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Full Length Research Paper

Cause of moisture substance on some physical properties of two acha varieties

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The effect of moisture content on some physical properties of two varieties of acha was investigated. The moisture content levels used were 10, 14, 18, 22 and 26% dry basis (d.b.), and the two acha varieties used were *Digitaria exilis* and *Digitaria iburua*. Increase in moisture content from 10 to 26% resulted in a decrease in bulk density, solid density, porosity and specific gravity for both acha varieties. However, increase in moisture content increased the 1000 grain mass, geometric mean diameter, sphericity, angles of repose and friction on mild steel, wood and glass surfaces for both varieties. This study concludes that variety and changes in moisture content significantly affected the determined physical properties of acha. High correlation values ranging between 87.2 and 99.8% were obtained for the relationships between moisture content and acha varieties for all the parameters determined.

Key words: Acha, *Digitaria exilis, Digitaria iburua,* moisture content, physical properties.

INTRODUCTION

Acha (*Digitaria* Spp.) is a minor cereal in many countries of West Africa where it is a staple food crop for several millions of tribal people (Vietmeyer et al., 1996). Acha (*Digitaria* Spp.) also known with other names such as fonio, findi, fundi, pom and kabug in different West African Countries has been reported as the oldest African cereal (NRC, 1996). Acha, sometimes considered as “small seed with a big promise” provides food early in the season when other crops are yet to mature for harvest (Ibrahim, 2001).

Although, a large number of species of the genus *Digitaria* are recognized as weeds, *Digitaria exilis* (white acha) and *Digitaria iburua* (black acha) are cultivated as cereal crops and utilized as food and also used in the industry for soap and beer making. At present, there are many limitations towards acha breeding because it is relatively unimproved and is characterized by a number of poor traits. The grains are very small (L: 1.5 mm, W: 0.9 mm) with an average of 1000 grains weighing 0.59 g (CIRAD, 2004). These among other factors hinder its production and make it an unattractive crop with restricted cultivation in countries where they are produced.

A total area of 347,380 ha was devoted to acha production in Africa in 2002 (FAOSTAT, 2003) while Cruz (2004) reported a production area of 380,000 ha with an output of 250,000 tons of grain annually. The crop supplies food to 3 to 4 million people (TNAP, 1996). Froment and Renard (2001) reported that acha will tolerate a wide range of soils, be they sandy, loamy, stony and shallow.

In gross nutritional composition, acha differs little from wheat. In one white acha (*D. exilis*) sample, the husked grain contained 8% protein and 1% fat. In a sample of black acha (*D. iburua*), a protein content of 11.8% was recorded. The amino acid profile of acha compared to that of whole-egg protein showed that except for the low

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score of 46% lysine, the other scores were high: 72% for isoleucine, 90 to 100% for valine, tryptophan, threonine, and phenylalamine; 127% for leucine; 175% for total sulphur; and 189% for methionine (TNAP, 1996). Thus, acha has important potential not only as survival food, but as a complement for standard diets.

Moisture-dependent physical properties have been reported for different types of grains and cereals. However, information on the effect of moisture content and variety on physical properties of acha (*D. exilis* and *D. iburua*) have not been available in the literature.

The objectives of this study were: (1) to investigate at various levels some moisture-dependent physical properties of two varieties of acha (*D. exilis* and *D. iburua*) and (2) to carry out a regression analysis on the effect of moisture content and acha variety of the studied physical properties.

MATERIALS AND METHODS

The physical properties of *D. exilis* and *D. iburua* were determined based on moisture content values of 10, 14, 18, 22 and 26%. The two varieties of acha (*D. exilis* and *D. iburua*) that were used in determining the effect of moisture content on the selected physical properties were obtained from a local farmer in Jos Local Government Area of Plateau State, Nigeria. The samples were thoroughly cleaned to remove foreign materials. The two varieties of acha, *D. exilis* and *D. iburua* which were labeled as samples A and B, respectively were divided into five batches each to make a total of 10 samples.

The samples were conditioned to 10, 14, 18, 22 and 26% moisture content. The physical properties namely; bulk density, solid density, porosity, one thousand grain mass (1000 mass), specific gravity, axial dimensions, angles of repose and angles of friction on three different surfaces were determined.

The experiment was designed in a randomized complete block design (RCBD) at 5 moisture content levels using 2 varieties of acha and these were replicated 5 times for each parameter determined.

Determination of moisture content

The initial moisture content of *D. exilis and D. iburua* were computed as 6.4 and 7.9%, respectively. The initial moisture content was determined using the ASAE standard S352.2 by the use of oven drying method (ASAE, 1998) and Equation 1 was used for the calculation.

$$MC(\%)_{d.b} = \frac{W_w - W_d}{W_d} x 100 \quad (1)$$

where MC is initial moisture content of acha; W_w is the wet mass of acha sample (g); W_d is the dry mass of acha sample (g).

