Effect of moisture content variation on some physical properties of Achi seeds

Oji Irouwa*, S.N. Asoegwuand C.D. Okereke

(Department of Agricultural and Bio-Resources Engineering, Federal University of Technology Owerri, Imo State, Nigeria)

Abstract: The physical properties of Achi seeds were determined as a function of moisture content in the range of 12.5% to 24% dry basis (average range of Achi seed between eating and harvesting) to provide information for the design of processing, handling, harvesting and storage equipment and facilities. The average equivalent diameter was found to increase from 12.31 mm at 12.5% d.b moisture content to 12.62 mm at 24% d.b moisture content; geometric mean diameter of 9.99 mm at 12.5% moisture content to 10.37 mm at 24% moisture content. At that range of moisture content investigated, the sphericity increased from 47.80% to 48.82%; the aspect ratio from 0.761 to 0.765; the volume from 977.4 mm^3 to 1053.89 mm^3; surface area from 313.6 mm^2 to 337.66 mm^2; square mean diameter from 12.15 mm2 to 12.46 mm2 while the bulk density decreased from 512.4 kg/m^3 to 474.4 kg/m^3. Results showed that there are effects of moisture variation on some physical properties of the Achi seeds.

Keywords: Achi, equivalent mean diameter, moisture content, sphericity, surface area, bulk density, volume, aspect ratio

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1 Introduction

Achi seed is classified as legume with its pod containing seeds, an economic tree crop that grows in the tropical rainforest of West Africa, and contains 56% carbohydrate, 15% crude fat, 9% protein, 4.5% ash and 2.9% crude fiber (Uhegbu et al., 2009).Processing of Achi to obtain the inner edible seeds (cotyledonous kernels) normally involves such operations as parboiling, soaking or roasting prior to dehulling. The finely ground seeds of Achi have been used in the treatment of sewage sludge and were found to improve sludge filterability and compare favourably with the traditional ferric chloride conditioner and the optimum value for Achi for this treatment is 21.5% (0.4 g/cm^3) and for ferric chloride is 25% (0.5 g/cm^3) (Eze, 2002). Also, Ikegwu et al., (2009) observed that the Achi seed flour contained 10.25% of moisture, 12.77% of crude protein, 10.52% of crude fat 1.48% of total ash, 2.2% of crude fibre and 58.77% of starch content. The Achi seed starch had low content of 0.61% protein, 0.25% fat, 0.69% crude fibre, 0.79% ash, 84.28% starch, respectively (Eze, 2002). The amylose content of Achi seed starch is20.88%.Uzomah and Ahiligwo (1999) recorded that the viscosity behaviour of Achi seed gum indicates that it may be a highly branched polysaccharide. They found that the overrun, viscosity, shape-factor and meltdown values of ice cream when Achi seed gum was added as stabilizer were 95%, 0.035 PaS (Pascal seconds), 72% and 32%, respectively. Generally, the tablets formulated from Achi seed mucilage were softer than those of gelatin, had good uniformity of weight and disintegrated within the official specified times for uncoated tablets (Ikegwu et al., 2009).

To fully appreciate the economic potentials of Achi seeds which depends on effective handling of seeds through processing operations, the effect of moisture content variations on some of its physical and frictional properties must be known, which led to this study.

2 Materials and methods

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***Corresponding author: Oji Irouwa,** Department of Agricultural and Bio-Resources Engineering, Federal University of Technology Owerri, Imo State, Nigeria. Email: iyroworld@yahoo.com

2.1 Seed test preparation

Fifty (50) kg of Achi seed was bought from ”Nkwo” market in Elu Ohafia in Abia state and were thoroughly cleaned of debris and hand sorted to eliminate dirt, stones, immature seeds and other foreign materials. The Achi seeds were thoroughly mixed and stored in a container at room temperature (25℃) to allow for a uniform distribution of moisture (Ndirika and Oyeleke, 2006; Asoegwu et al., 2010b) till when the seeds were to be conditioned for use. The size and principal axes (minor, intermediate and major) of 100 seeds from the seeds were determined using a micrometer screw gauge (Sheffied S 139 Br; up to 0.01 mm) and cross-checked with a vernier caliper. See Figure 1 please.

