Continental J. Applied Sciences
Chomo et al. (2026) 21 (4): 1 – 19 Doi: 10.52281/zenodo.20689277

Research Article

Characterization of Acha (*Digitaria Exilis*) Grains: Implications for Dehulling, Destoning, and Dechaffing Systems

D. I. G. Chomo[1*], Yakubu P. Davou[2], and Simon D. Datau[3]
[1]Mechanical Engineering Department, Plateau State Polytechnic, Barkin Ladi, Nigeria
[2]Science Laboratory Technology Department, Plateau State Polytechnic, Barkin Ladi, Nigeria
[3]Mechanical Engineering Department, University of Jos, Jos, Nigeria
*Corresponding author: digchomo@gmail.com

Abstract

Acha is an early indigenous cereal indigenous to most West African countries. The crop, also known as Fonio (Digitaria exilis and Digitaria iburua), is widely valued for its nutritional and economic importance. However, post-harvest processing of Acha remains largely traditional, labor-intensive, and inefficient due to the small grain size and the presence of impurities such as stones, chaff, and husks. The design and development of efficient dehulling, destoning, and dechaffing machines require adequate knowledge of the physical properties of the grain. This study evaluates the moisture-dependent physical properties of Acha (Digitaria exilis) with the aim of providing essential data for the design and optimization of dehulling, destoning, and dechaffing equipment. Standard experimental procedures were applied to determine key dimensional, gravimetric, and frictional properties at five moisture content levels (8, 12, 16, 20, and 24%). The results revealed that grain dimensions—length, width, thickness, arithmetic mean diameter, and geometric mean diameter—increased progressively with rising moisture content, indicating a direct relationship between moisture absorption and grain expansion. Similarly, spatial properties such as sphericity, volume, and surface area exhibited linear growth trends as moisture content increased, suggesting improved grain uniformity and size with higher moisture levels. In contrast, gravimetric properties, including bulk density, true density, and porosity, showed a decreasing trend with increasing moisture content, following non-linear relationships. This reduction is attributed to volume expansion exceeding mass gain during moisture absorption. Frictional properties, namely angle of repose and angle of internal friction, increased consistently across all

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

tested surfaces (steel, wood, and glass), indicating greater resistance to flow at higher moisture levels. Overall, the findings demonstrate that moisture content significantly influences the physical properties of Acha grains. These variations are critical for determining machine design parameters such as hopper inclination, sieve selection, and processing efficiency. The study provides valuable baseline data that can enhance the development of efficient and locally adaptable postharvest processing technologies for Acha, thereby supporting improved grain handling, reduced losses, and increased productivity.

Keywords: Fonio (*Digitaria exilis*), physical properties, dehulling destoning, dechaffing, moisture content, angle of internal friction

Received: 15 March 2026 **Accepted: 01 June 2026**

Citation: Chomo, D.I.G., Davou, Y.P., Datau, S.D. (2026). Characterization of Acha (*Digitaria Exilis*) Grains: Implications for Dehulling, Destoning, and Dechaffing Systems. Continental J. Applied Sciences, 21(4), 1-19. Doi: 10.52281/zenodo.20689277

Introduction

Acha is a Nigerian name for the cereal crop with the botanical name *Digitaria spp*. The commonly accepted name for the crop is Fonio and has other variant names such as Findi in Senegal, Findo in Gambia, Fonio in Sierra Leon, Founde in Mali, and Foni in Burkina Faso. Other names for it include Pom/Polin in Côte d'Ivoire, Podji in the Benin Republic, Kpendo in Guinea, and Hungry rice in English (Gyang and Wuyep, 2005; Fonio, 2011). It is the most significant of a varied range of wild and domesticated cereal crops from the grass family and is the smallest species of millet (Fonio, 2011).

The crop is the oldest indigenous grain cultivated in West Africa. The first reference to Acha as food dates back to the fourteenth century (Philip and Itodo, 2006). For thousands of years, West Africans from the Cape Verde Islands to Chad, and from Côte d'Ivoire to Cameroon, have cultivated it across the dry savannahs like Mali, Burkina Faso, Guinea, and Nigeria, where the crop is either the staple or a major part of the diet. (Fliedel et al, 2013).

In Nigeria, the crop is farmed commercially in Bauchi, Kaduna, Kebbi, Plateau, Nassarawa, Niger, Gombe, and the Federal Capital Territory. The largest producer, Plateau State, is believed to produce 20,000 tons annually (Gyang and Wuyep 2005). In regions with weak soils and semi-arid climates with sporadic and unpredictable rainfall, this crop can be depended upon. It can withstand drought and floods, grows so fast that two or three harvests can be made each year, and thrives on rocky or sandy Sahelian soils (National Research Council, 1996).

Some types of Acha reach harvest readiness well in advance of all other cereals due to their rapid maturity. Typically, each year, this turns into a "grain of life" for a few crucial months. With grain production occurring only 6 to 8 weeks after planting, they are arguably the quickest maturing cereal in the world. West Africa would experience a harsh annual hungry season in the absence of these unique Acha varieties. They supply food during the growing season, when the previous year's yield has been consumed, and the major crops are still too young to be harvested (*Digitaria exilis*, 2015; Cruz, 2011; Pankowska, 2019). Other Acha varieties take longer to mature; they usually take 23–26 weeks. This allows farmers to have grain accessible virtually all the time by planting a variety of slow and rapid varieties. Additionally, even under the most unpredictable and fluctuating growing conditions, they can improve their odds of obtaining enough food to survive (Ray and Schaffer, 2011).

