Some physical properties of Pearl millet (*Pennisetum glaucum*) seeds as a function of moisture content.

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ABSTRACT: Two varieties of Pearl millet seeds (Penisetum glaucum) (Ex-Borno and SOSAT C88) were obtained from the Lake Chad Research Institute, Maiduguri-Nigeria and reconditioned to moisture contents ranging from 10% - 20% w.b. The reconditioned seeds were then evaluated for dimensions, sphericity, bulk density, solid density, porosity, thousand seed mass, angle of repose and static coefficient of friction on five structural surfaces. Within the range of moistures analyzed, physical properties of millet seeds are related to the moisture content by polynomial equations. SOSAT C88 and Ex-Borno increased their width by 15.7% and 15.6%; similarly, their length increased by 15.3% and 19.8%, and their thickness increased by 22.4% and 7.8% respectively. Seeds from Ex-Borno were the smallest. Sphericity changed with the increase in moisture content with SOSAT C88 coming closer to a spherical form. The solid and bulk densities of the seeds for different moisture levels decreased with the increase in moisture content. The porosity started at 17% and 15.2 % and increased to 26.6% and 32.6% for SOSAT C88 and Ex-Borno varieties respectively. The thousand seed mass and angle of repose also increased with increasing moisture levels for both varieties. Both varieties showed a comparable behaviour in relation with the static coefficient of friction, this variable increased with moisture content on two structural surfaces namely concrete and plastic, but decreased with increasing moisture levels on glass, steel and aluminium. Regression equations that could be used to adequately express the relationship existing between the above properties and seed moisture were established.

Key words: Millet seed, physical properties, sample preparation.

Introduction

The millets are a group of small - seeded species of cereal crops or grains belonging to the family Gramineae and widely grown around the world for food and fodder. The most widely cultivated species in order of world wide production are pearl millet (*Pennisetum glaucum*), Foxtail millet (*Setaria italica*), Proso millet (*Panicum miliaceum*) and Finger millet (*Eleusine coracana*) (Crawford and Lee, 2003). The most important characteristic of millet is their unique ability to tolerate and survive under adverse condition of continuous or intermittent drought as compared to most other cereals like maize and sorghum (LCRI, 1997).

Millets are principally food sources in arid and semi-arid regions of the world. Ikwelle *et al.*, (1993) ranked pearl millet as the most important cereal in the southern Sudan and the northern guinea. Nkama (1998) outlined the uses and traditional food preparations of pearl millet in Nigeria. The grain serve as food for the majority of people of Africa who utilize it in the form of porridge produced from flour called 'tuwo', refreshing drink 'kunu', dessert 'dan wake' and palp 'ogi', millet beer in Cameroon , millet flour called ' Bajari' in western India. There are two major types of recommended and local varieties of millet in Northern Nigeria namely, Ex-Borno with a yield potential of 2,000 -3,000 kg/ha and the improved SOSAT variety with a yield potential of 2,500-

3,500 kg/ha (LCRI, 1997). Furthermore, the seed is a valuable food resource on account of its protein and lipids contents: 12% protein, 3% crude fibre, 4% fat (Ojediran, 2008).

There is a growing interest in the crop because of the technological possibilities of its utilization in such industrial applications as starch production. Therefore, consequent on the large scale production and commercial exploitation of the crop, is the need to study the physical and mechanical attributes of this crop, which are important in the design of equipment for handling, cleaning, storing and processing (J. Sanchez *et al.*, 2008; Vilche *et al.,* 2003; Kachru *et al.,* 1994). To date some physical properties of pearl millet seeds have been evaluated by Chukwu and Ajisegiri, (2005): size and shape, sphericity; Ajav and Ojediran, (2006): thousand seed mass, bulk and solid densities and terminal velocity. However, information on the combined effects of moisture variations and crop varieties on physical properties of pearl millet appear to be scanty in literature. The present study is therefore aimed at contributing to the knowledge of pearl millet seeds to improve the post-harvest handling and storage operations and equipment through investigation of some relevant physical properties such as axial dimensions, sphericity, bulk and solid densities, thousand seed mass, angle of repose and static coefficient of friction on five structural surfaces as affected by variety and moisture content.

