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PHYSICAL PROPERTIES OF TWO ACHA VARIETIES AS A FUNCTION OF MOISTURE CONTENT

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Abstract
"Acha" is a cereal crop of West African origin belonging to the family *graminaea*. There are many varieties of Acha, but the most prominent two are the white Acha *(Digitaria exillis)* and brown Acha *(Digitaria iburua).* Acha is used in the production of food and beverages, and manufacture of medicines. The grain therefore, has immense economic values. However, the mechanization of Acha processing has been limited by shortage of data on its physical properties that would aid the design of equipment for its post-harvest operations. Therefore, this study was undertaken to determine the variation of bulk density, particle size distribution, porosity, solid density, angle of repose and one thousand grain mass of the two varieties of the crop with moisture content. The moisture content range within which the study was conducted was 5 - 30% (d.b) for both white and brown variety. Results showed that as the moisture content of the two varieties of Acha increased, there was decrease in bulk density, porosity and solid density. However, increase in moisture content increased the 1000-grain mass and angle of repose of both varieties, with the values for white Acha being higher than those of brown Acha. The operation and adjustment of any Acha processing and storage equipment would therefore require a consideration of the variety and moisture content to obtain good performance.

Keywords: Acha, physical properties, moisture content, grain variety

1. Introduction

Acha is a cereal crop of West African origin belonging to the family *graminaea* (Gibon and Pain, 1985). The plant is an important crop in Southern Mali, western Burkina Faso, Eastern Senegal, Northern Guinea, North-Eastern Nigeria, and Southern Niger (Harlan, 1993; Jideani, 1999; Chukwu and Abdul-Kadir, 2008). There are many varieties of Acha, but the most prominent two are the white Acha *(Digitaria exillis)* and brown Acha (*Digitaria Iburua*) as shown in Figures 1 and 2 respectively.

Figure 2: Brown Acha grains (*Digitaria Iburua)*

Acha contains up to 85% dry matter, of which about 10% is starch (Morale-Payan *et al.*, 2002), 5% is mineral and 7% is crude protein (Temple and Bassa, 1991). The protein of Acha is of higher values compared to that of cowpea (Chukwu and Abdul-Kadir, 2008), and is reputed to contain almost twice as much methionine as egg protein does (Temple and Bassa, 1991). In gross nutritional composition, Acha differs little from wheat. The dehusked white Acha (*D. exillis*) grain contains 8% protein and

1% fat while the brown variety (*D. Iburua*), had a protein content of 11.8% recorded. The amino acid profile of Acha compared to that of whole-egg protein showed that except for the low score of 46% lysine, the other scores were high. Thus, Acha has important potential not only as survival food but as a complement for standard diets.

Acha is also known as one of the best diets for diabetic patients. The uses of Acha range from food, drinks to pharmaceuticals. However, in spite of its nutritional and economic importance, not much scientific data are available on the physical properties of Acha needed in the design of equipment for its handling and processing operations such as harvesting, threshing, cleaning, dehulling, milling, packaging, handling, storage, and aeration. The properties of biological materials are usually influenced by moisture content. Due to the lack of knowledge of the interplay between its properties and moisture content, the design and fabrication of processing machines for Acha have been fortuitous. A design that may be used to handle a given variety, may not suit all varieties, therefore, this study was conceived to investigate the effects of moisture content and grain variety on the physical properties of Acha. The properties investigated include: bulk density, porosity, particle size distribution, one thousand grain mass, solid density and angle of repose. The relation existing between the properties and the moisture content of the two varieties of Acha would be established.

2. Materials and Methods

2.1 Sample Procurement and Preparation

The Acha grains used for this study were undehulled white (*Digitaria exillis*) and brown (*Digitaria iburua*) Acha varieties, respectively. The bulk quantities of milk-white and dark-brown coloured Acha grains were obtained from the Wadata market, Makurdi, Benue State, Nigeria. The initial moisture content of the Acha grains was determined using the oven drying method (AOAC, 1984). The bulk of the grain mass of each variety was divided into four lots. The first lot was kept at the market storage moisture content, while the remaining lots were conditioned to the required moisture levels for the investigation. The samples were conditioned to desired moisture levels by adding water as calculated from Equation 1 according to Solomon and Zewdu (2009).

$$Q = \frac{W_s(M_f - M_i)}{100 - M_f} \tag{1}$$

where: Q = Quantity of water to be added, g, M_i = initial moisture content, %, M_f = required moisture content, %, W_s = weight of samples, g.