White Fonio (*Digitaria exilis*) is the most commonly consumed Acha variety growing in fields from Chad to Senegal. It is mostly grown on the central Nigerian highland plateau, where it is commonly referred to as "Acha," as well as in nearby areas. Only the Jos-Bauchi Plateau in Nigeria, together with the northern parts of Togo and Benin, is the other species consumed, like the black fonio or *Digitaria iburua* (Chukwu and Abdulkadir, 2008).

The crop could promote sustainable land use, increase food security, promote rural development, and improve nutrition. According to Morales-Panyan et al. (2002), the tiny seed is high in leucine (9.8%), methionine (5.6%), and valine (5.5%) and has a crude protein content of roughly 7%. It is also rich in iron and amino acids. It is also considered a grain with therapeutic and restorative qualities; it is frequently included in the diets of ill people and is advised for nursing mothers and diabetics.

Despite its nutritional and agronomic advantages, the processing of Acha remains a major challenge. The grains are extremely small and are usually mixed with stones, sand particles, husks, and chaff during harvesting and threshing operations. Traditional processing methods involving pounding, winnowing, washing, and manual sorting are tedious, time-consuming, and characterized by high grain losses and low processing efficiency. These limitations have hindered the large-scale commercialization and industrial processing of Acha.

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

Threshing, destoning, and cleaning of Acha may be affected by a knowledge of its physical properties. Grain kernels may crack and break as a result of poorly constructed machines and procedures, producing low-quality grain. These flaws can be fixed with an understanding of the physical characteristics of the grain. Grain dimensions are used to determine the power needed for the threshing process, choose sieve separators for grading, calculate kernel volume and surface area, and determine quantities like aspect ratio, surface area, sphericity, and geometric mean diameter that are necessary for the modelling of grain during drying and processing (Varnamkhasti et al., 2007). Mechanization of Acha processing operations such as dehulling, destoning, and dechaffing is therefore essential to improve productivity, reduce labor requirements, and enhance grain quality.

This study aims to evaluate the physical properties of Acha necessary for the design and development of Acha processing machines. The outcome of this research is expected to provide valuable engineering data that will support the mechanization of Acha processing operations, reduce post-harvest losses, improve product quality, and promote the commercialization of Acha production in Nigeria and beyond.

Materials and Methods

1. Sample preparation

The Acha used for this research was white Acha (*Digitaria exilis*) procured from the popular Makera market in Riyom Local Government Area of Plateau State, Nigeria. The Acha was winnowed, and bad grain, fractured, and disfigured was selected and discarded.

The samples were dried in an oven set to 105±5 ^{o}C for 24 hours in order to establish their equilibrium moisture content. In order to attain conditions below the level of balanced moisture, the sample was dried. The prepared samples were divided into five and each set is placed in a polythene bag and sealed. Equation 1, developed by Balasubramanian (2001) was employed to obtain the quantity of water to be added to achieve the desired moisture content.

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

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

where: Q = the amount of water to be added; W_i = dry sample weight (g), M_f = final

moisture content of sample (%), M_i = initial moisture content of sample (%).

After determining and applying the appropriate amount of distilled water to the samples, they were refrigerated to ensure even moisture. Before the experiment began, the samples were taken out of the refrigerator and allowed to adjust to room temperature. Five different moisture levels were examined for the physical properties: 8, 12, 16, 20, and 24%.

2. Dimensional Properties

One hundred Acha grains were chosen at random for each moisture content, and the three principal dimensions -length, breadth, and thickness - were measured with a digital vernier calliper that had an accuracy of 0.01mm. To measure dimensions, the grain is allowed to rest freely on a flat surface. Length (L) is the longest side, while width (W) is defined as the smaller measurement taken, and the vertical measure is taken as the thickness (T).

The arithmetic mean (Da) and geometric mean (Dg) of Acha grain was calculated using Equations 2 and 3 (Maduako and Hannan, 2004; Itodo, Yusuf, and Kaakuka, 2023).

$$Da = \frac{L+W+T}{3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 2$$

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

The sphericity (φ), volume of grain (V), and surface area of grain (S), were determined using Equations (4), (5), and (6) as defined by Kibar and Ozturk (2008).

$$\varphi = \left[\frac{B(2L-B)}{L^2}\right]^{1/3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 4$$

$$V = \frac{\pi B L^3}{6(2L-B)}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 5$$

$$S = \frac{\pi B L^2}{2L-B} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad 6$$

Where B = $(WT)^{\frac{1}{2}}$

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

3. **Gravimetric Properties**

i. **Bulk Density**

Using the approach described by Kibar and Ozturk (2008), the bulk density of the samples at a number of moisture levels was employed. To calculate bulk density, a 1000 ml capacity, 108mm high container was employed. The Acha grains were allowed to settle into the bulk density container after it was filled to a depth of 50mm. Equation 7 was used to determine the bulk density.

