Physical Properties of Roselle (*Hibiscus sabdariffa* L.) Seed

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ABSTRACT

The physical properties of Roselle seeds were determined at different moisture contents. The seeds were ground and classified into two particle sizes. The fine and coarse samples were conditioned by adding calculated amount of distilled water to different moisture contents from the initial moisture contents of 4.4 % and 5.14 %, respectively. The moisture contents were 4.4, 6.4, 8.4, 10.4 % for fine and 5.14, 7.14, 9.14, 11.14 % wb for coarse samples. The properties were determined using ASAE standards. The mean values of the physical properties of the seeds were determined as 4.75-4.85 mm length, 4.15-4.26 mm width, 2.62- 2.67 mm thickness, 3.73-3.83 mm geometric mean diameter, 648.31-619.14 kg/m^3 bulk density, 20.13°-24.85° angle of repose, 17-18.5 mm^2 surface area, 52.6-58.3 % porosity, 1367.0-1487.4 kg/m^3 true density, 29.7-40×10^{-6} m^3 volume, 5.8-7.1 m/s terminal velocity, 1.36-1.44 specific gravity. The coefficient of static friction was measured on mild steel (0.23-0.32), plywood with the grains parallel to the direction of motion (0.38-0.45) and glass (0.22-0.30). The physical properties of the seeds were found to increase as the moisture content increases with the exception of bulk density that decreased.

Keywords: Roselle, physical properties, moisture content, density

Nomenclature

ASAE	the American Society of Agricultural Engineers		
L	length of the seed, mm	W	width of the seed, mm
T	thickness of the seed, mm	D_g	geometric mean diameter, mm
m	mass of the seed, g	M_c	moisture content, % dry basis
T_{SM}	mass of thousand seeds, g	V_t	terminal velocity of the seed, m/s
ρ_b	bulk density, kg/m^3	ρ_t	true density, kg/m^3
P_f	porosity, %	θr	angle of repose, degree
γ	specific gravity of the seed	μ_{pl}	coefficient of friction on plywood
μ_{st}	coefficient of friction on steel	μ_g	coefficient of friction on glass
M_P	present moisture content, % db	M_R	required moisture content, % db
W_S	weight of the sample, g	Φ	sphericity
μ	coefficient of static friction	β	angle of tilt, degree

1. INTRODUCTION

Roselle, *Hibiscus sabdariffa* L. is a plant that is indigenous to the tropics. It belongs to the *Malvaceae* family (Murdock, 1995). It has a wide range of names worldwide depending on the locality which had earlier been documented by various authors (Schippers, 2000). In Nigeria, it is known as *Isapa pupa* in the South Western part of the country and *Zobo* in the Northern part (Adejumo, 1999; Ajiboso and Adejumo, 2003).

The only known product from this crop presently in Nigeria has been the non-alcoholic beverage drink called *Zobo* which people use to refresh themselves. The production of this beverage is still at the lower level. This drink has other uses like curing of certain diseases such as heart ailment, remedy of hypertension (Schippers, 2000). The seeds of this crop from which edible oil could be extracted are being wasted in its production areas after which the farmer might have taken the quantity needed for the next planting season for calyces production. The seed has been found to be a source of highly valued vegetable oil with properties similar to that of crude olive oil (Atta and Imaizumi, 2002).

Kachru et al. (1994) reported that it is essential to determine the physical properties of oilseeds for proper design of equipment for handling, conveying, separation, dehulling, drying, aeration and mechanical expression of oil from these seeds. It has been established that moisture content affects the physical properties of seeds appreciably (Desphande et al., 1993; Singh and Goswami, 1996). Work done on the physical properties of Roselle seed has been limited to some properties (Omobuwajo et. al., 2000; Sánchez-Medoza et al., 2008). Omobuwajo et al. (2000) determined some physical properties of Roselle seeds at 7.7 % moisture content, while Sánchez-Medoza et al. (2008) considered the effect of moisture content on some physical properties of Roselle seeds from three different countries at moisture content range of 13-25 %. They observed that the physical properties were affected by moisture content and locality of harvest. Nothing has been done on the effect of moisture content on the entire physical properties of the seeds. Hence this work is considering the entire physical properties of the seeds useful for the designing of equipment for its processing, storing, handling and aeration systems as influenced by its moisture content.

2. MATERIALS AND METHODS

Roselle seeds were obtained from the Department of Agricultural Engineering Teaching and Research farm of the Federal Polytechnic, Bida, Nigeria.

The initial moisture content of the seeds was determined using the ASAE standard S 352.2 involving the use of oven drying method (ASAE 1998). The seed samples were prepared to the desired moisture contents by adding calculated amount of distilled water and kept in separate low density polyethylene bags. The seed samples were kept in a refrigerator at a temperature of 5±1 °C for a period of five days. For each test, the required quantity of the seeds were taken out and allowed to attain room temperature for two hours before it was used. The amount of moisture added was calculated by the expression shown in equation 1.

$$\text{ml of water added} = \left[\frac{100 - M_P}{100 - M_R} - 1\right] \text{X } W_S \ . \qquad (1)$$

All the properties were determined at moisture contents of 8.8, 10.0, 12.5, 16.0 and 19.0 % (db).