All the physical properties of Acha grains were measured at moisture levels of 5.00, 11.00, 23.00 and 28.00% (d.b) for white variety and 5.00, 9.00, 21.00 and 30.00% (d.b) for brown variety, with three replications at each level for each of the varieties.

2.2 Moisture Content Determination

Moisture content was calculated from the relation used by Aviara *et al.* (2005).

$$M_{wb} = \left(\frac{W_i - W_f}{W_i}\right) \times 100 \tag{2}$$

where: M_{wb}= Wet basis moisture content (%), W_i= Initial weight (g), W_f= Final weight (g).

It was converted to dry basis moisture content by using the relation

$$M_{db} = \left(\frac{M_{wb}}{1 - M_{wb}}\right) \times 100 \tag{3}$$

where: M_{db}= Dry basis moisture content (%)

2.3 Particle Size Distribution

Sieve analysis method was used to determine the particle size distribution of Acha. Ukpabi and Ndimele (1990) used similar procedure to determine the particle size distribution of grain. About 143.6g of Acha at the first and second moisture content levels and 78.6g and 84g for the third and fourth moisture content levels were used in the sieve analysis, sieving one lot at a time. A sieving duration of 15min was used, and the weights retained at each sieve were recorded as percentages of the initial quantities poured into the sieve stack (0.425mm – 0.6mm).

2.4 One Thousand Grain Mass

The one thousand grain mass was determined by randomly counting and weighing 1000 grains of each sample of the white and brown varieties of Acha using an electronic weighing balance of about 0.001g accuracy.

2.5 Bulk Density

Bulk density was determined by weighing the grains packed in a container of known volume. The equation below as given by Waziri and Mittal (1983) was used to determine the bulk density of the two varieties of Acha.

$$\rho_b = \frac{M_s}{V_s} \tag{4}$$

where: ρ_b= Bulk density of Acha (kg/m^3), M_s = Mass of packed Acha (kg), V_s= Volume of container (m^3).

2.6 Solid Density

The Solid density was determined by using equations below as given by Okeke and Anyakoha (1987), by first determining the specific gravity of the seeds.

$$G_{sp} = \frac{m_4 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \tag{5}$$

where: G_{sp}= Specific gravity of the Acha, M_1= Mass of empty density bottle (g), M_2 = Mass of empty density bottle about one third full of Acha grains (g), M_3 = Mass of density bottle filled with grains and water (g), M_4 = Mass of density bottle filled with water only (g).
The specific gravity of the grains was then used to calculate the solid density of the grains.

$$P_s = P_w \times G_{sp} \tag{6}$$

where: P_s= Solid density (kg/m^3), P_w= Density of water (kg/m^3).

2.7 Porosity

The porosity of Acha grains was calculated using the Equation 7 as utilized by Tunde – Akintunde and Akintunde (2007).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_s} \times 100\right) \tag{7}$$

where: ε = Porosity (%), ρ_b= Bulk density (kg/m^3), ρ_s = Solid density (kg/m^3).

2.8 Angle of Repose

The angle of repose was evaluated using the cylindrical pipe method. A topless and bottomless cylinder was filled with grains and slowly raised on a surface until it leaves the seeds forming a cone, and the radius of the base and height of the cone that was formed by the grains were used to calculate the angle of repose. The formula due to Zewdu and Solomon (2007) was applied to determine the angle of repose.

$$\theta = \tan^{-1}(h/r) \quad (8)$$

where: θ = Angle of repose (^{o}), h = height of piled seed, (mm), r = Radius of base of cone formed by grains (mm).

Each experiment was replicated three times and the mean values of the properties obtained at each moisture level were regressed against moisture content.

3. Results and Discussions

The initial moisture contents of the white and brown Acha (*Digitaria exillis* and *Digitaria iburua*) grains were found to be 5% and 5% (d.b) respectively. The three other moisture levels obtained after conditioning the grains were 11, 23 and 28% for the white variety, and 9, 21 and 30% for the brown variety.

The variations of the particle size distribution of the two varieties of Acha grains with moisture contents are presented in the Figures 1a and 1b.