Materials and Methods

Sample Preparation

Pearl millet seeds (*Pennisetum glaucum*) varieties locally recognized as "Ex- Borno" and "SOSAT C88" obtained from the Lake Chad Research Institute (LCRI) were used in the tests. Their choice was based on their high yield potential as compared to other varieties. The seeds were cleaned to remove any foreign material, then divided into lots and thereafter conditioned to obtain four different levels of moisture content ranging from 10% to 20% w.b. by adding pre-determined quantities of distilled water and thoroughly mixing. These represent the storage and processing moisture content range. The prepared samples were sealed in hermetic polyethylene bags and stored at 5^0C in a refrigerator for 4 days to allow the moisture within the grain mass to be redistributed uniformly.

The moisture content was determined using the ASAE standard method (ASAE, 1993) by drying the unground millet samples in an air ventilated oven at 105^0C for 12-14 h.

Methods

To determine the average size of the seed, 30 seeds were randomly selected from each variety at each of the four moisture contents. The three major perpendicular dimensions namely length a, width b and thickness c, were determined using a micrometer screw gauge reading to 0.001mm. The sphericity of seeds (ϕ_S) was calculated using the relationship proposed by Mohsenin (1978):

$$\frac{\phi_S = (abc)^{1/3}}{a} \qquad (1)$$

Thousand seed mass (M_{1000}) was determined using an electronic balance reading to 0.001g.

The solid density (P_S) was determined at each moisture level using the water displacement method (Mohsenin, 1986; Oje 1994; Aviara *et al.*, 2005; J. Sanchez *et al.*, 2008). The average bulk density (P_b) was determined by filling a 25ml beaker with millet seeds by dropping them from a height of 10cm and then weighing the seeds. (J. Sanchez *et al.*, 2008).

Porosity (δ) was determined in terms of bulk density and solid density (Konak *et al.*, 2002) by using the relationship:

$$\delta = \left(\frac{P_S - P_{b\ (100)}}{P_S} \right) \qquad (2)$$

The static coefficient of friction (μ) of millet seeds against five structural surfaces namely glass, concrete, plastic, steel and aluminum was determined. These materials are commonly used in grain handling and processing. The inclined plane method was used (Dutta *et al.*, 1988; Mohsenin, 1986; Aviara *et al.*, 2005). The process involved placing an open box on an adjustable tilting surface which was formed with a structural surface. Millet seeds were poured full into the box and the structural surface with the box full of millet seeds was gradually raised with a screw device until the box started to slide down. The angle of tilt was read from a graduated scale and the tangent of this angle was taken as the static coefficient of friction.

The angle of repose was determined using an open ended box constructed from poly wood measuring 150 x 150 x 150mm in size whose front panel can be removed. The box was placed on a table and filled with millet seeds. The front panel was then removed and millet seeds slide and assume a natural slope.

Angle of repose was calculated from the depth of the free surface of the seeds measured at two known horizontal distances from one end of box. (Aviara *et al.,* 2005). All experiments were repeated thrice.

Regression curves of linear (Eq. 3) or polynomial type (Eq. 4) for each variable analyzed were obtained. Choice of one of them was by means of coefficient of determination (R^2).

$$Y = b_1 x + b_0 \tag{3}$$
$$Y = b_2 x^2 + b_1 x + b_0 \tag{4}$$

Results and Discussion

Seed dimensions

For both Ex-Borno and SOSAT C88 varieties, results obtained at the lowest moisture are similar to those reported by Ajav and Ojediran, (2006) at 10% moisture content. Dimensions of millet seeds increased with the increase in moisture content. The seeds expand in length, width and thickness. The relationship between the axial dimensions and seed moisture content is shown in Fig. 1 Summary of all the parameters at four moisture content levels for both millet varieties is presented in Table 1.