2.1 Measurement of Length, Width and Thickness

One hundred Roselle seeds were randomly selected for each of the moisture content considered and labeled for easy identification. The three principal dimensions namely the length, width and thickness were measured with a micrometer manufactured by Mitutoyo Corporation, Japan, to an accuracy of 0.001 mm.

2.2 Determination of Geometric Mean Diameter

The geometric mean diameter (D_g) of the seeds was evaluated using the relationship given by Mohsenin (1978).

$$D_g = (LWT)^{1/3} \qquad (2)$$

2.3 Determination of Sphericity

The degree of Sphericity was determined with equation 3.

$$\Phi = \frac{D_g}{L} = \frac{(LWT)^{1/3}}{L} \qquad (3)$$

2.4 Thousand Seed Mass Determination

Thousand seed weight was obtained by using the digital weighing balance of 0.01 g accuracy.

2.5 Measurement of Volume and True Density

The seed volume (V_s) and true density (ρ_t), as a function of moisture content, were determined by water displacement method (Mohsenin, 1978). The amount of displaced water was determined by hanging a bunch of thirty seeds in a graduated measuring cylinder. Prior to immersion in water, the seeds were coated with a very thin layer of epoxy resin adhesive (Araldite) to avoid any absorption of water during the experiment. The increase in weight of the seeds due to the adhesive coating was found to be less than 1.8 % and there was no change in weight of the Roselle seed bunches even when kept submerged in distilled water for two hours. The ratio of weight of seeds to the volume of displaced water is the true density.

2.6 Bulk Density Determination

The bulk density (ρ_b) of these seeds was determined by pouring the seeds into a container of 500 ml from a height of 15 cm and the excess seeds were removed by a strike-off stick. The content was weighed with a digital weighing balance, Model MT 2000 (Gibertini Electronical, Italy) having a sensitivity of 0.01 g and divided by the volume of the container.

2.7 Determination of Porosity

Porosity (P_f) of the bulk seed was computed from the values of the true density and bulk density of the seeds by using the relationship shown in equation 4.

$$P_f = (1 - \frac{\rho_b}{\rho_t}) \times 100 \quad (4)$$

2.8 Determination of Angle of Repose

The dynamic angle of repose was evaluated by using a specially constructed topless and bottomless box made of plywood, 450×450×450 mm with a removable front panel (Dutta *et al*, 1988; Olaoye, 2000). The box filled with Roselle seeds were placed on the floor and the front panel was then quickly removed allowing the seeds to slide down and assume natural slope. The angle of repose was calculated from the measurements of the height (x) of the free surface of the seeds and the diameter (y) of the heap formed outside the box using the following relationship:

$$\tan^{-1} \frac{x}{y} = \theta \quad (5)$$

2.9 Determination of Static Coefficient of Friction

Static coefficient of friction of the Roselle seed was determined with respect to each of the following three structural materials, namely, mild steel, plywood with grains parallel to the direction of motion and glass. A four sided plywood container with dimensions of 150×100×40 mm open at both the top and bottom was filled with the seeds and placed on an adjustable tilting surface. The structural surface with the box on its top was gradually raised by means of a screw device until the box just started to slide down. The angle of inclination was read from a graduated scale and the coefficient of friction was taken as the tangent of this angle (Olaoye, 2000; Adejumo, 2003). The same procedure was repeated for other materials.

$$\mu = \tan \beta \quad (6)$$

2.10 Determination of the Surface Area

The surface area was determined by first coating the surface of the seed with paint and coupled with printing on a light flexible paper. The surface edge was traced out with a very sharp thin pencil on a graph paper. The surface area was measured by counting the number of squares within the traced marks (Oje and Ugbor, 1991).

2.11 Determination of Terminal Velocity

The terminal velocity of the seed at different moisture content was determined using an air column. A few seeds were dropped from the top of a 60 mm diameter and 1 m long glass tube. The air flowed upwards in the tube from bottom to the top and the air velocity at which the seeds remain suspended was recorded by an anemometer having the sensitivity of 0.1 m/s and fixed near the location of the grain suspension.