Figure1: Sample of Achi seeds

The weights of the seeds were also determined using a digital scale of maximum weight of 4100 g and approximate error of 0.01 g, (model scout Pro SPU 405, made in China). The moisture content was determined using a drying oven of model uniscope SM9023, made in Surgiftiend Medicals, England. The angle of repose was determined using a tread on each heap as explained below in section 2.1.1.The rest of the bulk seeds were divided into five lots, put in high density polyethylene bags, tied and stored in a refrigerator till in use.

2.2 Physical and frictional properties determination

2.2.1 Determination of angle of repose

The Achi seeds of each seed group were manually cleaned by winnowing, poured onto the center of the pan to form heaps which were not disturbed for a while till the movement of particles became stationary. The height and the perimeter of the base were noted with the help of thread which was the method described by Irtwange and Igbeka (2002). This was done for the Achi seeds at the five different moisture contents (as is shown in Figure 2 below)

Figure 2: Measurement of angle of repose. (Irtwange and Igbeka, 2002).

$\alpha = \tan^{-1}(h/r)$

where,

h = height of cone, mm

r = ½ base of cone, mm

α = angle of repose, degree.

2.2.2 Determination of moisture content variation

These were obtained by adding calculated quantity of distilled water followed by spreading out in thin layer to dry in natural air in the room for about eight hours. The amount of distilled water added was calculated using the Equation 1 given by Sacilik et al. (2003) quoted by Isik (2007):

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad (1)$$

Where Q is the amount of distilled water added, g; W_i = 5kg, is the initial mass of sample, g; M_i = 12.5%d.b.,is the initial moisture content of sample,% wb (average dehulling-point moisture content); and $M_f$is the final moisture content of sample, % w.b. (average harvest-point moisture content). The samples were sealed in separate polyethylene bags and kept in a Thermo cool (T200) refrigerator at 5°C until when needed to allow the moisture to equilibrate. See Table 1 please.

Table 1 Amount of distilled water added to Achi seeds

Moisture content, % d.b.	Added distilled water, kg
12.5	-
15.0	14.7
18.0	33.5
21.0	53.8
24.0	75.7

2.2.3 Bulk density determination

The Achi seeds were poured from a fixed height to completely occupy 100ml in a measuring cylinder. The amount collected was weighed. The amount of Achi seeds collected averaged (512 g) per unit volume occupied gives the bulk density of the material. The experiments were replicated three times and the average taken.

2.2.4 True density determination

The true or particle density of each of the 100 seeds randomly picked from each of the five different moisture content bags was obtained using the water displacement method in which the seeds were individually dropped or poured slowly into a graduated cylinder filled to a known level with some water. The volume of the displaced water is the value of the volume of the seeds. The experiments were replicated three times and the average taken.

2.2.5 Porosity

The porosity for the Achi seed group at any particular moisture content was determined using the Equation 2 below:

$$\varepsilon = \left\{\frac{p\mathrm{b} - pt}{pb}\right\} * 100\% \qquad (2)$$

where, ε = porosity, %

pb= bulk density of seed, kg/m^3

pt= true density of seed, kg/m^3

The average was calculated for each moisture content group.

2.2.6 Size determination

The size was determined by measuring the linear dimensions; length, width, and thickness of 100 randomly selected seeds from each Achi seed moisture content group using a vernier caliper. The geometric mean diameter (D_g), sphericity (Ø) and surface area (S) were determined from the following Equations 3 to 8:

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

$$Ø = \frac{(LWT)^{1/3}}{L} \qquad (4)$$

$$S = (\pi((LWT)^{1/3})^2 \qquad (5)$$

Equivalent diameter, $d_e = \frac{F1+F2+F3}{3}2.$ (6)

Where,

F_1 = Arithmetic mean diameter = $\frac{L1+L2+L3}{3}2.$ (7)

F_2 = Geometric mean diameter

F_3 = Square mean diameter = $\{(L_1\ L_2 + L_2\ L_3 + L_3\ L_1)/3\}^{1/2}$ (8)

L_1, L_2 and L_3 = the three orthogonal lengths of the seeds measured with vernier caliper with an accuracy of 0.01mm.Where L_1=L is the length; L_2=W is the width and L_3=T is the thickness. These relationships have been used by Moshenin (1986) and Asoegwu et al. (2010a).

2.2.7 One thousand seed mass

The thousand seed mass was determined using a digital electronic balance Tubol 005 model having an accuracy of 0.001 g. To evaluate the thousand seed mass, 1000 seeds were randomly selected from the bulk sample and weighed. The experiments were replicated three times and average taken.