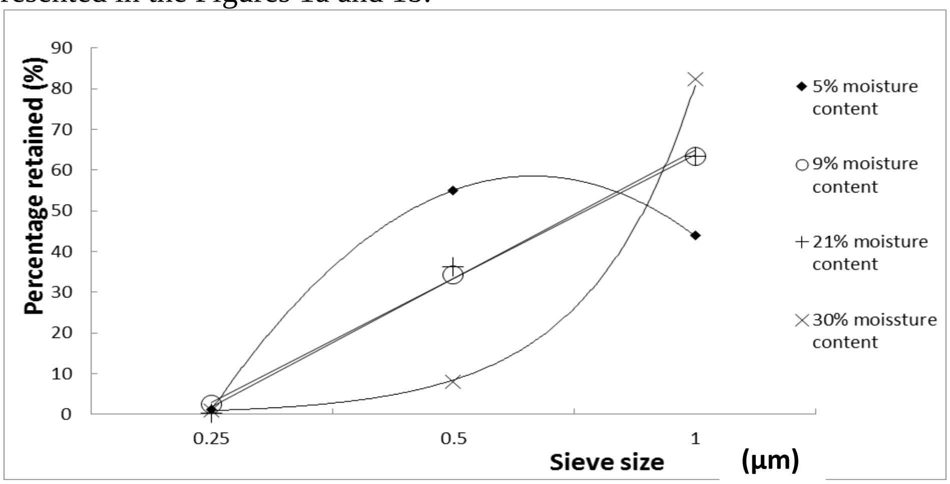

Figure 1a: Effect of moisture content on the particle size distribution of *Digitaria Iburua*

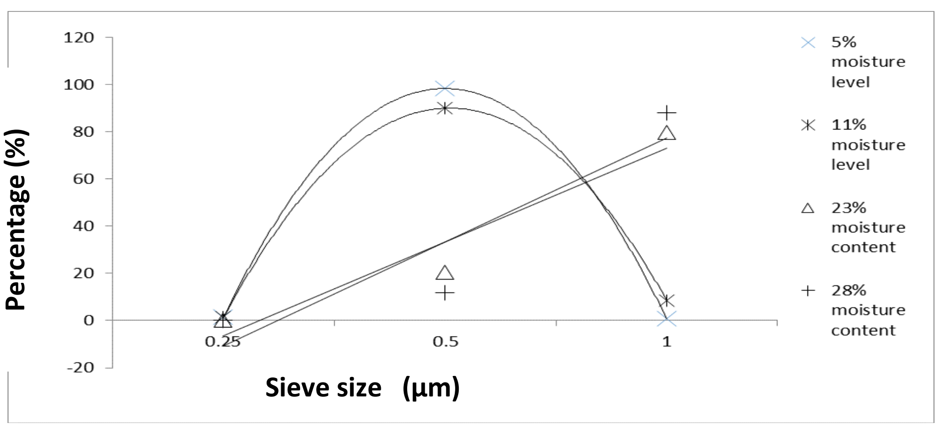

Figure 1b: Effect of moisture content on the particle size distribution of *Digitaria Exillis*

The results of the particle size distribution as affected by change in moisture content reveals that only a little fraction (less than 1.5%) of the grains passed through the 0.425mm sieve for both varieties considered in the study. The 600µm sieve and sieves with larger openings retained most of the grains (more than 98%). This clearly shows that the diameter of Acha grain for both varieties is more than 600µm and that Acha grains increasingly swell as its moisture content increases. This also implies that drying of Acha is expected to be accompanied with particulate shrinkage.
The variations in the one thousand grain mass with moisture content for white and brown Acha varieties are presented in Figures 2a and 2b respectively.

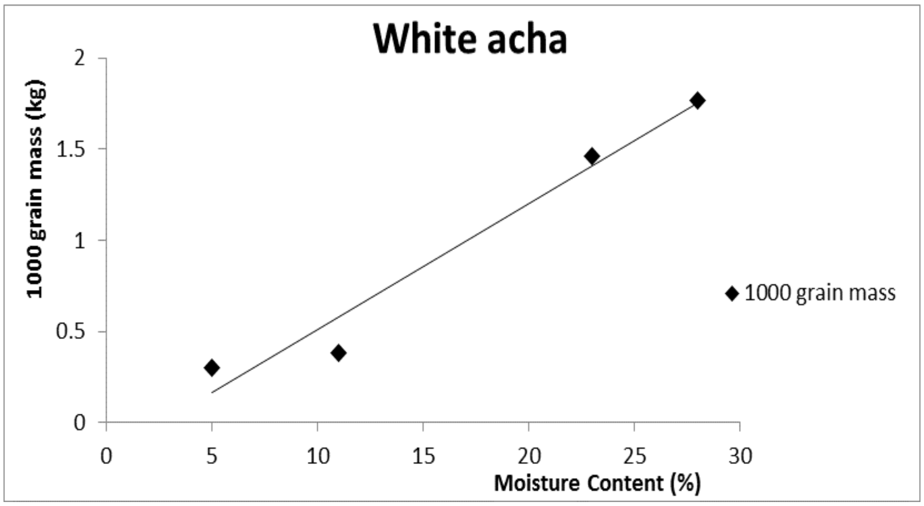

Figure 2a: The effect of moisture content on 1000 - grain mass of white Acha variety