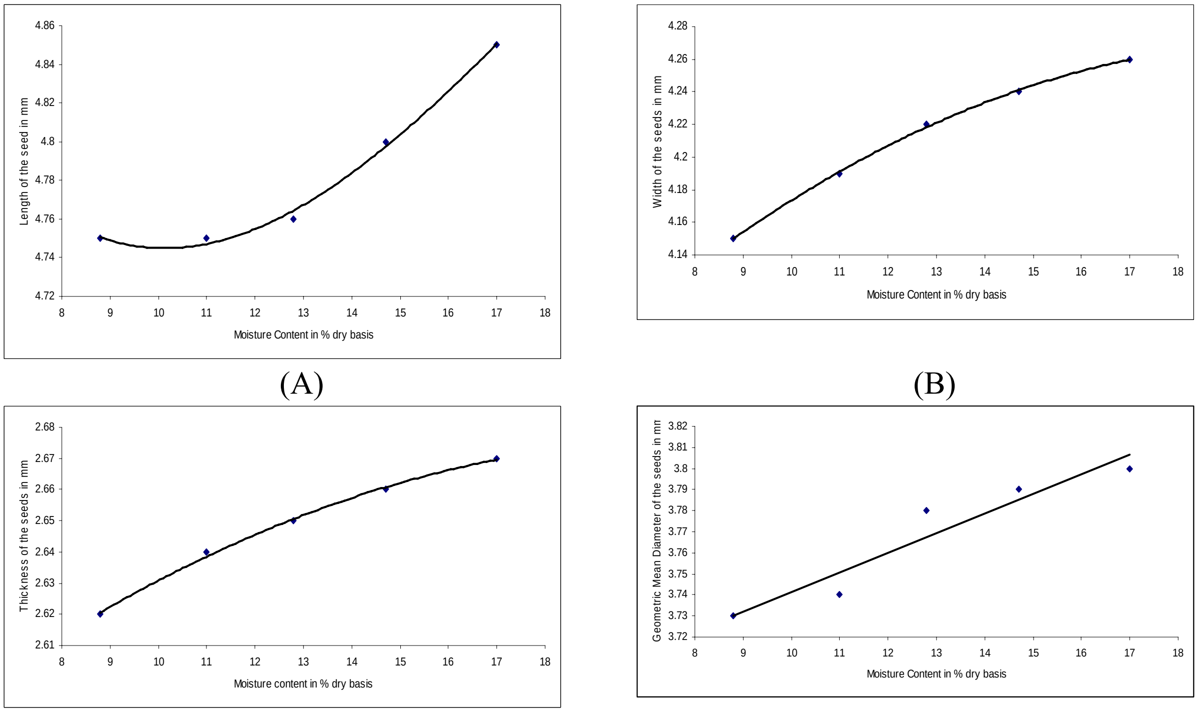
2.12 Determination of Specific Gravity

The specific gravity was determined as a function of moisture content by using a void meter manufactured by Jecons Scientific Limited, Bedfordshire, England. Roselle seed was placed in the sample jar and water was added to determine the percentage void content by reading value from the scale on the tube. After this, the material was weighed and the mass recorded. The percentage void content of the sample was computed on the basis of the mass of the sample in the sample jar which was subtracted from the mass of the sample in the jar. The value obtained was used to divide the weight of the sample to obtain the specific gravity.

All measurements and determinations were replicated five times at each moisture content of seeds considered in this study. The mean values of the measurements and determinations were reported and analyzed using regression analysis.

3. RESULTS AND DISCUSSIONS

The mean dimensions (L, W and T) of Roselle seeds at different moisture contents are presented in figure 1. An increase in the dimensions was observed as moisture content increases. The length showed an increase from 4.75 to 4.85 mm which is 2.1 % increase. The width was found to increase from 4.15 mm to 4.26 mm which gave a percentage increase of about 2.7 %, while the thickness varied between 2.62 to 2.67 mm. These values are lower than that of obtained by Omobuwajo et al. (2000) at 7.7 % moisture content. Similarly, the values were lower than the values obtained from cultivars from China and Sudan, but higher than the cultivar from Mexico, all at higher moisture content. This showed that the physical properties are not only affected by moisture content, but by the locality where it was planted. It was observed that the Roselle seed expands more in width than the other two principal dimensions. This may be attributed to the arrangements of the seed cells. The relationships between the dimensions and the moisture contents are shown in table 1. Dimensions were significantly correlated to moisture content of the seed.



(A) (B) (C) (D)

Figure 1. Effect of moisture content on the dimensions of Roselle seed (A – length, B – width, C – thickness, D – geometric mean diameter)

Table 1. Equations representing relationship between physical properties and moisture content (M_c) of Roselle seed.

M_c, % db	Equation	R^2
	$L = 5.9834 - 0.3242\ M_c + 0.0271\ M_c^2$	0.999
	$W = 3.8966 + 3.6900\ M_c - 9\times10^{-4} M_c^2$	0.999
	$T = 2.5139 + 0.0153\ M_c - 0.0004\ M_c^2$	0.998
	$D_g = 3.6477 + 0.0094\ M_c$	0.955
	$m = 4\times10^{-5} M_c^3 - 1.4\times10^{-3} M_c^2 + 1.89\times10^{-2}\ M_c - 0.046$	1.000
	$T_{SM} = 0.4159\ M_c + 26.453$	0.959
	$V_s = 1.2913\ M_c + 19.094$	0.974
8.8-19.0	$\rho_b = 678.82 - 3.4185\ M_c$	0.991
	$\rho_t = 1225.8 + 15.307\ M_c$	0.984
	$P_f = 0.6954\ M_c + 46.677$	0.994
	$V_t = 0.1551\ M_c + 4.6614$	0.921
	$\gamma = 1.1789 + 0.0271\ M_c - 0.0007\ M_c^2$	0.984
	$\mu_{pl} = 0.0075\ M_c + 0.32$	0.986
	$\mu_{st} = 0.01\ M_c + 0.126$	0.986
	$\mu_g = 0.0089\ M_c + 0.1472$	0.992

The geometric mean diameter, sphericity and surface area of Roselle seed varied from 3.73 – 3.80 mm, 0.78 – 0.82, and 17 – 18.5 mm^2 respectively as moisture content increased. The increase in the values might be attributed to its dependence on the three principal dimensions of the seed. The geometric mean diameter value was lower than 4.2 mm obtained by Omobuwajo et. al. (2000) for Roselle seeds at lower moisture content. This shows that locality of harvest is an important factor in the physical properties. It varied linearly with the moisture content of the seed and significantly correlated as seen in table 1.