Conditioning of acha grains to desired moisture content

The acha grains were prepared to the desired moisture content levels by adding calculated amount of distilled water using Equation 2. These were kept in separate air-tight plastic containers and stored in a refrigerator at a temperature of 5 ± 1°C f or a period of 5 days. The required sample quantity for the experiment were taken out and allowed to attain room temperature for two hours before the experiment (Bamgboye and Adejumo, 2009).

$$Q = \frac{A(M_f - M_i)}{100 - M_f} \quad (2)$$

Where Q is the mass of water to be added; A is the initial mass of sample (kg); M_i is the initial moisture content of grain (%) $_{d.b}$; M_f is the final (desired) moisture content of sample (%) $_{d.b}$.

Determination of axial dimensions

Fifty acha seeds were randomly selected for each of the moisture content level considered and labeled for easy identification. The three principal dimensions namely length (a), width (b) and thickness (c) were measured using a digital vernier caliper with accuracy of 0.001 mm. The geometric mean diameter (D_g) of the acha seeds was evaluated using Equation 3 (Mohsenin, 1986).

$$D_g = (abc)^{1/3} \quad (3)$$

Determination of sphericity

Sphericity of a product (grain) expresses the shape of that product relative to that of a sphere. The sphericity of acha was determined using Equation 4.

$$\phi = \frac{D_g}{a} \quad (4)$$

Determination of thousand seed mass

The thousand seed mass was determined by counting and weighing 1000 seed of each sample of acha varieties A and B. This was replicated 5 times for each sample and the result for the five moisture content levels of both varieties was recorded. A digital weighing balance of 0.01 g accuracy was used.

Determination of bulk density, solid density and porosity

Bulk density was determined by weighing the grains packed in a container of known volume. The grains were densely packed by tapping the container gently to allow the grains settle in the container. A digital weighing balance of 0.01 g accuracy was used to determine the mass of acha in container. Equation 5 as given by Waziri and Mittal (1983) was used to determine the bulk density of the two varieties of acha samples.

$$\rho b = \frac{M_{mp}}{k} \quad (5)$$

Where ρ_b is bulk density of acha (kg/m^3); M_{mp} is the mass of packed acha (kg), V_k is the known volume of container (m^3).

Solid density was determined by using Equations 6 and 7 as given by Okeke and Anyakoha (1987).

$$G_{sp} = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \qquad (6)$$

$$\rho_s = \rho_w \times G_{sp} \qquad (7)$$

Where G_{sp} is the specific gravity of the acha, m_1 is the mass of empty density bottle (g), m_2 is the mass of empty density bottle about one – third full of acha grains (g), m_3 is the mass of density bottle filled with grain and water (g), m_4 is the mass of density bottle filled with water only, ρ_s is the solid density (kg/m^3), ρ_w is density of water (kg/m^3).

Porosity of a bulk grain is defined as the ratio of inter-granular spaces to the total shape occupied by the grain; it was calculated using Equation 8 as given by Tunde-Akintunde and Akintunde (2007).

$$\varepsilon = \frac{1 - \rho_b}{\rho_s} \times 100\% \qquad (8)$$

Determination of angle of repose

The angle of repose was evaluated by using the apparatus (Plate 1) that was available in the Department of Agricultural and Environ-mental Engineering, University of Agriculture, Makurdi, Benue State, Nigeria. The angle of repose was determined using the method described by Ogbonnaya and Fatai (2007). Three surfaces were used, namely; wood, mild steel and glass for the varieties at different moisture content. The angle of repose was calculated by using Equation 9 (Ogbonnaya and Fatai, 2007).

$$\theta = \tan^{-1}\frac{x}{y} \qquad (9)$$

Where θ is the angle of repose (^{o}), x is the height of grain (mm) and y is the radius of the heap formed $\frac{D}{2}$ (mm).

Determination of angle of friction

Angle of friction of a material is the angle at which the material begins to slide on a surface inclined to a reference horizontal (Obetta and Onwualu, 1999). The angle of friction of the two varieties A and B were determined by using the apparatus (Plate 2) constructed by Umogbai (2009). The corresponding angle at which sliding of the sample started was recorded as the angle of friction (^{o}).

Statistics

The analysis of variance (ANOVA) was used to determine the variation in results of the experiments for both the dependent and independent variable at probability level of P ≤ 0.05. The means were separated using Duncan's new multiple range test (DNMRT) at a probability level of P ≤ 0.05.