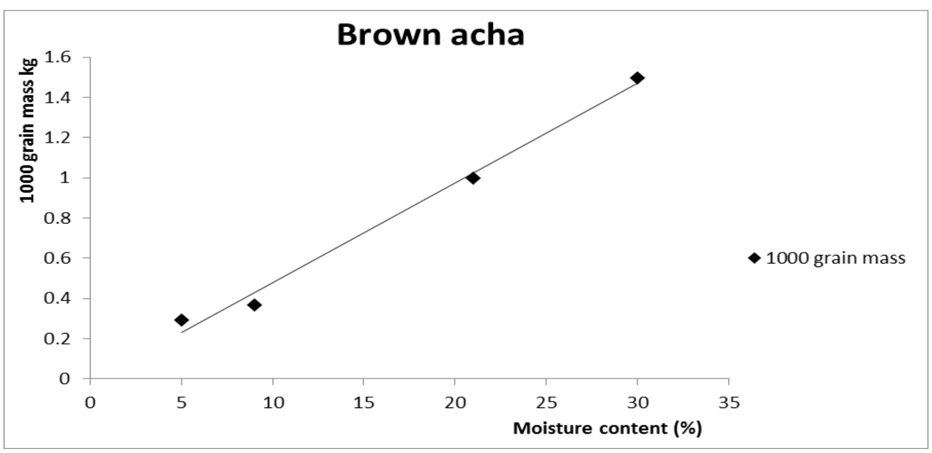

Figure 2b: The effect of moisture content on 1000 - grain mass of brown Acha variety

The results showed that the one thousand grain mass increased from 0.297 to 1.765kg in the moisture range of 5 – 28% (db) for the white variety and increased from 0.294 – 1.499kg in the moisture range of 5 – 30% (db) for the brown variety. This positive trend of one thousand grain mass with moisture content was due to increase in weight gained by the grains after absorbing moisture at high capacity which shows that after moisture absorption, extra weight was gained resulting in increased axial dimensions and surface area thereby producing a heavier grain. The relationship between moisture content and mass of one thousand Acha grains was found to be linear as in equations 9 and 10:

$$W_{1000\,(W)} = 0.0692M - 0.1819 \quad (9)$$

$$W_{1000\,(b)} = 0.0496M - 0.0166 \qquad (10)$$

The coefficients of determination (R^2) were found to be 0.9648 and 0.9904 for white and brown varieties respectively.

Similar trend was reported by Theertha *et al.* (2014) on black gram, Kaleemullah and Gunasekar (2002) for arecanut, Aviara *et al.* (2005) for sheanut, Isik (2007) for round red lentil grain and Simoyan *et al.* (2007) for Samaru sorghum. This result on seed mass can be applied practically in the design of equipment for cleaning, separation, conveying and elevating unit operations. It can also be used to estimate the overall bulk mass of Acha during bulk handling.

The effect of moisture content on the solid densities of Acha grains are presented in Figures 3a and 3b.

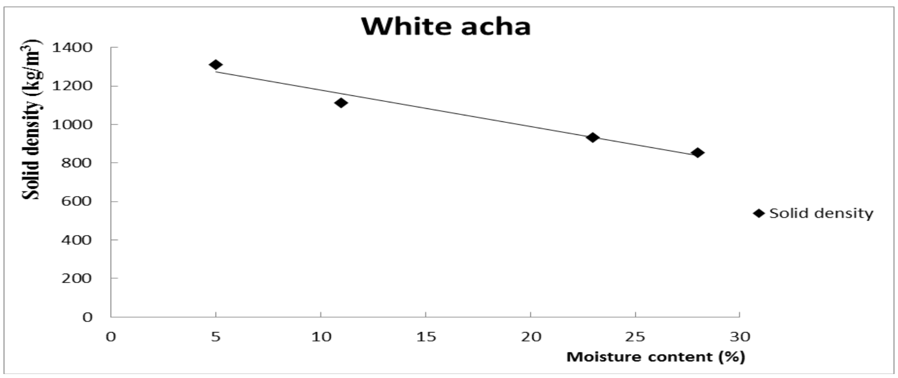

Figure 3a: The effect of moisture content on the solid density of white Acha grains