Results shown in Fig. 1 indicate that SOSAT C88 variety is of bigger seeds than Ex-Borno variety. However, increase in size as a function of moisture content is similar to both varieties. Within the range of analyzed moistures, SOSAT C88 and Ex-Borno millet varieties increased their length by 15.3% (3.87-4.46mm) and 19.8% (3.17-3.80mm) respectively. Similarly, their width was increased by 15.7% (2.93-3.39mm) and 15.6% (2.30-2.66mm) and their thickness was increased by 22.4% (2.05-2.51mm) and 7.8% (1.54-1.66mm) respectively. The relationships existing between axial dimensions and moisture content for both varieties were found to be polynomial of the third order and can be expressed as:

$$a_s = -0.0024M^3 + 0.1223M^2 - 1.9336M + 11.586, \ R^2 = 1 \tag{5}$$

$$a_e = 0.0088M^3 - 0.3954M^2 + 5.763M - 23.860, \quad R^2 = 1 \tag{6}$$

$$b_s = -0.0139M^3 + 0.6098M^2 - 8.4729M + 41.519, \ R^2 = 1 \tag{7}$$

$$b_e = 0.0093M^3 - 0.4129M^2 + 5.9209M - 24.966, \quad R^2 = 1 \tag{8}$$

$$c_s = -0.0005M^3 + 0.0355M^2 - 0.6719M + 6.596, \quad R^2 = 1 \tag{9}$$

$$c_e = -0.0098M^3 + 0.4133M^2 - 5.5374M + 25.244, \ R^2 = 1 \tag{10}$$

where: a_s and a_e are length of SOSAT C88 and Ex-Borno varieties

respectively, b and c are width and thickness for each millet variety.

Table1: Some physical properties of Ex-Borno and SOSAT C88 millet seeds

Variety Parameters Moisture Content (% w.b)	Ex-Borno					SOSAT C88				
	10	13	15	20	R^2	10	13	15	20	R^2
Length, a (mm)	3.16 *(.253)*	3.57 *(.113)*	3.33 *(.157)*	3.80 *(.134)*	1	3.87 *(.364)*	3.80 *(.110)*	3.79 *(.076)*	4.46 *(.063)*	1
Width, b(mm)	2.30 *(.090)*	2.65 *(.082)*	2.45 *(.126)*	2.66 *(.109)*	1	2.93 *(.379)*	2.77 *(.085)*	2.62 *(.412)*	3.39 *(.053)*	1
Thickness, c (mm)	1.54 *(.069)*	1.64 *(.179)*	1.49 *(.086)*	1.6 *(.049)*	1	2.05 *(.348)*	1.78 *(.176)*	2.19 *(.438)*	2.51 *(.082)*	1
Sphericity	.7007 *(.0006)*	.692 *(.0006)*	.6849 *(.0003)*	.6675 *(.0004)*	1	.7285 *(.0008)*	.6930 *(.0008)*	.7289 *(.0008)*	.7445 *(.0002)*	1
1000 seed mass, (g) (M_{1000})	7.3 *(.492)*	9.08 *(.017)*	9.99 *(.012)*	10.06 *(.026)*	1	9.47 *(.611)*	11.42 *(.012)*	11.09 *(.024)*	11.95 *(.026)*	1
Bulk density(kg/m^3)	811.4 *(.064)*	684.8 *(11.973)*	679.2 *(12.749)*	646.4 *(5.987)*	1	817.64 *(.305)*	728.8 *(8.908)*	726.0 *(7.155)*	725.6 *(9.329)*	1
Solid density (kg/m^3)	958.1 *(36.255)*	953.26 *(35.331)*	956.13 *(49.041)*	960.59 *(32.458)*	1	995.24 *(42.560)*	982.48 *(18.269)*	985.21 *(30.473)*	988.61 *(12.082)*	1
Porosity (%)	15.17 *(.033)*	27.26 *(.037)*	26.18 *(.035)*	32.64 *(.023)*	1	17.28 *(.036)*	20.37 *(.013)*	26.3 *(.027)*	26.60 *(.002)*	1
Angle of repose (^{0})	32.67 *(1.247)*	37.67 *(.047)*	34.67 *(.471)*	40.00 *(0)*	1	29.33 *(5.185)*	34.67 *(.471)*	34.67 *(.471)*	40.00 *(0)*	1

(Numbers in parenthesis are standard deviations)

Table 2. Coefficient of friction on structural surfaces.