$$\gamma = \frac{G_2 - G_1}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 7$$

where: γ = bulk density (kgm^{-3}), G_1 = free weight of bulk density bucket (kg), G_2 = weight of bulk density bucket with Acha (kg), and V = volume of density bucket

ii. **True Density**

The true density of Acha samples was evaluated using the liquid displacement method, established by Baryeh (2001) and Abalone et al. (2004). Due to its low surface tension and reduced absorption by Acha, toluene (C_7H_8) was substituted for water in this technique. The air-dried weight of the samples was first calculated in order to evaluate the true density. After that, the samples were immersed in toluene, and the volume displaced was estimated. Equation (8) was employed next to evaluate the true density of the samples as follows:

$$\rho = \frac{m_s + m_w}{V_s + V_w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 8$$

where: m_s = weight of liquid (kg), m_w = weight of air-dry sample (kg), V_s = volume of liquid (m^3), V_w = volume of sample (m^3).

iii. **Porosity**

Porosity ($\boldsymbol{\rho}$) is defined "as the fraction of space in the bulk grain, which is not occupied by grain and calculated from average values of bulk density and true density" (Kibar and Ozturk, 2008). Equation 9 was used to obtain the porosity (Kibar and Ozturk, 2008; Itodo, Yusuf, and Kaankuka, 2023).

$$\varepsilon = \left(1 - \frac{\gamma}{\rho}\right) x100\ (\%) \qquad \ldots\ldots\ldots\ldots \qquad 9$$

Where ε = Porocity, γ = bulk density, and ρ = true density

4. **Frictional Properties**
i. **Angle of Repose**

The angle of repose was evaluated using an open-ended cylinder having a 15cm diameter and a 30cm height. Acha grains were poured into the cylinder, which was positioned in the middle of a 70cm circular plate. Tapping was done intermittently while filling to ensure even packing. On the circular plate, the cylinder was gradually lifted until it formed a cone. The cone's height, H, was noted. Equation 10 was used to determine the angle of repose (θ_R) (Umogbai, 2009; Davies, 2009).

$$\theta_R = tan^{-1}\frac{2H}{D}\ \text{(Degrees)} \qquad \ldots\ldots\ldots\ldots \qquad 10$$

Where; θ_R = angle of repose (^{o}), H = vertical height of conical heap of grains (mm), and D = the diameter of the base of the cone formed (mm).

ii. **Angle of Friction**

The angle at which a material starts to slide on a surface that is inclined to a reference horizontal is known as its angle of friction (Obetta and Onwualu, 1999). An apparatus similar to that built by Umogbai (2009) was used to calculate the angles of friction of Acha. The angle of friction, expressed in degrees (^{o}), was the corresponding angle at which the sample began to slide.

Results and Discussions

The physical properties of Acha are discussed under axial dimensions, spatial dimensions, gravimetric, and frictional properties.

1. **Axial Dimensional properties of Acha**

The axial dimensions, i.e., length (L), width (W), and thickness (T), and their mean values, i.e. arithmetic and geometric mean, at moisture contents of 8, 12, 16, 20 and 24% are presented in Table 1 and a graph of the dimensions against moisture content is drawn

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

and shown in Figure 1(a) for axial dimensions and Figure 1(b) for mean axial dimensions. As moisture content increases, all dimensions also increase.

Table 1: Effect of moisture content on axial dimensions of Acha

Moisture content (M_c)	Length (L)	Width (W)	Thickness (T)	Arithmetic mean (D_a)	Geometric mean (D_g)
8	1.64	0.80	0.62	1.02	0.92
12	1.69	0.83	0.66	1.06	0.97
16	1.75	0.86	0.70	1.10	1.02
20	1.82	0.88	0.75	1.15	1.06
24	1.93	0.90	0.81	1.21	1.11