The sphericity of 0.78 to 0.82 shows that seeds were spherical in shape and can slide on flat surfaces easily. This is within the range obtained by Sánchez-Medoza et al. (2008) for Roselle seeds from three different countries, but higher than the values obtained by Omobuwajo et al. (2000). This property should help in the design of hoppers and dehulling equipment for the seed.

The mass of the seeds increased from 0.0345 g to 0.0411 g with increase in moisture content. The increase in mass may be attributed to the weight increase on moisture absorption. This property was found to be smaller than those of pumpkin seed and Kano white variety of bambara groundnut (Adejumo et al., 2007). The best fit is represented by a polynomial function of the third degree with the moisture content (figure 2). The relationship between this property and moisture content was found to be linear as shown in table 1.

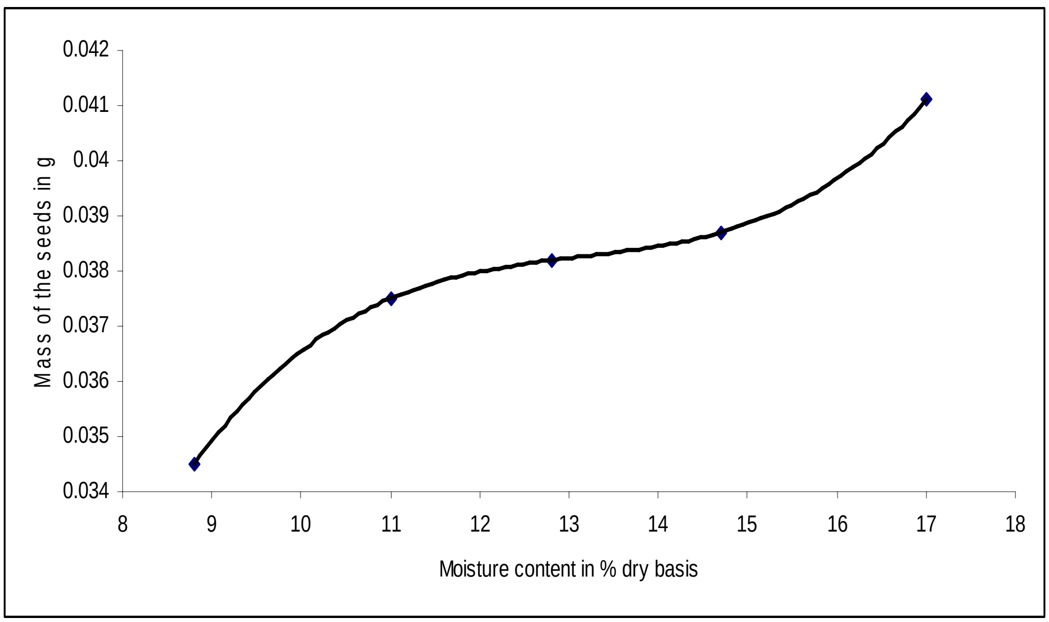


Figure 2. Effect of moisture content on the mass of the seed

Figure 3 shows the variation on the thousand seed mass with moisture content (the weight increased with increase in moisture content). It increased from 30.39 g to 33.69 g. These values are lower than what was obtained by Omobuwajo et al. (2000) and Sánchez-Medoza et al. (2008). The relationship with the moisture content is well correlated as shown in table 1.