RESULTS

Table 1 gives a summary of each determined physical properties of the two acha varieties (*D. exilis* and *D. iburua*) as affected by different levels of moisture content. Tables 2 and 3 show the means separation for the physical properties determined. Figures 1 to 13 show the effect of moisture content on the selected physical properties of acha varieties.

DISCUSSION

The average bulk density for *D. exillis* and *D. iburua* was observed to decrease from 1167.2 to 1045.3 kg/m^3 and 1145.3 to 1035.8 kg/m^3, respectively as moisture content was increased from 10 to 26% (Figure 1). The relation-ship between bulk density and moisture content for *D. exilis* and *D. iburua* are represented by second poly-nomial Equations 10 and 11, respectively. The decrease in bulk density with increase in seed moisture content was mainly due to the higher rate of increase in volume than mass. The same relationship was also observed by Sahoo and Srivastava (2002) for okra seed, Deshpande et al. (1993) for soya bean and Ogut (1998) for white lupin.

$$\rho_{bex} = -0.258MC^2 + 1.612MC + 1178 \ (R^2 = 0.984) \qquad (10)$$

$$\rho_{bib} = 0.074MC^2 - 9.9362MC + 1243 \ (R^2 = 0.984) \qquad (11)$$

The solid density of the two variety of acha decreased from 1733.6 to 1322.4 kg/m^3 for *D. exilis* and from 1666.2 to 1169.3 kg/m^3 for *D. iburua* (Figure 2) as the moisture content was increased. The relationship between the solid density and moisture content for *D. exilis* and *D. iburua* are described by second degree polynomial Equations 12 and 13, respectively.

Same decrease was recorded by Abalone et al. (2004) for Amaranth seeds and Ijabo and Alabi (1998) for Tiger nut. The decrease in solid densities of acha was due to the rate of increase in the moisture content which directly increased the volume than mass. The solid densities of the two varieties bear a non-linear decreasing relation-ship with increase in moisture content.

$$\rho_{sex} = -1.276MC^2 + 21.88MC + 1632 \ (R^2=0.974) \qquad (12)$$

$$\rho_{sib} = -1.024MC^2 + 5.376MC + 1719 \ (R^2=0.998) \qquad (13)$$

The average mean porosity decreased from 32.7 to 21.1% for *D. exilis* and from 31.3 to 11.4% for *D. iburua* as the moisture content increased from 10 to 26% (Figure 3). The moisture-dependence of porosity for *D. exilis* and *D. iburua* is a polynomial relationship and are described by Equations 14 and 15, respectively. This decrease in porosity is attributed to its dependence on the density

Table 1. Effect of moisture content and variety on some physical properties of acha.

	Digitria exilis					*Digitaria iburua*				
	Moisture content (%)d.b									
Physical properties	**10**	**14**	**18**	**22**	**26**	**10**	**14**	**18**	**22**	**26**
Bulk density (kg/m^3)	1167.2	1157.8	1115.6	1093.9	1045.3	1145.3	1136.1	1072.2	1065.0	1035.8
Solid density (kg/m^3)	1733.6	1676.8	1592.3	1536.5	1322.4	1666.2	1606.5	1477.0	1340.0	1169.3
Porosity (%)	32.7	31.1	29.9	28.8	21.1	31.3	29.3	27.4	20.5	11.4
1000 grain mass (kg)	0.593	0.644	0.827	1.364	1.665	0.594	0.627	0.771	0.997	1.299
Specific gravity	1.734	1.677	1.592	1.536	1.324	1.666	1.606	1.479	1.340	1.169
Angle of repose (^{o})										
Mild steel	30.8	31.3	31.7	33.9	36.3	31.7	32.3	32.6	35.1	36.6
Wood	32.5	32.7	33.8	35.2	37.5	31.7	32.5	34.3	36.0	38.1
Glass	27.6	28.1	29.1	30.3	31.2	28.4	28.7	29.6	30.6	33.4
Angle of friction (^{o})										
Mild steel	35.4	36.8	38.8	44.2	47.8	35.8	37.2	39.8	45.8	48.2
Wood	43.2	44.6	45.0	47.4	49.0	44.2	45.2	45.8	49.4	50.2
Glass	32.2	32.6	36.4	41.0	42.2	33.2	33.8	37.4	42.6	43.8
Grain size (mm)										
Length (a)	1.67	1.70	1.79	1.87	1.98	1.76	1.81	1.84	1.87	1.96
Width (b)	0.79	0.85	0.86	0.87	0.90	0.81	0.83	0.85	0.87	0.94
Thickness (c)	0.66	0.66	0.74	0.78	0.84	0.65	0.73	0.75	0.80	0.88
Geometric mean Dia. (mm)	0.9549	1.0133	1.0444	1.0826	1.1439	0.9749	1.0312	1.0546	1.0918	1.1748
Sphericity	0.806	0.849	0.860	0.879	0.912	0.808	0.846	0.861	0.886	0.947