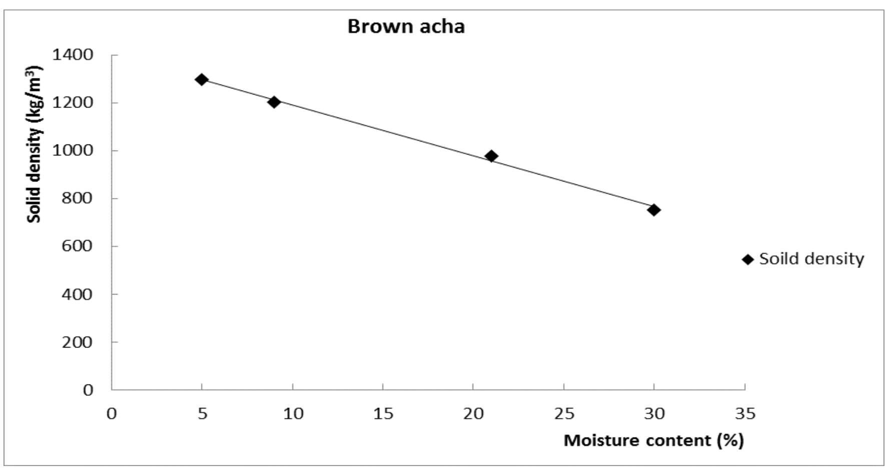

Figure 3b: The effect of moisture content on the solid density of brown Acha grains

This shows that solid density decreased from 1.31 – 0.85kgm^{-3} in the moisture range of 5 - 28% (d.b) for the white variety and decreased from 1.30-0.75kgm^{-3} in the moisture range of 5 - 30% (d.b) for the brown variety. The decrease in solid densities of Acha was mainly due to the rate of increase in moisture content which directly increased the volume of the grains than its mass. The relationship existing between solid density and moisture content was found to be linear and is given as:

$$\rho_{sw} = -18.922M + 1369.4 \qquad (11)$$
$$\rho_{sb} = -21.317M + 1404.5 \qquad (12)$$

where: ρ_{sw} = Particle density for white Acha (kg/m^3), ρ_{sb} = Particle density for brown Acha (kg/m^3), M = Moisture content (%). The correlation coefficients (R^2) of the equations for the white and brown varieties were found to be 0.9680 and 0.9962 respectively.

Abalone *et al.* (2004) recorded same decrease for Amaranth seeds. Same was also reported by Baumler *et al.*(2006), and Coskuner and Karababa (2007) reported a polynomial relationship between particle density and moisture content for safflower and coriander seeds respectively. Aviara *et al.* (2005) and Isik (2007) reported same relation for sheanut and round red lentil grains respectively. The particle density of agricultural products have been reported to play significant importance in the design of silos and storage bins, maturity and quality evaluation of products which are essential to grain marketing. It could also prove useful in the separation and transport of the seeds by hydrodynamic means (Omobuwajo *et al.*, 2000).
The effect of moisture content on the bulk density of two varieties of Acha grains are shown in Figures 4a and 4b.

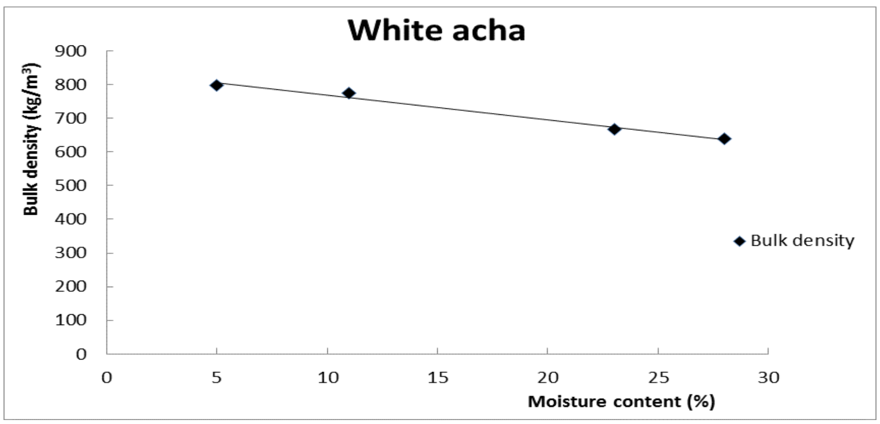

Figure 4a: The effect of moisture content on the bulk density of white Acha grains

