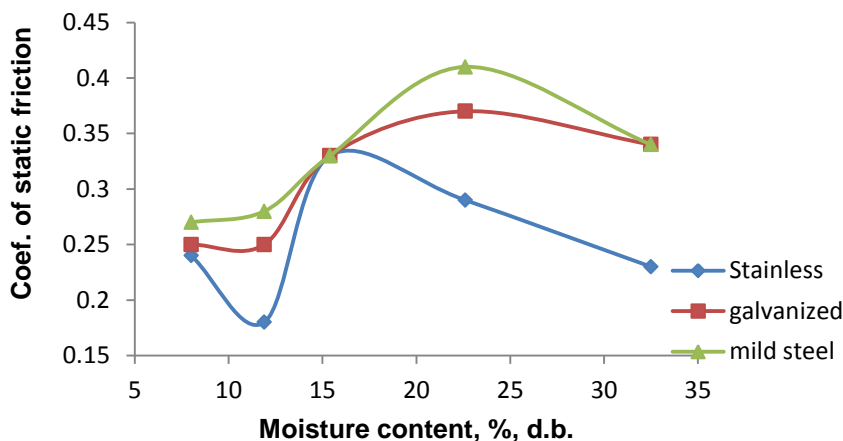

Figure 5 Effect of moisture content on static coefficient of friction of sour-sop seed

Equations represent the relationship between moisture content, angle of repose and coefficient of static friction on the three surfaces were presented in Table 3.

Table 3 Equations representing relationship between moisture content with angles of repose and coefficient of static friction

	Moisture content, %, d.b.	Regression equations
Angle of repose:	$Ar = 0.307MC + 23.38$	$R^2 = 0.995$
Stainless:	$8.0 - 32.5$　$\mu_{St} = 0.0043MC + 0.230$	$R^2 = 0.583$
Galvanized:	$\mu_{Gv} = 0.0043MC + 0.230$	$R^2 = 0.583$
Mild steel:	$\mu_{Ms} = 0.0006MC + 0.244$	$R^2 = 0.009$

4　Conclusions

1. The geometric properties of sour-sop seed such as principal axial dimensions, arithmetic and geometric mean diameters increased with increased in moisture content.

2. Porosity decreased linearly with moisture content.

3. Angle of repose increased linearly with moisture content.

4. The highest coefficient of static friction was observed on mild steel and galvanizedat moisture level of 22.6% while stainless steel has the minimum friction value at moisture level of 15.4%.

5. The data obtained is useful for engineer in the design of machinesand processes involve in processing sour-sop seed.

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