2.2.8 Coefficient of static friction

The coefficient of static friction was obtained with respect to galvanized iron because it is a common material used for the construction of materials handling equipment for transportation, storage and handling operations of grains, pulses and seeds. It is also used for the construction of hoppers, storage and drying bins. A hollow metal cylinder 50 mm diameter and 50 mm high and open at both ends was filled with the seeds at the desired moisture content and placed on an adjustable tilting table that was made from wood. On the surface of the table was placed a galvanized iron sheet, cut to the size of the table. The hollow cylinder, containing the seeds, was pulled up slightly to avoid contact between it and the friction surface. The tilting surface was raised gradually by means of a screw device until the seeds in the cylinder just began to slide down. This was repeated three times for each seed bulk for the five moisture contents. This adjustable tilting table method has been used for other grains and seeds by previous researchers to obtain static coefficient of friction (Aviara et al., 2013; Sacilik, et al., 2003 and Isik, 2007). The coefficients of static friction are given as:

$$\mu_s = \tan\alpha \qquad (10)$$

where,

μ_s = coefficient of static friction;

α = angle of repose, degree.

2.2.9 Coefficient of mobility

The coefficient of mobility (α_m) which represents the "fluidity" or freedom of motion of the seeds was calculated using Stepanoff (1969)'s equation (Equation 11) as used by Isik (2007).

$$\alpha_m = 1 + 2\,\mu_s^2 - 2\,\mu_s(1 + \mu_s^2)^{1/2} \qquad (11)$$

where,

α_m= coefficient of mobility

μ_s = coefficient of internal friction = tan α

α = angle of repose, degree.

3 Results and discussion

3.1 Seed dimensions and equivalent diameter

The values of the measured and calculated physical and frictional parameters of Achi seeds at different moisture contents (12.5%-24.0% d.b.) are presented in Table 2.

Table 2 Physical parameters for Achi seeds

Moisture. Content	12.5	15	18	21	24
A(mm)	20.9	20.96	21.08	21.15	21.23
B(mm)	15.90	15.95	16.11	16.18	16.24
C(mm)	3.0	3.04	3.11	3.18	3.23
D_g(mm)	9.99	10.05	10.18	10.29	10.37
D_e(mm)	12.31	12.36	12.49	12.56	12.62
D_a (mm)	13.27	13.32	13.43	13.50	13.57
Sphericity (%)	47.8	47.97	48.31	48.63	48.82
Bulk density (kg/m^3)	512.4	505.2	490.3	481.2	474.4
Aspect ratio	0.761	0.761	0.764	0.7650	0.7650
Volume (mm^3)	977.5	989.8	1019.7	1038.1	1053.9
Surface area (mm^2)	313.6	318	325.9	332.5	337.7
Square mean diameter. (mm^2)	12.2	12.2	12.3	12.4	12.5

A = major diameter, length, mm;
B = intermediate diameter, width, mm;
C = minor diameter, thickness, mm;
D_g = Geometric mean diameter, mm;
D_e = Effective mean diameter, mm;
D_a = Arithmetic mean diameter, mm

3.2 Effect of moisture content on the physical and flow properties of Achi seeds

The physical properties of the Achi seeds increased with the increase in moisture content from 12.5% to 24.0% with the exception of bulk density which decreased with the increase in moisture content as can be seen from Table 2.

Many researchers have found linear relationships between orthogonal dimensions, arithmetic and geometric mean diameters, equivalent diameter, bulk and true densities, sphericity and porosity, angles of repose and internal friction, as well as coefficient of static friction of several seeds and moisture contentviz Ndukwu (2009)for *Brachystegia eurycoma* seeds; Asoegwu et al. (2010a) for African bread fruit.

3.2.1 Effect of moisture content on Achi triaxial dimensions (major, intermediate and minor diameters) See Figure 3 please.