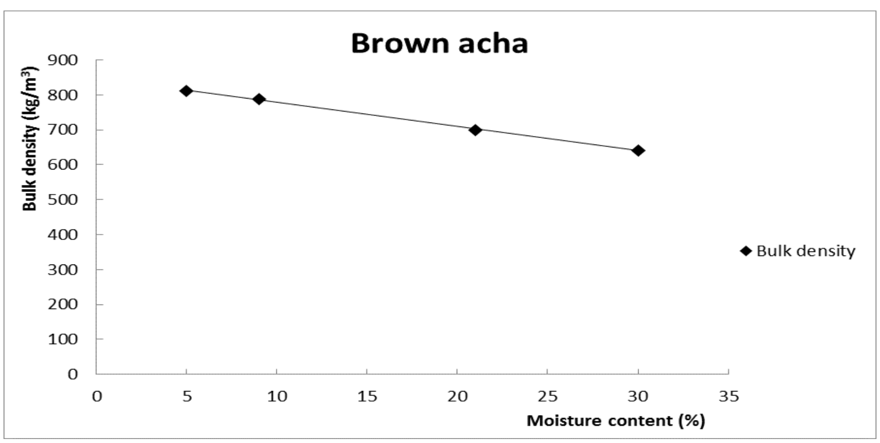

Figure 4b: The effect of moisture content on the bulk density of brown Acha grains

The bulk density was found to decrease from 0.798 – 0.639kg/m^3 with increase in moisture content from 5 – 28% (d.b) for the white variety. It was also found to have decreased from 0.811 – 0.641kg/m^3 with increase in moisture content from 5 – 30% (d.b) for the brown variety. This showed that, as the moisture content increased, the size of the seeds increased resulting in less mass and amount of seeds occupying equal bulk volume. Therefore, the decrease in bulk density of the seeds resulted from increase in size with moisture content which gave rise to decrease in quantity of the seeds occupying the same bulk volume. In addition, the resistance of the seeds to consolidation may have increased with moisture content as a result of increase in internal pressure. The relationship existing between moisture content and bulk density was observed to be a linear relationship for both cases and is represented by the equations:

$$\rho_{bw} = -7.3504M + 842.89 \quad (13)$$

$$\rho_{bb} = -6.9047M + 847.2 \quad (14)$$

where: ρ_{bw}= Bulk density of white Acha grains (kg/m^3), ρ_{bb} = Bulk density of brown Acha grains (kg/m^3), M = Moisture content (%). The coefficients of determination (R^2) were 0.9846 and 0.9991 for the white and brown varieties respectively.

Carman (1996), Gupta and Das (1997), and Visvanathan *et al.*, (1996) found the bulk density of lentil seeds, sunflower seeds and neem nuts respectively to have decrease as the seed moisture content increases. Bulk density is applied practically in the calculation of thermal properties in heat transfer problems, in determining Reynold's number of materials and in predicting physical structure and chemical composition.
The effects of moisture content on the porosities white and brown varieties of Acha are presented in Figures 5a and 5b.