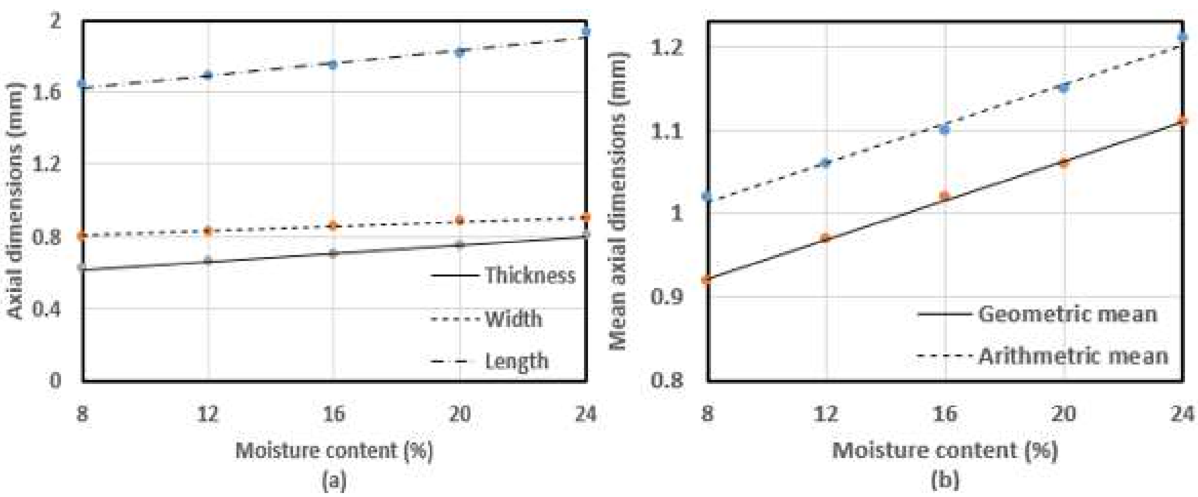

Figure 1: Effect of moisture content on axial dimensions of Acha

The relationships between the axial dimensions (L, W, and T) and the moisture content of grain (Mc) can be represented by the regression equations.

$$L = 1.45 + 0.02\ Mc \quad (r^2 = 0.97) \quad \ldots\ldots \quad 11$$

$$W = 0.69 + 0.01\ Mc \quad (r^2 = 0.93) \quad \ldots\ldots \quad 12$$

$$T = 0.55 + 0.01\ Mc \quad (r^2 = 0.99) \quad \ldots\ldots \quad 13$$

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

This regression shows that there is a significant positive relationship between axial dimensions of Acha and moisture content.

Mean values, i.e., arithmetic and geometric mean, increased linearly as shown in Figure 1(b), were observed to be 1.02 and 1.21mm at moisture content of 8% and 24%, respectively, for the arithmetic mean and 0.92 and 1.11mm at moisture content of 8% and 24%, respectively, for the geometric mean.

The linear relationships that exist between the mean dimensions (arithmetic, D_a, and geometric mean, D_g) with moisture content are given by Equations 14 and 15, respectively.

$$D_a = 0.95 + 0.01\,Mc \qquad (r^2 = 0.99) \qquad \ldots\ldots\ldots\ldots \qquad 14$$

$$D_g = 0.86 + 0.01\,Mc \qquad (r^2 = 0.99) \qquad \ldots\ldots\ldots\ldots \qquad 15$$

As the moisture content increases, Sahoo and Srivastava (2002) reported an increase in dimension for okra seeds, Abalone et al. (2004) for amaranth seeds, and Ndirika and Oyeleke (2006) for millet seeds. The values and pattern are consistent with Itodo, Yusuf, and Kaankuka (2023), and Bako and Bardey (2020) for Acha.

An understanding of the axial dimension of seeds is used to determine the clearance between dehulling cylinders and drums so as to minimize damage to grains (Tokan et al., 2012; Solanki et al, 2018; Simonya and Yiljep, 2008). When designing indented cylinders for Acha grain cleaning, the axial dimension of the grain can also be employed.

2. Spatial Dimensional Properties of Acha

Spatial dimensions, which include sphericity, volume, and surface area, are determined at stated moisture content and tabulated in Table 2. Figure 2a illustrates how sphericity and moisture content of grain relate. The sphericity of the samples increased linearly with an increase in moisture content. At 8% moisture content, the sphericity was 0.82; whereas, at 24% moisture content, it was 0.86.

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

Table 2: Effect of moisture content on spatial dimensions of Acha

Moisture content (Mc)	Sphericity (φ)	Volume (V)	Surface area (S)
8	0.82	0.63	2.31
12	0.83	0.71	2.54
16	0.84	0.80	2.82
20	0.85	0.89	3.05
24	0.86	1.04	3.33

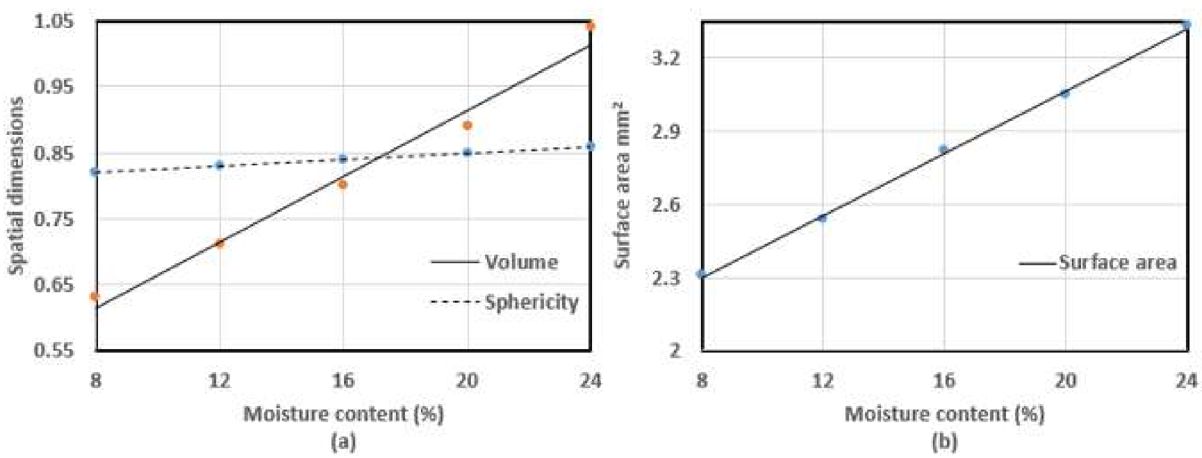

Figure 2: Effect of moisture content on Spatial dimensions of Acha

The regression equation in Equation 16 illustrates the relationship between sphericity and moisture content.