Table 2. Mean effect of moisture content levels on some physical properties of *D. exilis* and *D. iburua.*

MC (%)d.b	Bulk density (kg/m^3)		Solid density (kg/m^3)		1000 grain mass (kg)		Specific gravity	
	D. exilis	*D. iburua*	*D. exilis*	*D. iburua*	*D. exilis*	*D. iburua*	*D. exilis*	*D. iburua*
10	1167.2[a]	1145.3[a]	1733.6[a]	1666.2[a]	0.593[a]	0.594[bc]	1.732[a]	1.666[a]
14	1157.8[a]	1136.1[a]	1676.8[ab]	1606.5[a]	0.644[ab]	0.627[bc]	1.677[ab]	1.606[ab]
18	1115.6	1072.2[b]	1592.3[bc]	1477.0	0.827[b]	0.771[ab]	1.592[abc]	1.479[bc]
22	1093.9	1065.0[b]	1536.5[c]	1340	1.364	0.997[a]	1.536[c]	1.340[c]
26	1045.3	1035.8	1322.4	1169.3	1.665	1.299	1.324	1.169

Means having the same letter in the same column are not statistically different from each other at P≤0.05 using DNMRT.

Table 3. Mean effect of moisture content levels on angle of repose and friction on *D. exilis* and *D. iburua* as affected by material surfaces.

MC (%)d.b	Angle of repose (°)						Angle of friction (°)			
	Wood		Glass		Mild steel		Wood		Glass	
	D. exilis	*D. iburua*	*D. exilis*	*D. iburua*	*D. exilis*	*D. iburua*	*D. exilis*	*D. iburua*	*D. exilis*	*D. iburua*
10	32.52^{c}	31.72^{a}	27.6^{d}	28.46^{b}	30.8^{c}	31.7^{c}	43.2^{a}	44.2^{a}	32.2^{b}	33.2^{b}
14	32.72^{bc}	32.5^{a}	28.52^{cd}	28.62^{b}	31.3^{bc}	32.3^{c}	44.6^{a}	45.2^{a}	32.6^{b}	33.8^{b}
18	33.82^{ab}	34.34	28.96^{bc}	29.6^{ab}	31.7^{bc}	32.6^{c}	45^{b}	45.4^{ab}	36	36.8
22	35.16^{a}	36.04	30.26^{ab}	30.62^{a}	33.9^{ab}	35.1^{a}	47.4^{b}	47.4^{b}	41^{a}	42.6^{a}
26	37.48	38.12	31.18^{a}	33.4	36.3^{a}	36.6^{a}	49	50.2	42.2^{a}	43.8^{a}

Means having the same letter in the same column are not statistically different from each other at P≤0.05 using DNMRT.

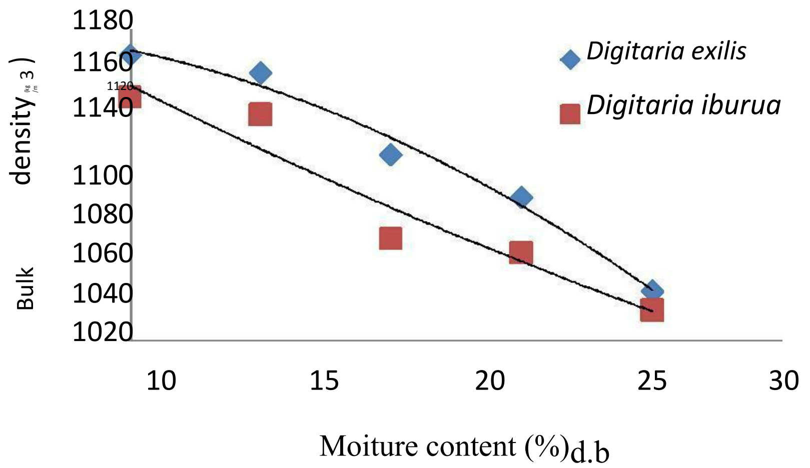

Figure 1. Effect of moisture content on bulk density of acha variety

density and solid density of the seed. The same trend was reported by Bamgboye and Adejumo (2009) for Roselle seed and Joshi et al. (1993) for Pumkin seed. The values calculated are useful in packaging as well as air and heat (fluids) properties. 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 seeds, invariably reducing the porosity of the grain bulk.