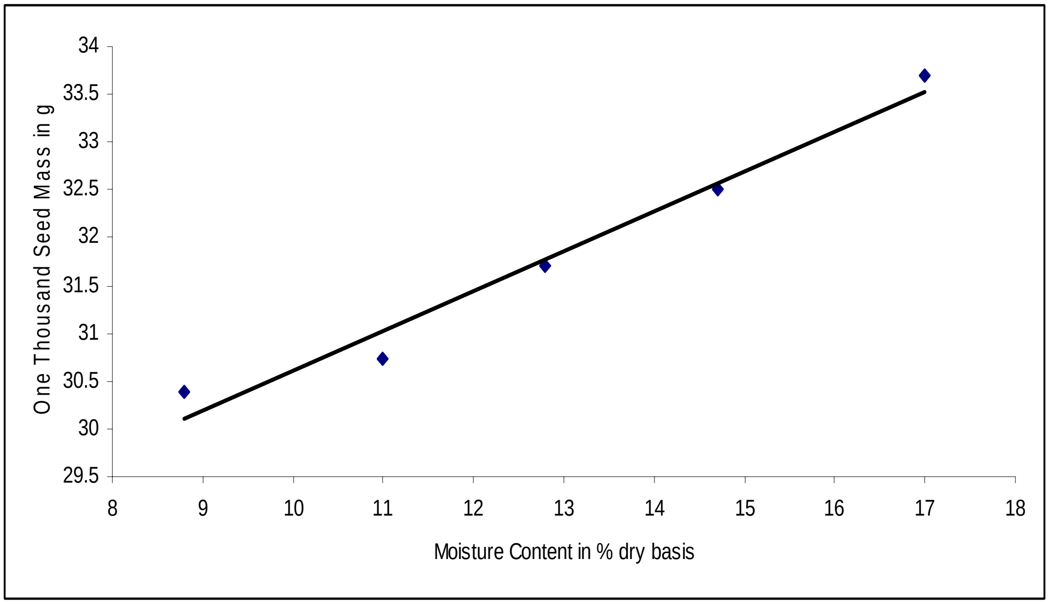


Figure 3. Effect of moisture content on thousand seed mass

The mean volume of the seeds ranged from 29.7×10^{-6} m^3 to 40×10^{-6} m^3 as the moisture content increased from 8.8 to 17 % dry basis. This volumetric expansion may be attributed to the expansion in the dimensions which contributed to weight increase of the seeds thereby resulting to the displacement of more liquid. A linear relationship was observed with moisture content as shown in figure 4. The variation of the volume with moisture content is similar to the trend shown in table 1.

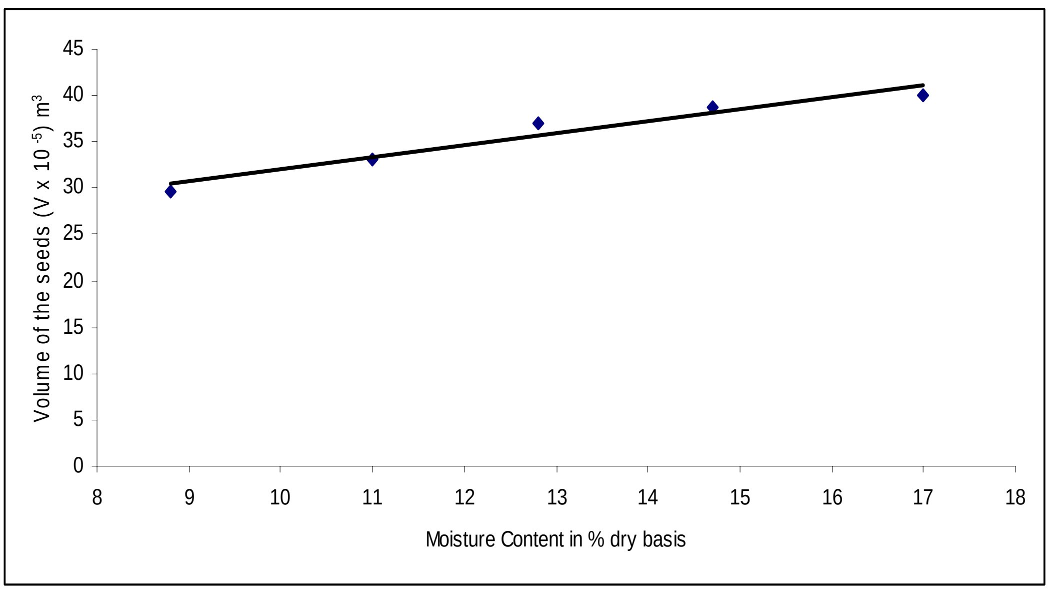
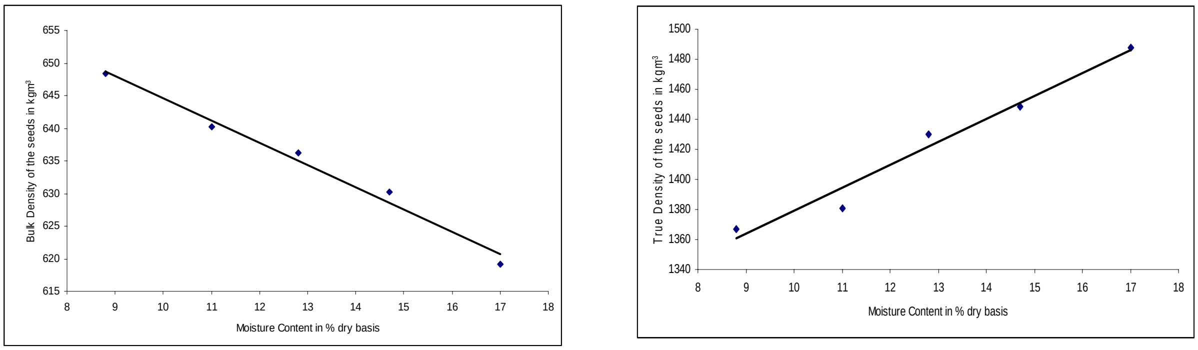


Figure 4. Effect of moisture content on the volume of Roselle seed

The bulk density of the Roselle seeds as shown in figure 5 varied between 648.31 to 619.14 kg/m^3. The values were observed to decrease with increase in moisture content. The decrease in value could be attributed to the volumetric expansion of the seed and pore spaces which became proportionally greater on moisture absorption, resulting to a decrease in bulk density. The same trend was observed in the bulk density of Roselle seeds from other countries (Sánchez-Mendoza et al., 2008). The values are close to the values from China and Mexico, and greater that the values obtained in Sudan. The values are lower than 0.627 to 0.651 g/cm^3 obtained at 7.65 % moisture content (Omobuwajo et al., 2000). This further buttresses the fact that bulk density decreases with an increase in moisture content. A linear relationship exists between the bulk density and moisture content as shown in table 1.