$$\varphi = 0.8 + 0.003\ M_c \qquad (r^2 = 0.99) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 16$$

Grain products like peanuts (Baryeh, 2001; Baryeh and Mangope, 2002), groundnuts, soy beans (Deshpande et al., 1993), and okra seeds (Sahoo and Srivastava, 2002) exhibit a linear positive change in sphericity as the moisture content increases. Conveyors, storage structures, and hoppers are designed using sphericity values.

The change in volume due to the change in moisture content of grain is shown in Figure 3b. As the moisture content increases, the volume of grain samples increases linearly, and as the moisture content increases from 8% to 24%, the grain's volume increases from 0.63

to 1.04mm^3. The relationship between the volume (V) of grains and moisture content (Mc) can be expressed by the following regression equation;

$$V = 0.41 + 0.03\ Mc \qquad (r^2 = 0.98) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 17$$

The surface area of samples was observed to increase with the increase of moisture content (Figure 2b). The relationship between surface area (S) of grain and moisture content (Mc) can be expressed generally as follows:

$$S = 1.85 + 0.06\ Mc \qquad (r^2 = 0.99) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad 18$$

One useful method for figuring out the morphology of the seeds is their surface area. Actually, this will serve as a preview of how the kernels will respond during processing on oscillating surfaces.

3. Gravimetric Properties

The physical properties of Acha (Bulk density, True density, and Porosity) are determined and tabulated in Table 3, and the graph depicting the relationship of these properties to moisture content is shown in Figure 3a and 3b. The bulk density of Acha varied between 1171.9 and 1063.6 kgm^{-3} at moisture content of 8 and 24%, respectively. This indicates that as the moisture content increased, the bulk density decreased nonlinearly. True density ranged from 983 to 905 kgm$^{-3,}$ which implies decreasing nonlinearly as the moisture content increases (Figure 3a).

Table 3: Effect of moisture content on Gravimetric Properties of Acha

Moisture content	Bulk density	True density	Porosity
8	1171.9	1762.0	33.5
12	1162.5	1705.2	31.9
16	1136.7	1634.6	30.5
20	1104.8	1564.4	29.4
24	1069.6	1429.5	25.0

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

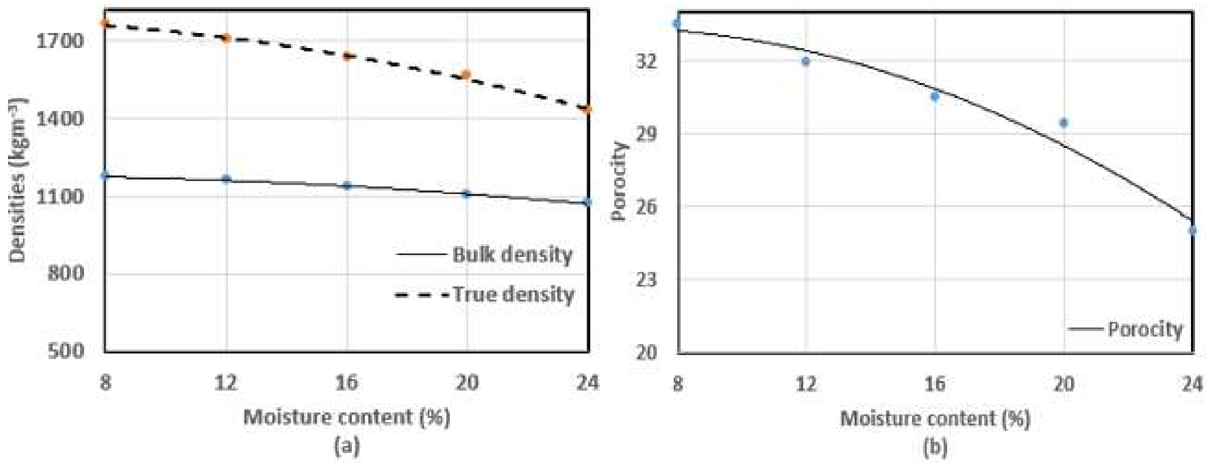

Figure 3: Effect of moisture content on Gravimetric Properties of Acha

The relationships between the two densities, bulk density (γ), solid density (ρ), and moisture content (Mc), can be expressed thus:

γ = 1176.3 + 1.69Mc - 0.26Mc^2 (r^2 = 0.99) ……………… 19

ρ = 1785.7 + 2.11Mc - 0.69Mc^2 (r^2 = 0.99) ………………. 20

The regression equations show that both bulk density and actual density decreased as the moisture content increased. Additionally, studies by Baryeh (2001), Sahoo and Srivastava (2002), Aviara et al. (2005), Altuntaþ et al. (2005), Mwithiga and Sifuna (2005), and Yalçýn (2007) found that the increase in grain moisture content, which was dependent on the fibre structure in grains, affected both bulk density and true density. The true density shows that the grain density is greater than that of water, which is a crucial characteristic for food grains during wet cleaning because they don't float on water. These densities help calculate the processing machine's theoretical capacity. The same trend is also recorded for Tiger nuts (Ijabo and Alabi, 1998) and amaranth seeds (Abalone et al., 2004). The rate at which the moisture content increased caused the solid densities of Acha to fall since it directly increased volume while maintaining mass. There is a non-linear decrease in the true densities as the moisture content increases.