$$\varepsilon_{ex} = -0.054MC^2 + 1.307MC + 24.42 \quad (R^2 = 0.932) \quad (14)$$

$$\varepsilon_{ib} = -0.085MC^2 + 1.870MC + 20.82 \quad (R^2 = 0.994) \quad (15)$$

The effect of moisture content and variety on acha 1000 grain mass is shown in Figure 4. Table 1 Table 1 shows that the average 1000 grain mass increase as moisture content increased from 10 to 26% level was 0.593 to 1.665 g for *D. exilis* and

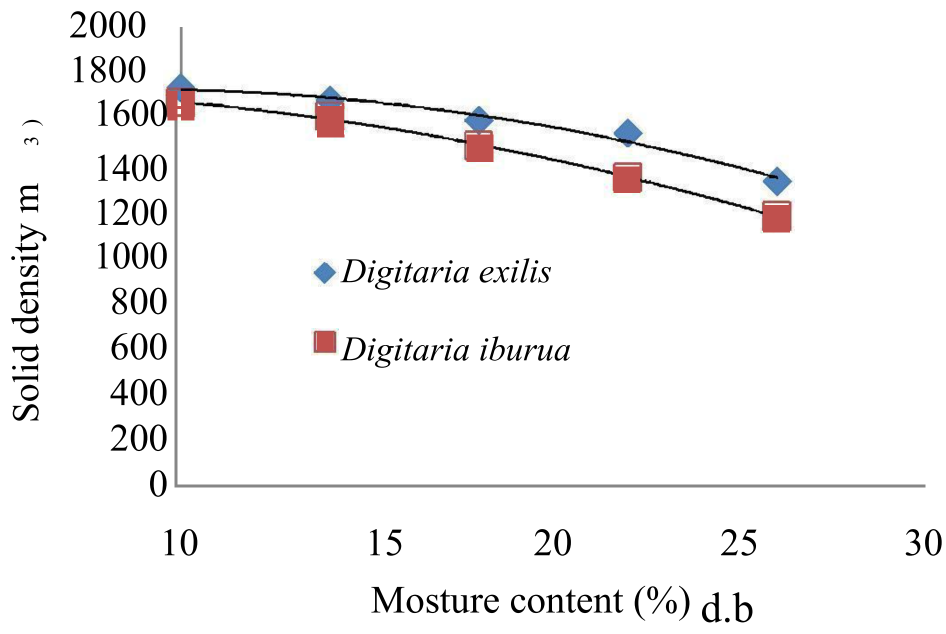

Figure 2. Effect of moisture content on solid density of acha variety.

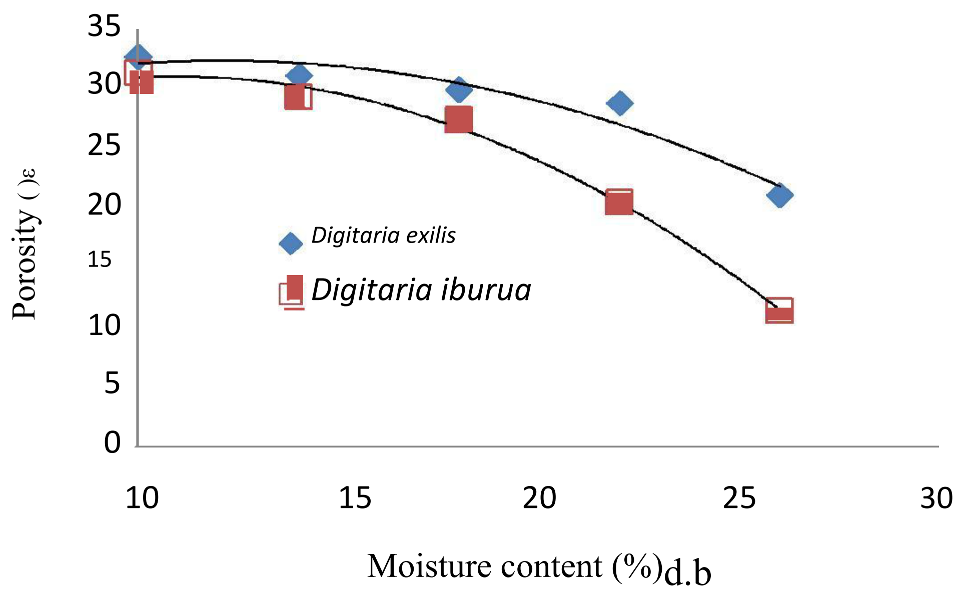

Figure 3. Effect of moisture content on porosity (%) of acha variety.