(A) (B)

Figure 5. Effect of moisture content on the bulk (A) and true density (B) of Roselle seeds

The true density of the Roselle seed was found to increase from 1367.0 to 1487.4 kg/m^3 as shown in figure 5. This increase in value may be attributed to the possible higher weight increase of the seed in comparison to its volumetric expansion on moisture gain. The values were within the range of values obtained by Omobuwajo et al. (2000) and Sánchez-Medoza, et al. (2008). A linear relationship exists between the true density and moisture content as shown in table 1. Moisture content had significant effect on both the bulk density and the true density as shown in the high values of the coefficient of determination.

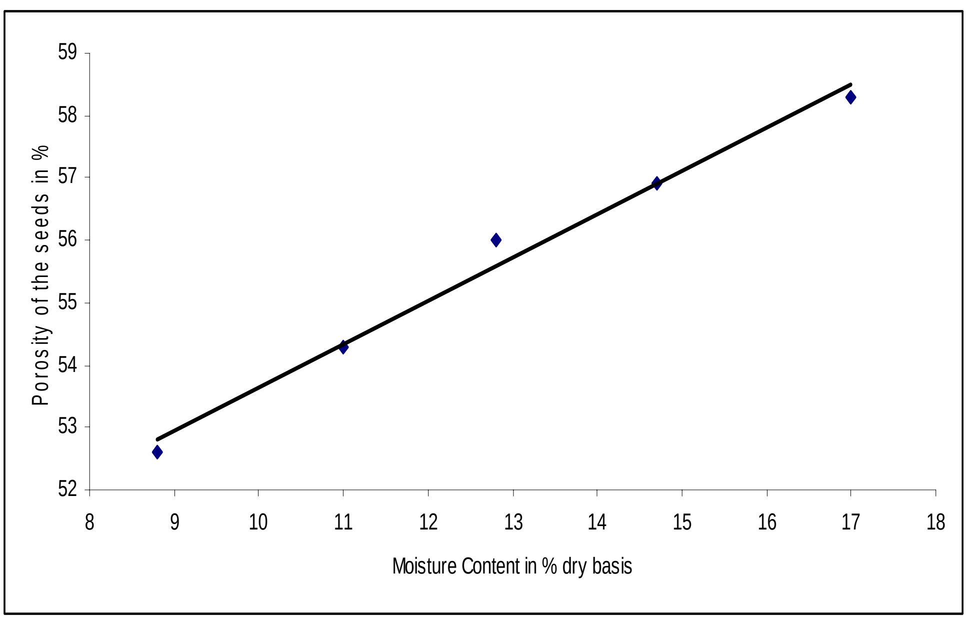


Figure 6. Effect of moisture content on the porosity of Roselle seeds

The Porosity of the seed varied linearly and increased with the moisture content from 52.6 to 58.3 % (fig. 6). This variation may be attributed to its dependence on the bulk and true densities of the seed. The mean values were higher than those of pigeon pea and gram while it was lower than those of cumin and pumpkin seeds. The values were within the range for Roselle seeds by Sánchez-Medoza et al. (2008). The change in porosity with moisture content indicated a linear relationship similar to the trend shown in table 1.

As shown in figure 7, the angle of repose of Roselle seeds increased with increase in moisture content from 20.13° to 24.85°. This property showed a linear increase with moisture content. The experimental values were seen to be higher than that of oilbean seed (Oje and Ugbor, 1991). The angle of repose of the seed correlated well with the moisture content as shown in table 1.