The relationship between porosity and moisture content is shown in Figure 3b. The porosity of the samples decreased nonlinearly as the moisture content rose. The following is the relationship between porosity (ε) and moisture content:

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

$$\varepsilon = 32.56 + 0.27Mc - 0.02Mc^2 \quad (r^2 = 0.97) \quad \ldots\ldots\ldots\ldots \quad 21$$

The average mean porosity decreased from 33.5 to 25.0% as the moisture content increased from 8 to 24% (Figure 3b). This decrease in porosity is attributed to its dependence on the bulk density and true density of the seed. Bamgboye and Adejumo (2009) and Joshi et al. (1993) both noted a similar pattern for pumpkin seeds and rosella seeds, respectively. The decrease in solid densities of Acha was due to the rate of increase in the moisture content, which directly increased the volume while mass remained unchanged. The true density bears a non-linear decreasing relationship with an increase in moisture content.

Grain hardness, breaking susceptibility, milling, drying rate, and resistance to fungal development are all influenced by the porosity of the grain (Chang, 1988).

4. Frictional Properties

Frictional properties include angle of repose and angle of internal friction. Table 4 shows the values of the frictional properties of Acha at varying moisture content. The frictional property was measured on steel, wood, and glass.

Table 4: Effect of moisture content on Frictional Properties of Acha

Moisture	Angle of Repose (θ_R)			Angle of Friction (θ_F)		
Content (Mc)	Steel	Wood	Glass	Steel	Wood	Glass
8	30.3	31.2	26.6	32.6	42.5	30.4
12	31.3	32.3	27.5	36.5	43.6	32.9
16	32.6	33.6	28.4	39.8	45.2	35.6
20	34.4	34.9	29.6	42.9	46.5	38.7
24	35.7	36.2	30.8	46.2	48.4	41.5

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

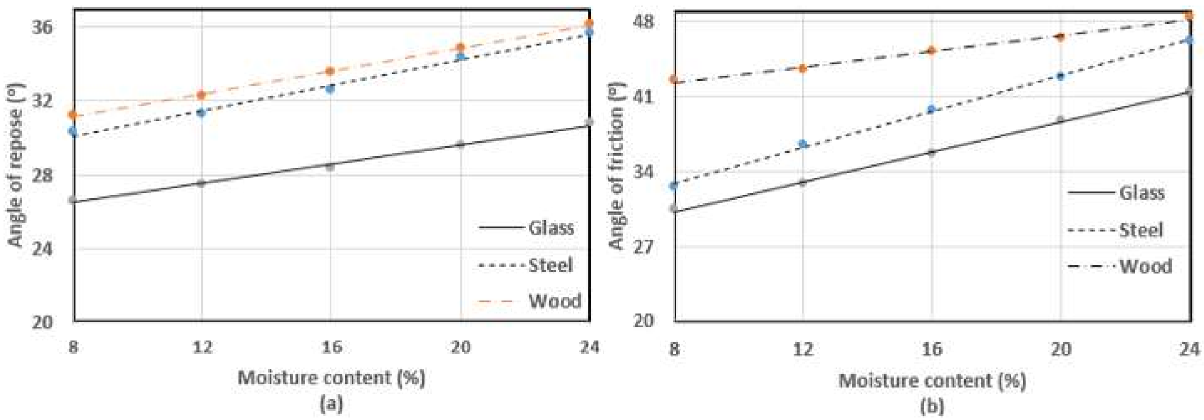

Figure 4: Effect of moisture content on Frictional Properties of Acha

As the moisture content rose from 8 to 24 percent, so did the angles of repose. The angle of repose for Acha on mild steel, wood, and glass surfaces went up from 30.3 to 35.7° on mild steel, from 26.6 to 30.8° on glass, and from 31.2 to 36.2° on wood. Wood has the greatest angle of repose value (36.2°), which could be because of its rough surface. Equations 22 and 24, respectively, provide the relationship between the angles of repose and moisture content for the surfaces (glass, wood, and mild steel).

$\theta_{R\ STEEL}$= 27.3 + 0.35 Mc (r^2 = 0.99) ……………..….. 22

$\theta_{R\ WOOD}$= 28.48 + 0.32 Mc (r^2 = 0.99) ……………… 23

$\theta_{R\ GLASS}$= 24.44 + 0.26 Mc (r^2 = 0.99) ……………… 24

The characteristics shown in Figure 4a are consistent with the findings of the studies on grain seed, sunflower seed, and lentil seed by Dutta et al. (1988), Gupta and Das (1997), and Amin et al. (2004), respectively. The handling and processing industries use the information acquired from the measurement of the angle of repose to construct hoppers and conveyors.