0.594 to 1.299 g for *D. iburua*. The relationship between moisture content and the 1000 grain mass for *D. exilis* and *D. iburua* was found to be linear and represented by Equations 16 and 17, respectively. The value obtained from 1000 grain mass is useful in the design of hopper, handling and storage facilities.

$$M_{ex} = 0.071MC - 0.270 \ (R^2 = 0.916) \quad (16)$$

$$M_{ib} = 0.044MC + 0.056 \ (R^2 = 0.919) \quad (17)$$

The value of specific gravity of acha variety was found to decrease from 1.734 to 1.324 for *D. exilis* and from 1.666 to 1.169 for *D. iburua*. The effects of moisture content on the two varieties of acha are shown in Figure 5. Linear relationship established by Equations 18 and 19 exists between *D. exilis* and *D. iburua,* respectively as moisture content increased.

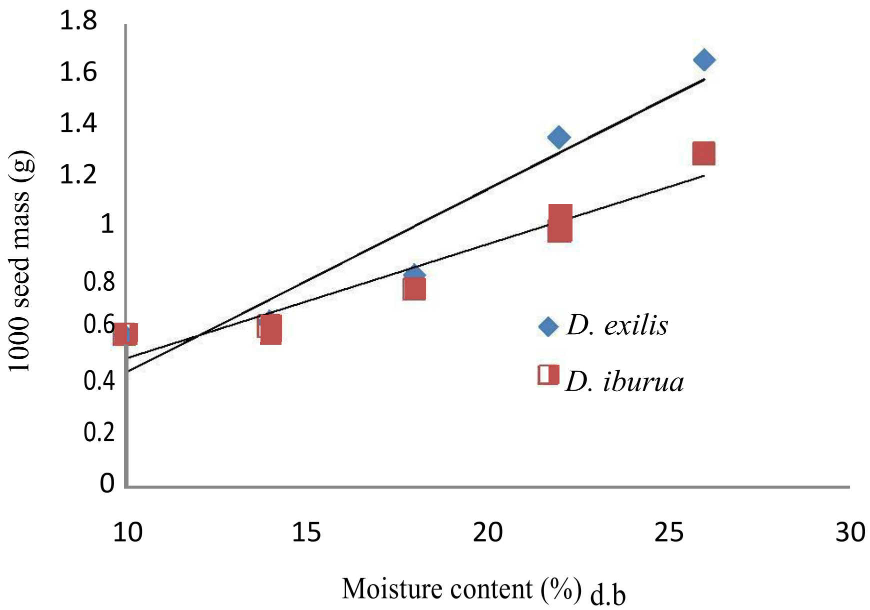

Figure 4. Effect of moisture content on 1000 seed mass of acha variety.

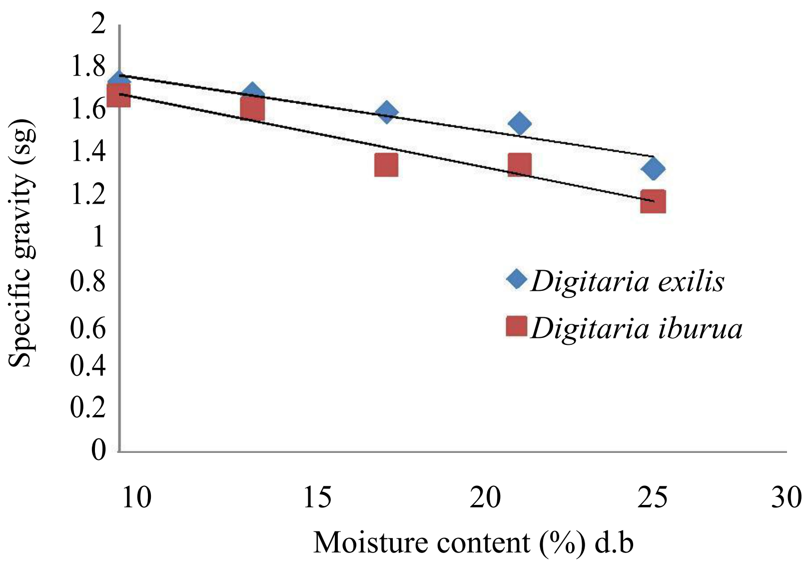

Figure 5. Effect of moisture content on specific gravity of acha variety.

$$Gsp_{ex} = -0.024MC + 2.005\ (R^2 = 0.919) \quad (19)$$

$$Gsp_{ib} = -0.031MC + 1.991\ (R^2 = 0.929)$$

The average angle of repose for *D. exilis* and *D. iburua* using mild steel, wood and glass surfaces increased from 30.8 to 36.3° and 31.7 to 36.6 on mild steel, 32.5 to 37.5 and 31.7 to 38.1 on wood and from 27.6 to 31.2 and 28.4 to 33.4° on glass surface for the two varieties, respectively. Wood gave the highest values of angle of repose this may be due to the rough surface of wood. As moisture content was increased from 10 to 26%, angles of repose also increased for both varieties of acha. The linear relationship between angles of repose and moisture content for the surfaces (mild steel, wood and glass) considered for *D. exilis* and *D. iburua* are given by Equations 20 to 25, respectively. The trends in Figures 6 and 7 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,