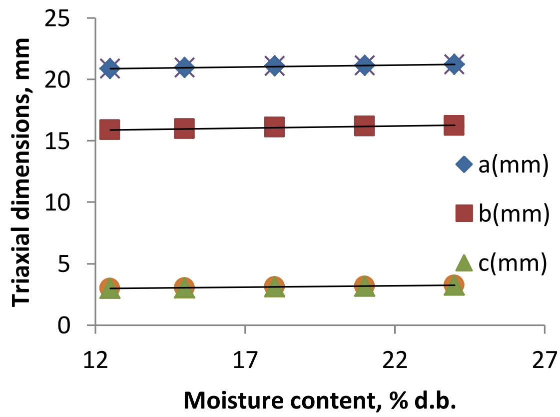

Figure 3: Moisture content against triaxial dimensions of Achi

The triaxial dimensions (major, intermediate and minor diameters) of Achi seed increased as the moisture content increased from 12.5% to 24% d.b. The major diameter increased from 20.9 mm to 21.23 mm; intermediate diameter increased from 15.9 to 16.2 mm and the minor diameter increased from 3.0 to 3.23 mm with an increase of moisture content in the range as stated above. These relationships can be represented by the linear equations: Equation 12, Equation 13 and Equation 14.

$$L_1 = 0.0293M + 20.533 \qquad R^2 = 0.992 \qquad (12)$$

$$L_2 = 0.0314M + 15.508 \qquad R^2 = 0.967 \qquad (13)$$

$$L_3 = 0.0207M + 2.7371 \qquad R^2 = 0.996 \qquad (14)$$

3.2.2 Effect of moisture content on Achi geometric properties (geometric mean diameter, arithmetic mean diameter, square mean diameter and effective mean diameter,) See Figure 4 please.

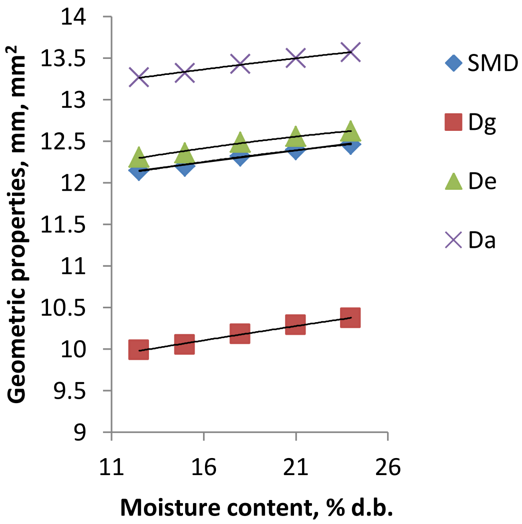

Figure 4: Moisture content against geometric properties of Achi

From Figure 4 above, the geometric properties increased as the moisture content increased (geometric mean diameter, 9.99 – 10.37 mm; arithmetic mean diameter, 13.27– 13 57 mm; effective mean diameter, 12.31 – 12.62 mm and square mean diameter, 12.20 – 12.46 mm) and their respective linear equations are shown from Equations 15 to 18 below:

$D_a = 0.0297M + 10.043$ $R^2 = 0.9965$ (15)

$smd = 0.0303M + 10.023$ $R^2 = 0.9969$ (16)

$D_e = 0.0303M + 10.013$ $R^2 = 0.9969$ (17)

$D_g = 0.0279M + 10\ 013$ $R^2 = 0.9965$ (18)

3.2.3 Effect of moisture content on Achi geometric properties (bulk density, volume, and surface area)

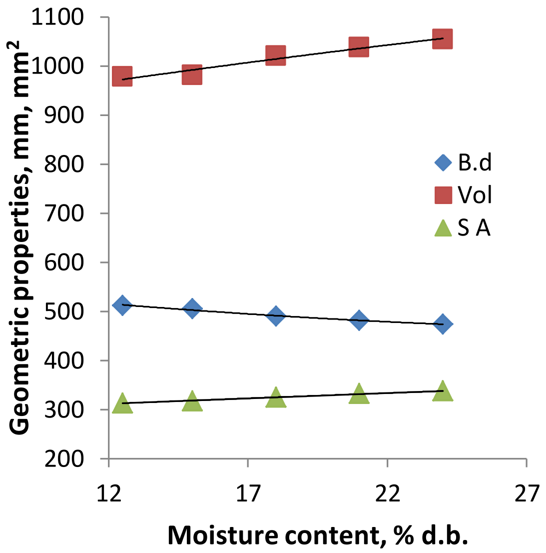

Figure 5: Moisture content against geometric properties of Achi

It can be seen from the graph above that the volume increased with an increase of the seed’s moisture content. This relationship is represented with the linear Equation 19 below;

$Vol = 12.9M + 822.3$ $(R^2 = 0.944)$ (19)

It was observed that the increase in mass due to moisture gain is lower than the accompanying volumetric expansion of the bulk samples of Achi and this has been observed for flax-seed (Wang *et al.*, 2007).