As the moisture level of the samples increased, so did the angle of internal friction. The angle of internal friction was shown to have a positive linear relationship with the moisture content. The angles of friction on all surfaces increased as the moisture content increased (Figure 8).

For the surfaces (glass, wood, and mild steel), Equations 25 to 27 provide the linear relationship between the angles of internal friction and moisture content, respectively.

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

$\theta_{F\ STEEL}$= 26.16 + 0.84 Mc (r^2 = 0.99) ………………. 25
$\theta_{F\ WOOD}$= 39.28 + 0.37 Mc (r^2 = 0.99) ………………. 26
$\theta_{F\ GLASS}$= 24.28 + 0.72 Mc (r^2 = 0.99) ………………. 27

In their investigation, Molenda et al. (1998) also discovered that the angle of internal friction rose linearly as the moisture content rose.

The presented angle of friction data will be useful for design calculations when analyzing friction on the Acha seed across various surfaces during handling or processing procedures.

Conclusion

This study established that moisture content has a significant influence on the physical properties of Acha grains. Dimensional characteristics increased steadily with rising moisture levels, indicating grain expansion. Similarly, spatial properties such as sphericity, volume, and surface area showed linear increases. These changes suggest improved grain uniformity and surface interaction at higher moisture contents.
Gravimetric properties, including bulk density, true density, and porosity, decreased non-linearly as moisture content increased. This trend reflects the dominance of volume increase over mass gain during moisture absorption. Frictional properties, namely angle of repose and internal friction, increased across all contact surfaces. This implies reduced flowability and higher resistance during handling at elevated moisture levels.

The observed relationships provide critical insights for engineering design considerations. They are particularly useful for determining machine settings such as hopper angles, sieve sizes, and material-handling systems. Overall, the results provide a reliable dataset for the development and optimization of Acha processing equipment.

References

Abalone R., Cassinera A., Gaston A., and Lara M.A., (2004). Some physical properties of amaranth seeds. Biosystems Eng., 89, 109-117.

Altuntas E., Özgöz E., and Taser Ö.F., (2005). Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. J. Food Eng., 71, 37-43.

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

Amin M. N, Hossain M. A, Roy KC (2004). Effect of moisture content on some physical properties of lentil seeds. J. Food Engin., 65: 83-87

Aviara, N. A., Oluwole, F. A., and Haque, MA. (2005). Effect of moisture content on some physical properties of sheanut (*Butyrospermum paradoxum*). International Agrophysics, 19: 193-198

Bako, T. and Bardey, I. A. (2020). Engineering properties of acha (*Digitaria exilis*) grains in relation to the design of grain processing machines. Agricultural Engineering International: CIGR Journal, 22 (2):159-170.

Balasubramanian, D. (2001). Physical properties of raw cashew nut. J. Agric. Eng. Res., 78, 291-297.

Bamgboye, A. I. Adejumo OI (2009). Physical properties of Roselle (Hibiscus sabdariffa L) seed. CIGR Ejournal. Manuscript 1154, Vol. XI. http://www.cigr-ejournal.tamu.edu./articles.html

Baryeh E. A., (2001). Physical properties of Bambara groundnuts. J. Food Eng., 47, 321-326.

Baryeh, E. A. and Mangope, B. K. (2002). Some physical properties of QP-38 variety pigeon pea. J. Food Eng., 56, 59-65.

Chang, C. C. (1988). Measuring density and porosity using gas pycnometer. Cereal Chemistry, 65(1): 13-15.)

Chukwu, O. Abdulkadir, A. J. (2008). Proximate chemical composition of acha (*Digitaria exilis* and *Digitaria iburia*) grains. J. .foods Technol. 6(5): 214-216. Retrieved April, 21 2025 from http://medwelljournals.com

Cruz, J. (2011). Final Report Summary - FONIO (Upgrading quality and competitiveness of fonio for improved livelihoods in West Africa) retrieved from http://publications.europa.eu/index_en.htm

ISSN: 3043-6087. Science and Education Development Inst., Nigeria

Davies, R. M. (2009). Some physical properties of groundnut grains. Research Journal of Applied Science, Engineering and Technology, 1(2): 10-13.

Deshpande, S. D. Bal, S and Ojha, T. N. (1993). Physical Properties of soybean. J. Agric. Engin. Res., 56: 89-98.

Digitaria exilis (2015). From Wikipedia, the free encyclopaedia. Retrieved December 17, 2015 from https://en.wikipedia.org/w/index.php/digitaria exilis.

Dutta, SK., Nema VK., and Bhardwaj, RK. 1988. Physical properties of gram. Journal of Agricultural Engineering Research, 39: 259-268.

Fliedel, G., Koreissi, Y., Boré Guindo, F. Dramé, D. Brouwer, I., and Ribeyre, F. (2013). *Sensory diversity of fonio landraces from West Africa.* In African Journal of Biotechnology Vol. 12(15), pp. 1836-1844, 10 April, 2013. Retrieved from http://www.academicjournals.org/AJB DOI: 10.5897/AJB11.765)

Fonio (2011). Retrieved from http://en.wikipedia.org

Gupta, R. K. and Das, S. K. (1997). Physical properties of sunflower seeds. J. Agric. Eng. Res., 66, 1-8.