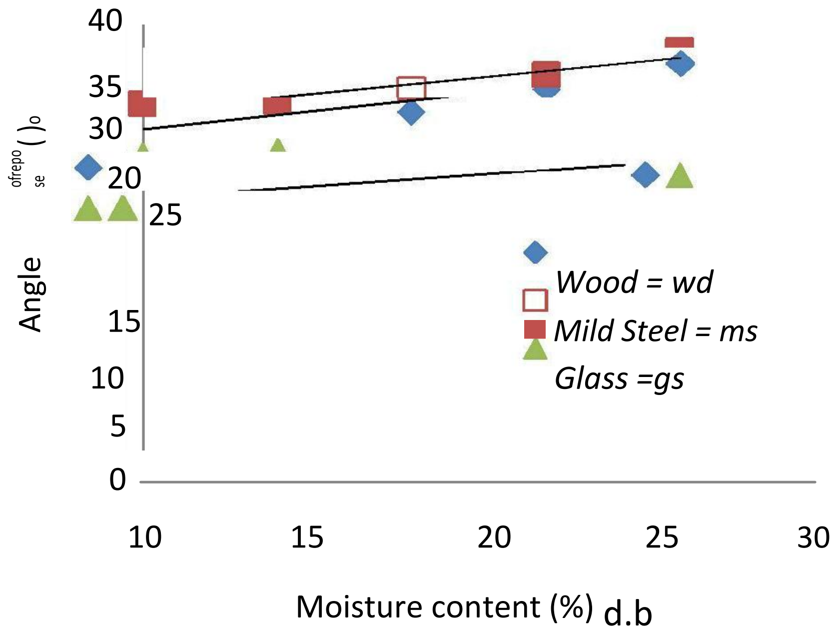

Figure 6. Effect of moisture content on angle of repose (^{o}) of *D. exilis* on different surfaces.

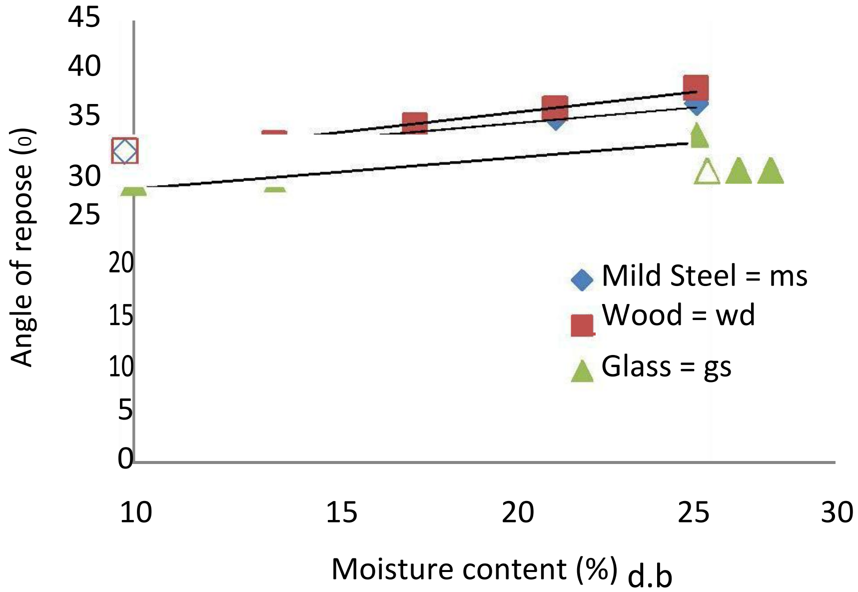

Figure 7. Effect of moisture content on angle of repose (^{o}) of *D. iburua* on different surfaces.

respectively. Information obtained from the angle of repose is used in the design of hopper and conveyors in handling and processing industries.

$$\theta ex._{ms} = 0.312MC + 28.71 \ (R^2 = 0.914) \quad (20)$$

$$\theta ex._{wd} = 0.34MC + 26.68 \ (R^2 = 0.884) \quad (21)$$

$$\theta ex._{gs} = 0.235MC + 25.03 \ (R^2 = 0.984) \quad (22)$$

$$\theta ib._{ms} = 0.315MC + 27.99 \ (R^2 = 0.905) \quad (23)$$

$$\theta ib._{wd} = 0.407MC + 27.18 \ (R^2 = 0.980) \quad (24)$$

$$\theta ib._{gs} = 0.297MC + 24.78 \ (R^2 = 0.872) \quad (25)$$

With increasing moisture content, the angles of friction increased on all surfaces for *D. exilis* and *D. iburua* (Figures 8 and 9), respectively. The highest values were