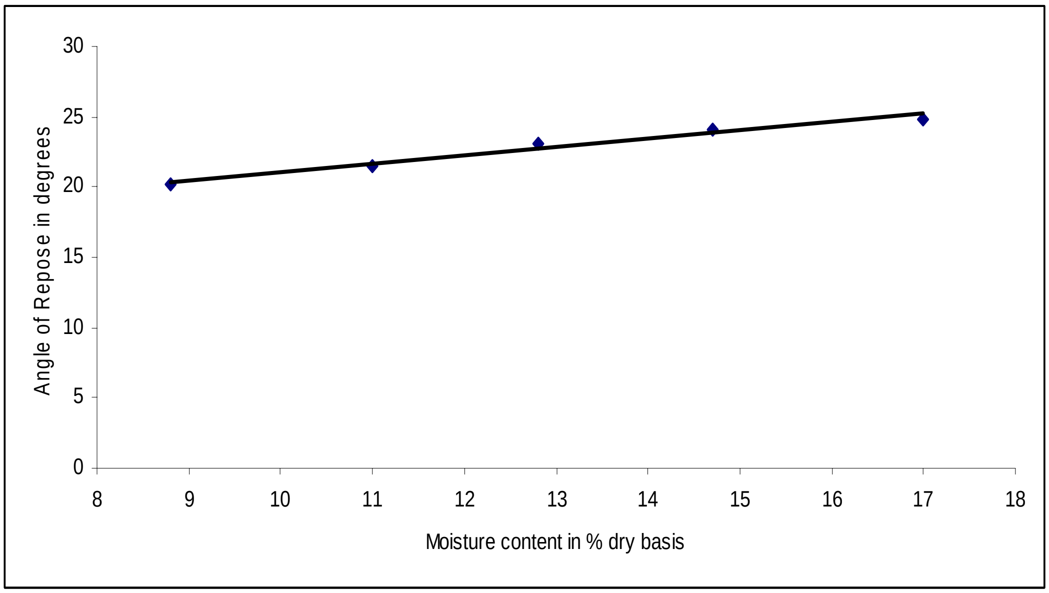


Figure 7. Effect of moisture content on the angle of repose of Roselle seeds

The value of specific gravity of Roselle seed was found to vary from 1.36 to 1.44 as shown in figure 8. The parameter increased with increase in moisture content which is a result of weight increase. The relationship between this parameter and the moisture content, which was found to follow a polynomial function (table 1), shows that moisture content correlated well with specific gravity.

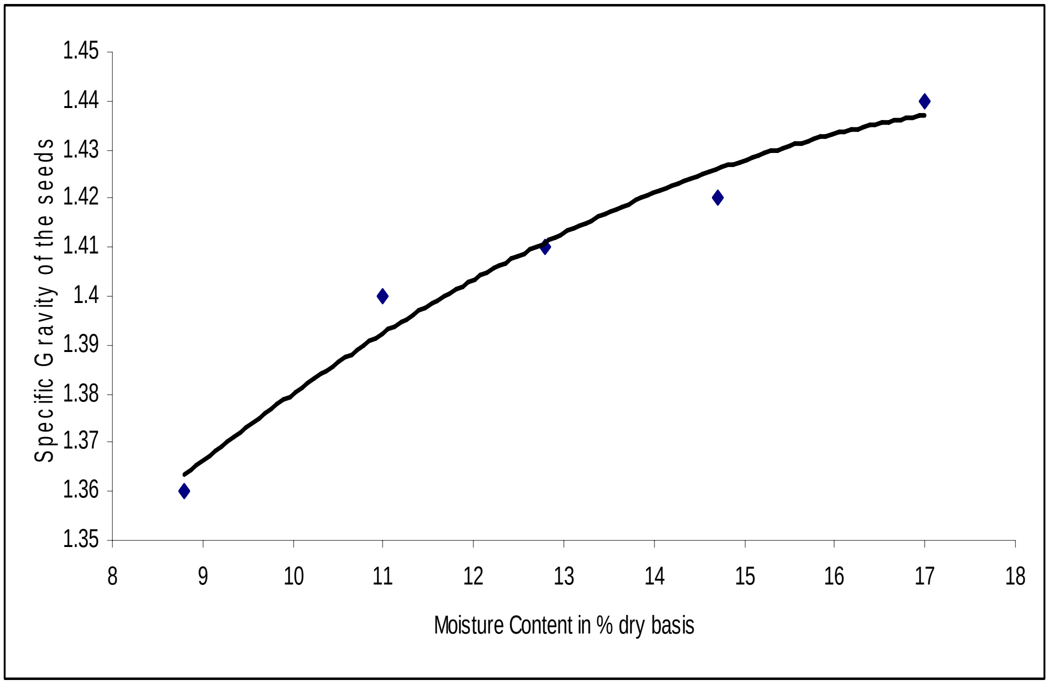


Figure 8. Effect of moisture content on the specific gravity of Roselle seeds

The variation of the terminal velocity with respect to moisture content is shown in figure 9. It was evident that as the moisture content increased from 8.8 to 17 % dry basis, the terminal velocity increased linearly from 5.77 m/s to 7.19 m/s. The values are lower than what was obtained by Omobuwajo et al. (2000) for Roselle seed at 7 % moisture content. This can be attributed to the increase in mass of individual seed per unit frontal area presented to the airflow and also to the friction of the edges of the seeds. The relationship between moisture content and terminal velocity can be represented by a linear equation as shown in table 1.