Gyang, J. D. and Wuyep, E. O. (2005). Acha, the grain of life. A biannual publication of the Raw Material Research and Development Council, vol.6, No. 1:39-41.

Ijabo, O. J. and Alabi, A. (1998). Effect of Moisture Content and Variety on Physical Properties of Tiger Nut. A B. Eng Project Submitted to the Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria. pp. 34-42.

Itodo, I. N., Yusuf, P. O. and Kaankuka, T. K., (2023). Some Physical Properties of Acha (*Digitaria Exilis*) Relevant in Mechanical Dehulling and Cleaning. Arid Zone Journal of Engineering, Technology & Environment Azojete December 2023. Vol. 19(4):705-718

Jideani, I. A. (1999). Traditional and possible Technological uses of *Digitaria exilis* (Acha) and *Digitaria ibrua* (iburu). A Review of Plant Food for Human Nutrition. Kluwer: Academic Publishers.

Joshi, D. C., Das, S. K., and Mukherjee, R. K. (1993). Physical Properties of Pumpkin seeds. J. Agric. Engin. Res., 54(3): 219-229.

Karababa, E. (2006). Physical properties of popcorn kernels. January 2006. Journal of Engineering. 72(1): 100-107. Retrieved from DOI; 10.1016/J, JFOODENG. 2004.11.028

Kibar, H. and Öztürk, T. (2008). Physical and mechanical properties of soybean from www.international-agrophysics.org

Maduako, J. N. and Hannan, M. 2004. Determination of some physical properties of three of groundnut varieties. Nigerian Journal of Technology, 24 (2): 12-18

Morales-Payán, J., Pablo, J., Ortiz, Richard, Cicero, Julio and Taveras, Francisco (2002). Janick, J.; Whipkey, A., eds. *Digitaria exilis* as a crop in the Dominican Republic. Supplement to: Trends in new crops and new uses. Alexandria, VA: ASHS Press.

Molenda M., Horabik J., and Ross I.J., 1998. Stress and deformation of wheat in direct shear test. Int. Agrophysics, 12, 115-118. 244

Mwithiga, G. and Sifuna, M.M. (2005). Effect of moisture content on the physical properties of three varieties of sorghum seeds. J. Food Eng., 75, 480-486.

National Research Council (1996). Lost crops of Africa, volume 1, Grain, National Research Council, Washington, DC: National Academy Press.

Ndirika, V. I. O. and Oyeleke, O. O. (2006). Determination of Selected Physical Properties and their Relationship with Moisture Content for Millet (*Pennisetum glauchim* L.). African Society of Agricultural and Biological Engineers ISSN 0883-8542.

Obetta, S. E. and Onwualu, A. P. (1999). Effect of Different Surface and Moisture Content of Food Grains. J. Food Sci. Technol., 36(1): 58-60.

Pankowska, K. (2019). Will fonio become the new quinoa? Retrieved from http://inco-fonio-en.cirad.fr/links

Philip, T. and Itodo, I. (2006). Acha (*Digitaria spp*) a rediscovered indigenous crop of West Africa, Agricultural Engineering International: the CIGR Journal.

Ray, D. E. and Schaffer, H. D. (2011). Fonio, a crabgrass relative and a hardy grain, supplies nutrition to millions in Africa. Retrieved from www.agriculture.utk.edu/).

Sahoo, P. K. and Srivastava, A. P. (2002). Physical properties of Okra seed. Central Institute for Research on Goats, Indian Agricultural Research Institute, New Delhi. Biosyst. Engin., 83(4): 441-448.

Simonyan, K. J. and Yiljep, Y. D. (2008). Investigating grain separation and cleaning efficiency distribution of a conventional stationary rasp - bar sorghum thresher. Agricultural Engineering International, 10: 1-13.

Solanki, C. D., Mridula, S. K., Aleksha, K., and Gupta, R. K. (2018). Buckwheat dehuller and optimization of dehulling parameters. International Journal of Current Microbiology and Applied Sciences, 7 (11):1041-1052.

Tokan, A., Danladi, Y. B., Shekarau, M. B. E. and Dada, S. G. (2012). Design, fabrication and testing of a fonio dehusking machine. International Journal of Engineering Innovation and Research, 1(6): 2277 – 5668.

Umogbai, V. I. (2009). Development of the Angle of Friction Measuring Device. Journal of Engineering Science and Technology, 4(1): 116-121.

Varnamkhasti, M. G., Mobli, H., Jafari, A., Keyhani, A. R., Soltanabadi,M. H., Rafiee, S., and Kheiralipour, K. (2008). Some physical properties of rough rice (*Oryza Sativa* L.) grain. Journal of Cereal Science 47 (2008) 496-501.Retrieved April 21, 2025 from www.elsevier.com/locate/jcs

Yalçýn I., (2007). Physical properties of cowpea (*Vigna sinensis* L.) seed. Journal of Food Engineering, volume 79, issue 1 79, 57-62