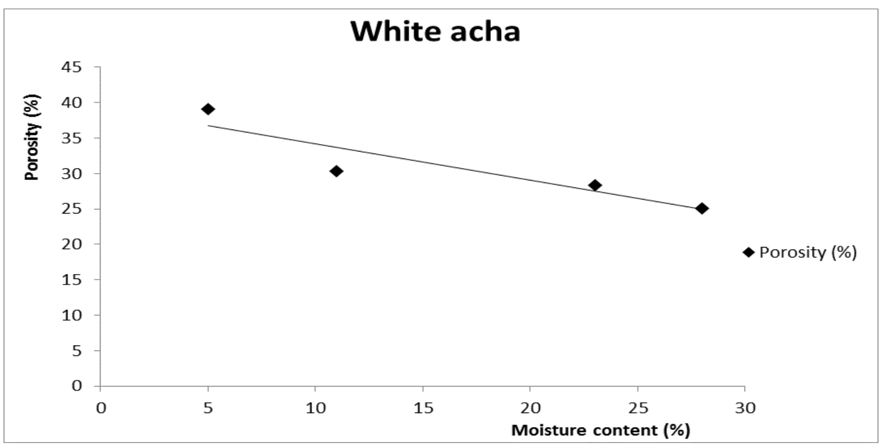

Figure 5a: The effect of moisture content on the porosity of white Acha grains

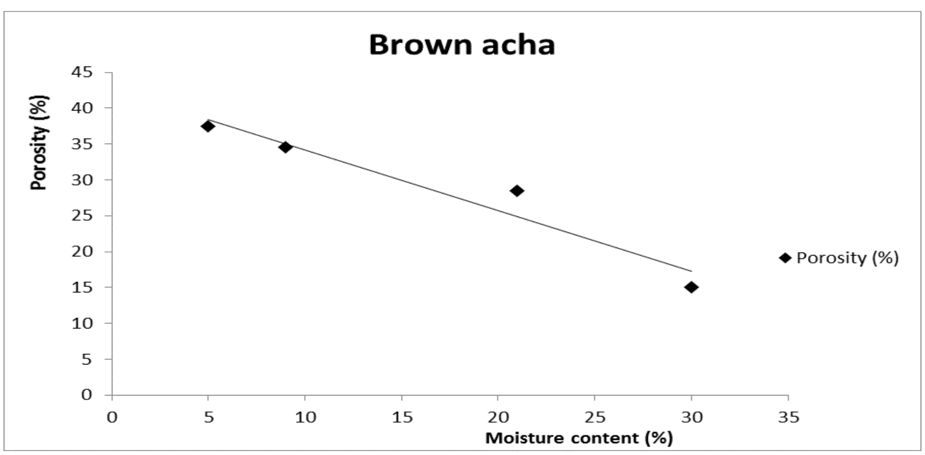

Figure 5b: The effect of moisture content on the porosity of brown Acha grains

The average mean porosity decreased from 39.1 - 25.1% for the white variety as the moisture content increased from 5 - 28% (db) and from 37.5 - 15% for the brown variety with increase in moisture content in the range of 5 - 30% (db). This decrease in porosity is attributed to its dependence on the bulk and solid densities of the grain. The decrease in porosity is because an increase in moisture content results in a more significant increase/swelling of the linear dimensions, thus reducing the air spaces and giving a more compact arrangement of the grains, invariably reducing the porosity of the grain bulk. The relationship existing between porosity moisture content was found to be linear with the following equations:

$$\varepsilon_w = -0.516M + 39.369 \qquad (15)$$
$$\varepsilon_b = -0.8473M + 42.669 \qquad (16)$$

where: ε_w = Porosity of white Acha (%), ε_b = Porosity of brown Acha (%), M = Moisture content (%).The coefficient of determinations (R^2) of 0.8975 and 0.8352 was found for the white and brown varieties respectively.

The same trend was reported by Joshi *et al.* (1993) for pumpkin seeds. Similarly, Konak *et al.* (2002) reported a linear increase in porosity with increase in moisture content for gram and chick pea seed. Baryeh (2002), and Coskuner and Karababa (2007) reported a polynomial relationship between porosity and moisture content for millet seeds and coriander seeds. The values calculated are useful in packaging as well as air and heat (fluids) properties.
Values of experimentally determined angle of repose are plotted against moisture content as shown in Figures 6a and 6b.

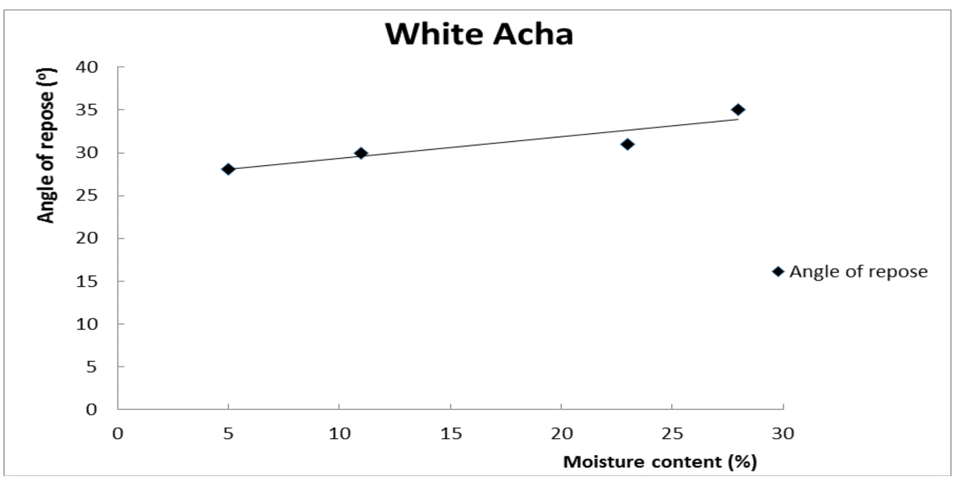

Figure 6a: The effect of moisture content on the angle of repose of white Acha grains