Variety	Glass		Concrete		Plastic		Steel		Aluminum	
	A	B	A	B	A	B	A	B	A	B
Moisture content (%w.b.)										
10	.3908 *(.025)*	.4041 *(.016)*	.3906 *(.019)*	.3973 *(.009)*	.3906 *(.019)*	.3974 *(.019)*	.4177 *(.009)*	.4041 *(.016)*	.4108 *(.009)*	.4041 *(.016)*
13	.3889 *(.016)*	.4040 *(0)*	.3908 *(.025)*	.4108 *(.009)*	.4108 *(.009)*	.4041 *(.016)*	.4041 *(.009)*	.4108 *(.025)*	.3906 *(.009)*	.4041 *(.016)*
15	.3772 *(.009)*	.3973 *(.009)*	-4109 *(.019)*	.4108 *(.009)*	.4108 *(.009)*	.4041 *(.016)*	.3906 *(.009)*	.3908 *(.025)*	.3906 *(.009)*	.4108 *(.016)*
20	.3706 *(.009)*	.3706 *(.009)*	.4109 *(.019)*	.4177 *(.009)*	.4041 *(.016)*	.4041 *(.016)*	.3706 *(.009)*	.3906 *(.009)*	.3706 *(.009)*	.3839 *(0)*

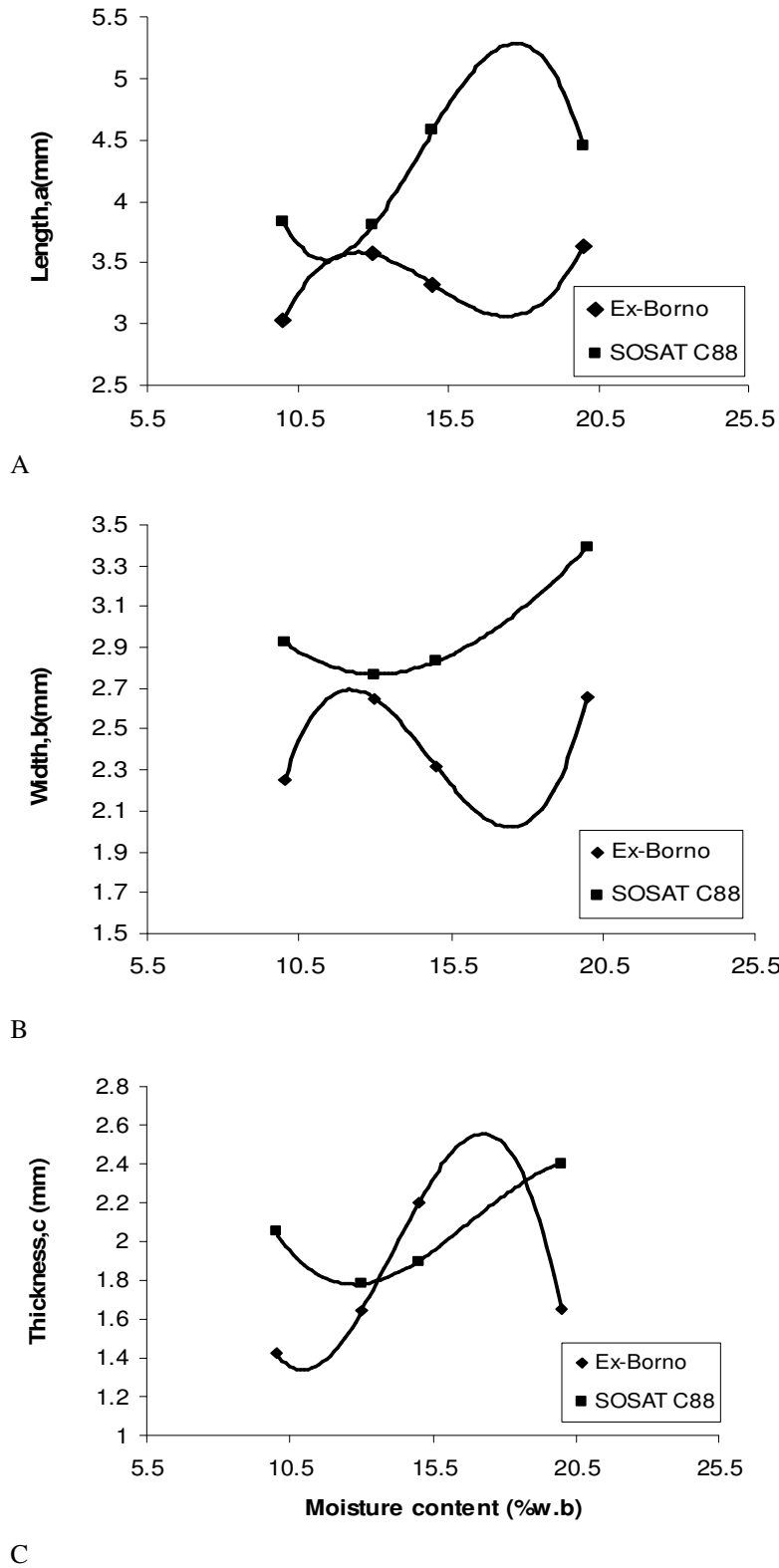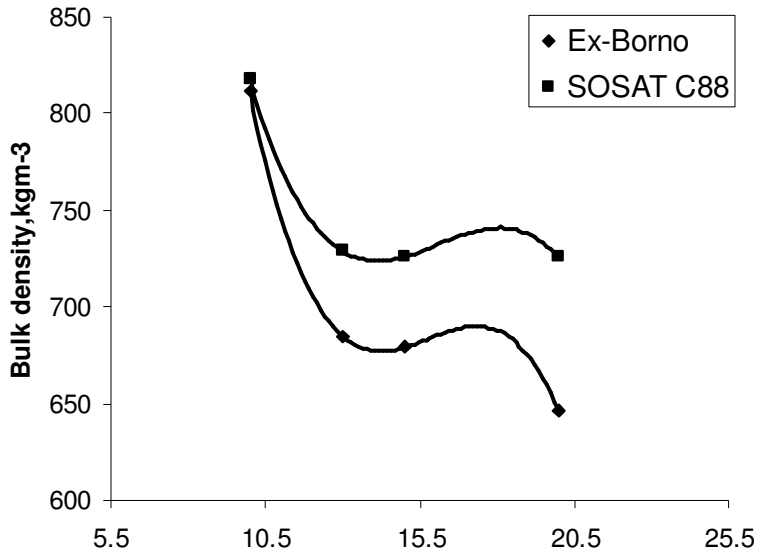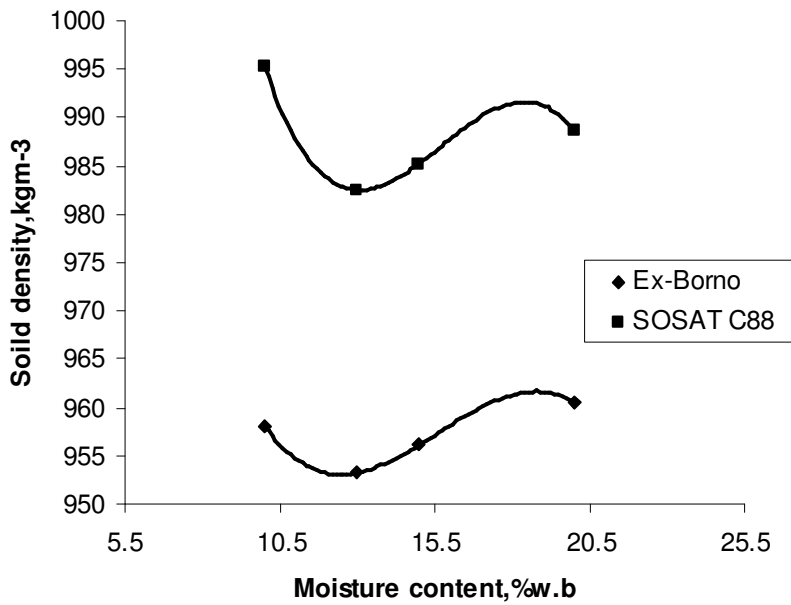A = **Ex-Borno**
B = **SOSAT**

Figure 1: Effect of moisture content on millet seed dimensions A: length, B: width and C thickness

A

B

Figure 2: Effect of moisture content on millet seed bulk density A and solid density B