It can be seen from the graph that the surface area increases with an increase in moisture content. This relationship can be represented with the linear Equation 20:

$Sa = 2.1725M + 286.07$ $(R^2 = 0.9946)$ (20).

The surface area of Achi increased from 313.6 to 337.7 mm^2 as the moisture content increased from 12.5% to 24% d.b.

Similar trends have been reported by Asoegwu et al. (2006) for African oil bean.

3.2.4 Effect of moisture content on Achi sphericity and angle of repose

The values of sphericity were calculated individually with Equation 4 by using the data on geometric mean diameter and the major axis of the seeds and the results obtained are presented in Table 2. The sphericity of the "Achi" seed increased from 0.478 to 0.488 as the moisture content increased from 12.5% to 24% d.b. The relationship between sphericity and moisture content appears linear. This can be graphically represented in Figure 6 below.

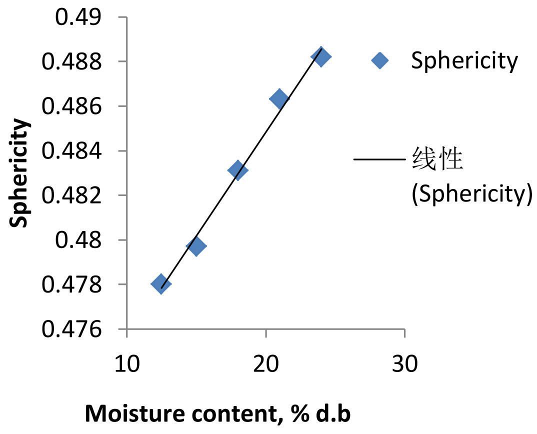

Figure 6: Moisture content against sphericity of Achi

The linear Equation 21 of the graph is:

$$\Psi=0.0009M + 0.4662 \quad (R^2=0.9908) \qquad (21)$$

The geometric dimensions (D_g) and other orthogonal dimensions increased linearly ($p < 0.05$; $R^2 = 0.983 – 0.9969$) as their moisture contents increased. These follow from the indication that each principal dimension appeared to increase with the increase in moisture content except for bulk density. Very high correlation between the D_g and moisture content indicates that upon moisture absorption, the Achi seeds expand in major (L_1), intermediate (L_2) and minor (L_3) diameters within the moisture range of 12.5% to 24.0% (d.b.). The L_1, $L_2$and $L_3$of the seeds increased from 20.9 to 21.23 mm, 15.9 to 16.24 mm and 3.0 to 3.23 mm, at the above stated moisture contents. These results showed that there is an important and positive relationship between moisture content and axial dimensions of grains and seeds. Such dimensional increase with moisture content is important in determining orifice (aperture) size in the design of grain handling and processing machinery.

For fibered flaxseed, Wang et al., (2007) found the thickness of the seed to be polynomially related to moisture content, while Isik (2007) found an exponential relationship between the projected area of round red lentil grains and moisture content. Ndukwu (2009) determined some physical properties of *Brachystegia eurycoma* seed at the moisture content of 12.9% (d.b.) but did not address the variation of the properties with moisture content and processing methods. The moisture-dependent characteristics of physical properties of agricultural products have been noted to have effects on the adjustment, performance efficiency and energy consumption of processing machines (Aviara et al., 1999).

Several researchers (Aydin, 2003; Aviara et al., 1999; Wang et al., 2007) investigated the moisture dependence of physical properties of oil seeds and nuts (almond nut, high oleic sunflower seed and fibered flax seed) and reported increase of these properties with moisture content with the exception of bulk density that decreased with the increase in moisture content.

Therefore, the effect of moisture content on physical properties of Achi seed is an important consideration in the design of the handling.

4 Conclusion

Increase in moisture content caused a little variation in Achi sizes. The geometric mean diameter, surface area, sphericity, volume and angle of repose increased with the increase in the seeds' moisture content. The true density varied non-linearly in the considered range of moisture content. At the same time, an increase in moisture content yields a decrease in bulk density.

The findings from the research shows good agreement with some of the general trend and ranges obtained for other similar crops. It is of opinion that data from this test will be useful in the design and development of the appropriate machines for handling and processing of the seed.

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