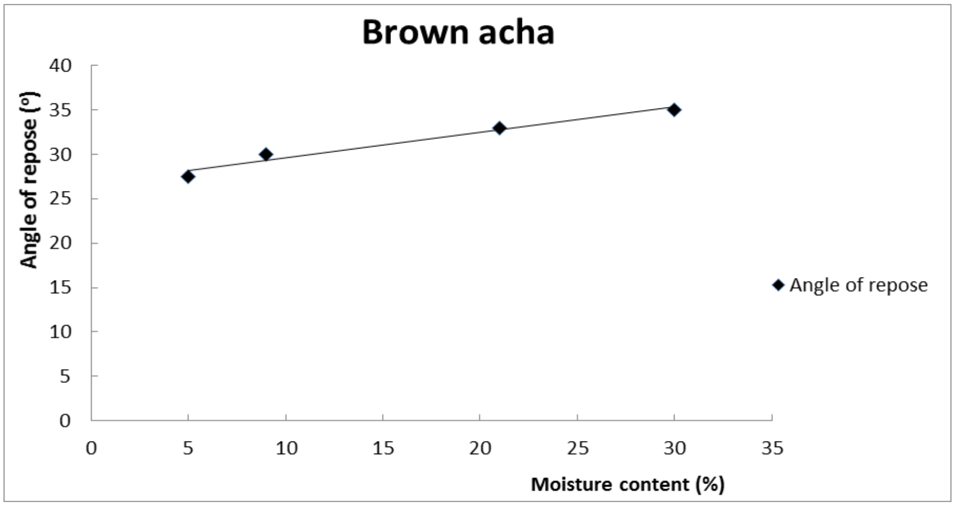

Figure 6b: The effect of moisture content on the angle of repose of brown Acha grains

It was observed that the angle of repose increased from 28.1 - 35° as the moisture content increases from 5 – 28% (d.b) for the white variety and the brown variety increased from 27.5 - 35° in the moisture content range of 5 – 30% d.b. It was also observed that at higher moisture content within the experimental range, seeds tend to stick together resulting in better stability and less flow ability, which as a result increases the value of θ. The relationship between moisture content and the angle of repose of the seeds was found to be linear with the equations:

$$\theta_w = 0.2519M + 26.806 \quad (17)$$

$$\theta_b = 0.2844M + 26.754 \quad (18)$$

where: θ_w = Angle of repose for the white variety ($^{\circ}$), θ_b = Angle of repose for the brown variety ($^{\circ}$), M = Moisture content (%).The values of coefficient of determination R^2 of 0.841 and 0.9668 were found for the white and brown varieties respectively.

The trends in Figures 6a and 6b follow the same pattern with the reports from Dutta *et al.* (1988), Gupta and Das (1997) and Amin *et al.* (2004) on grain seed, sunflower seed and lentil seeds respectively. Information obtained from the angle of repose is used in the design of hopper and conveyors in handling and processing industries.

4. Conclusions

The moisture dependence of some physical properties of *Digitaria exillis* and *Digitaria iburua* grains in the moisture range of 5 to 28% and 5 to 30% respectively were determined. This could be useful in machine designs for planting, processing, packaging and storing of the products. The white variety had more influence of moisture content on the properties than the brown variety by presenting higher values at most instances. The investigation showed that Acha grains swell when they become moist. One thousand grain mass increased from 0.297 – 1.765kg and 0.294 – 1.499kg for the white and brown varieties respectively, the above moisture ranges. Solid density of Acha grains decreased from 1311.6 – 854kg/m^3 and 1297.3 – 752.6kg/m^3 for the white and brown varieties respectively and the bulk density also decreased from 798 – 639kg/m^3 and from 811 – 641kg/m^3 for the white and brown varieties respectively. The porosity of Acha grains was seen to decrease from 39.1 – 25.1% for the white variety and also decreased from 37.5 – 15% for the brown variety while the angle of repose of the grains increased with increase in moisture content from 28.1 – 35^o and from 27.5 – 35^o for the white and brown varieties respectively.

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