Sphericity

Sphericity of millet seeds changed with increase in moisture content and the relationship between moisture content and sphericity can be represented by the regression equation(4) and coefficient of determination R^2 shown in Table 1

Bulk density

Bulk density values for all moisture levels studied decreased with increase in moisture content (Fig. 2). The relationship with moisture content was quadratic as shown in Table 1. Similar trend was reported for cumin seeds (Singh and Goswani, 1996), roselle seeds (J. Sanchez *et al.*, 2008)

Solid density

The effect of moisture content on the solid density of millet is presented in Fig. 2. The values of Solid density for both varieties of millet decreased with the increase in moisture content. Similar results were reported for amaranth seeds (Abalone *et al.*, 2004) popcorn kernels (Karababa, 2006) roselle seed (J. Sanchez *et al.*, 2008).

This behaviour is due to the simultaneous increase of mass and volume of millet seed as a result of the water absorbed (J. Sanchez *et. al.*, 2008). However, Aviara *et al.* (2005) reported an increasing trend in solid density with increase in moisture content for sheanut.

Porosity

The porosity of millet seed was found to increase non-linearly from 15.2%-32.6% and 17.3%-26.6% for Ex-Borno and SOSAT C88 varieties respectively, within the moisture content range of 10%-20% w.b.(Table 1) Similar findings were reported for cumin seeds (Singh and Goswami, 1996), sheanut (Aviara *et al.*, 2005) and roselle seed (J. Sanchez *et al.,* 2008)

Thousand seed mass(M_{1000})

Table1 shows the thousand seed mass M_{1000} variation with moisture content. The thousand seed mass increased from 7.3 to 10.1g and 9.5 to 11.94g for Ex-Borno and SOSAT C88 varieties respectively, in the moisture range of 10-20% w.b. A quadratic relationship between M_{1000} and moisture content M was obtained and can be expressed using the equation:

$$M_{1000(s)}=0.0209M^3 -0.9547M^3+14.264M-58.557, \quad R^2=1 \qquad (11)$$
$$M_{1000(e)}=-0.0038M^3+0.1204M^2-0.683M+5.960, R^2 =1 \qquad (12)$$

S and e stand for SOSAT C88 and Ex-Borno.

Static coefficient of friction

The static coefficient of friction of millet seeds decreased quadratically with moisture content for both millet varieties on glass, steel and aluminium structural surfaces, but increased on concrete and plastic structural surfaces. Concrete has the highest static coefficient of friction followed by plastic. This is shown in Table 2.

Angle of Repose

The variation of the angle of repose of millet with moisture content is shown in Table 2. Angle of repose increased quadratically with moisture content from 32.6 to 40.0 and 29.3 to 40.0 for Ex-Borno and SOSAT C88 varieties respectively, in the moisture range of 10-20% (w.b). The relationship can be expressed by the equation

$$Y_S =-484.53M^3+6153.5M^2-25973M+36463, R^2 =1 \qquad (13)$$
$$Y_e =0.1M^3 - 4.433M^2 + 63.729M - 261.31, R^2=1 \qquad (14)$$

where; Y_S and Y_e are angles of repose of SOSAT and Ex-Borno varieties respectively.

Conclusions

1. In the moisture range of 10-20% (w.b), dimensions of millet seeds increased with the increase in moisture for both varieties. SOSAT C88 increased from 3.87-4.46mm, 2.93-3.39mm and 2.05-251mm for length, width and thickness respectively. Ex-Borno increased for the same dimensions as 3.33-357mm, 2.30-2.66mm and 1.54-1.66mm respectively.
2. The sphericity changes with increase in moisture content.
3. The estimated porosity was found to increase with the increase in moisture content. The porosity started at 15.2% and 17.3% and increased to 32.6% and 26.6% for Ex-Borno and SOSAT C88 varieties respectively.
4. The thousand seed mass increased with increase in seed moisture content for both varieties, while bulk density and solid density decreased.
5. Both millet varieties showed a comparable behaviour in relation with the static coefficient of friction, this variable increased with moisture content on two structural surfaces namely; concrete and plastic, but decreased on glass, steel and aluminium. Angle of repose increased with increase in moisture content for both varieties in the moisture range of 10 -20 % (w.b).

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