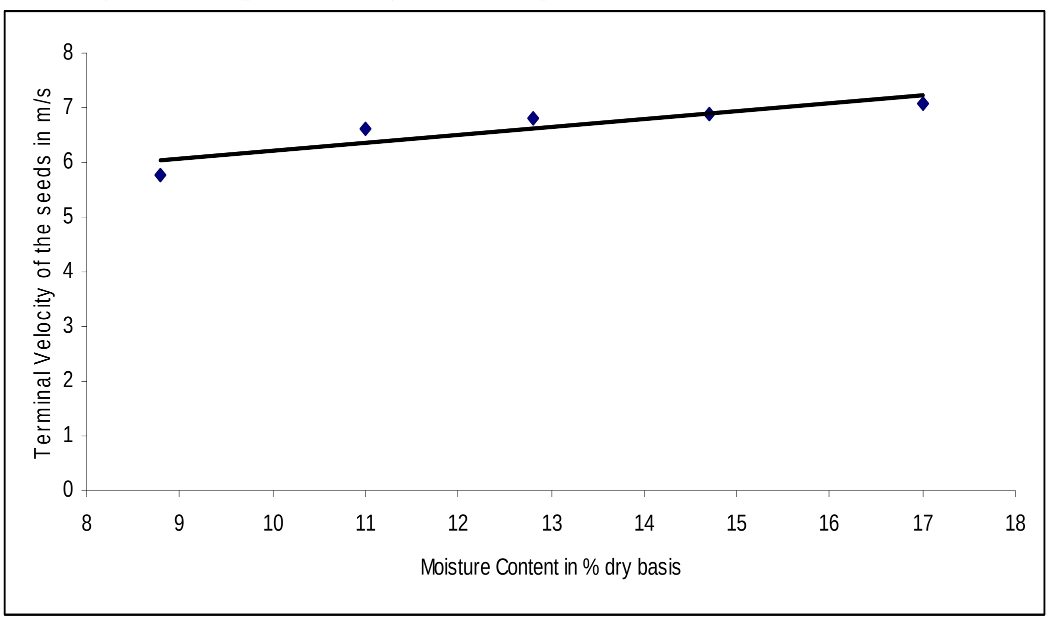


Figure 9. Effect of moisture content on the terminal velocity of Roselle seeds

The variation of coefficient of friction of Roselle seed on three surfaces (plywood, mild steel and glass) with moisture content are shown in figure 10. The coefficient of friction increases with moisture content as 0.23-0.32, 0.38-0.45, and 0.22-0.30 for mild steel, plywood and glass, respectively. At higher moisture contents it was observed that the seeds became a bit rough and sliding characteristics were diminished, this might be the reason of the increase in the coefficient of friction. When the values obtained on these materials for this seed were compared with those of other seeds using the same material, it was discovered that the values were lower than that of sainfoin seeds on both mild steel and plywood with grains parallel to the direction of motion, while it was higher than that of grasspea seed. On glass, the values were within the range obtained for Kano white variety of bambara groundnut while it was lower than that of locust bean seed (Adejumo et al., 2007). These low values for both glass and mild steel may occur as a result of the polished nature and smoothness of these structural surfaces as well as that of the seed. The coefficient of friction varies linearly with the moisture content for the three surfaces as shown in table 1.

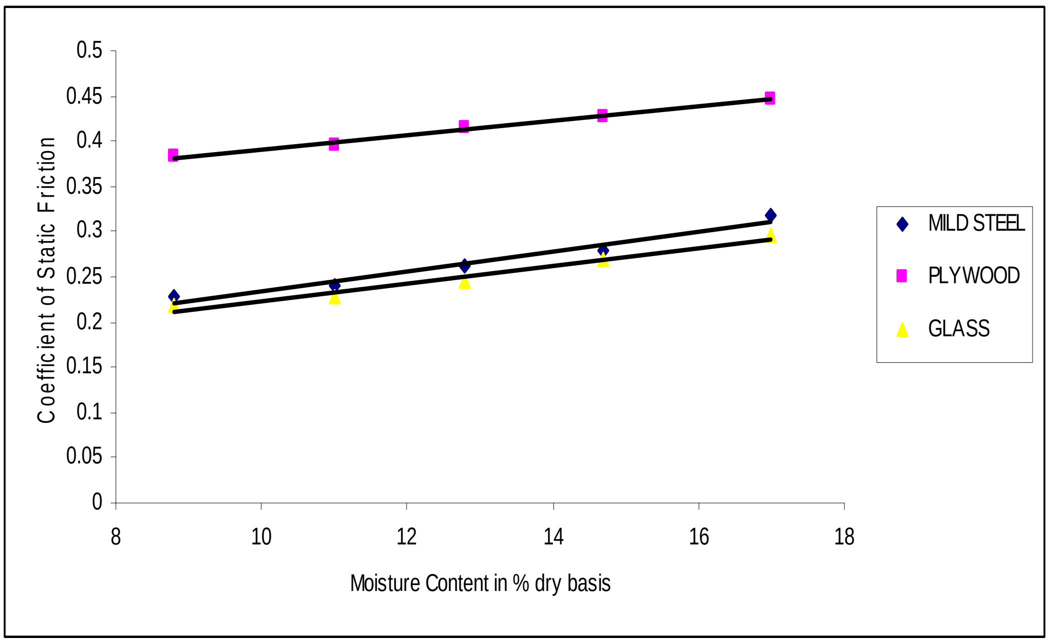


Figure 10. Effect of moisture content on the coefficient of friction on the structural surfaces

4. CONCLUSIONS

1. The physical properties of the seed determined as a function of moisture content varied significantly with increase in moisture content.
2. The sphericity, geometric mean diameter, thousand seed mass, angle of repose, surface area, true density, porosity, coefficient of static friction and terminal velocity showed an ascending linear relationship except the bulk density which has a descending linear relationship on moisture gain. These properties would provide important and essential data for efficient process and equipment design.
3. The observations that the level of true and kernel density were higher than that of water as well as the specific gravity was greater than unity make it possible to design a cleaning or a separation process for the seeds since the lighter fractions would float.

4. The high level of seed sphericity is an indication that the shape tends towards a sphere.

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