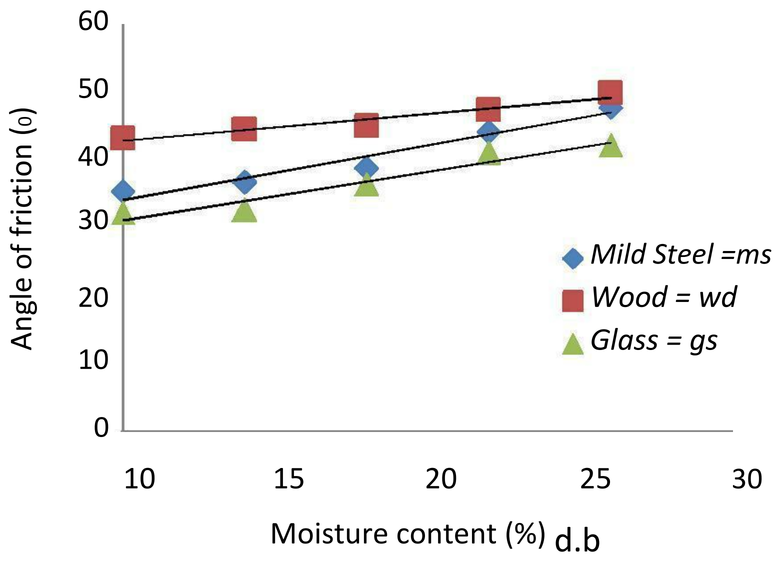

Figure 8. Effect of moisture content on angle of friction (^{o}) of *D. exilis* on different surfaces.

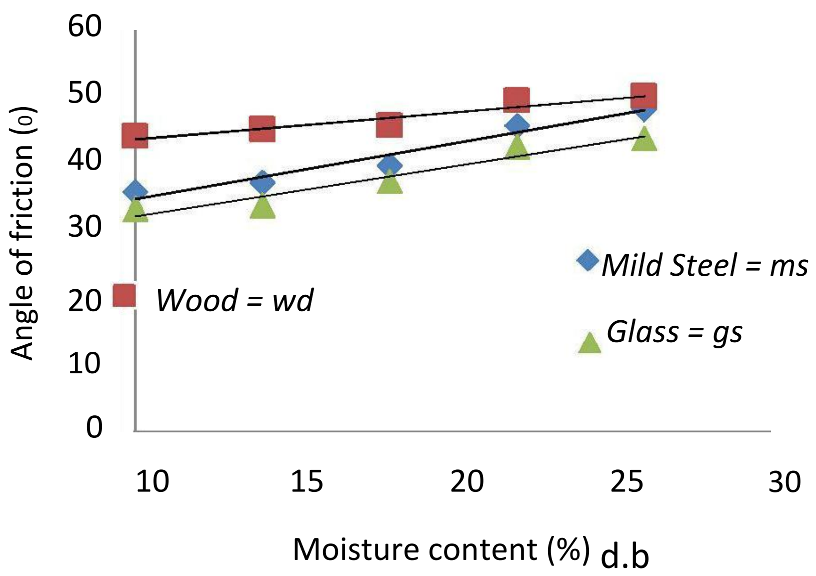

Figure 9. Effect of moisture content on angle of friction (^{o}) of *D. iburua* on different surfaces.

obtained at 26% moisture content on wood surface for the two varieties at 49.9^o and 50.2^o for *D. exilis* and *D. iburua,* respectively. At all moisture contents, the least angle of friction was found at 10% moisture content on glass at 32.2^o and 33.2^o for *D. exilis* and *D. iburua*, respectively. The linear relationship between angles of repose and moisture content for the surfaces (mild steel, wood and glass) considered for *D. exilis* and *D. iburua* are given by Equations 26 to 31, respectively. The information on the angle of friction provided will help in design calculations in the analysis of friction on acha seed over different surfaces during processing or handling operations.

$$\mu ex._{ms} = 0.805MC + 26.11\ (R^2 = 0.946) \quad (26)$$

$$\mu ex._{wd} = 0.405MC + 38.73\ (R^2 = 0.938) \quad (27)$$

$$\mu ex._{gs} = 0.71MC + 24.1\ (R^2 = 0.940) \quad (28)$$

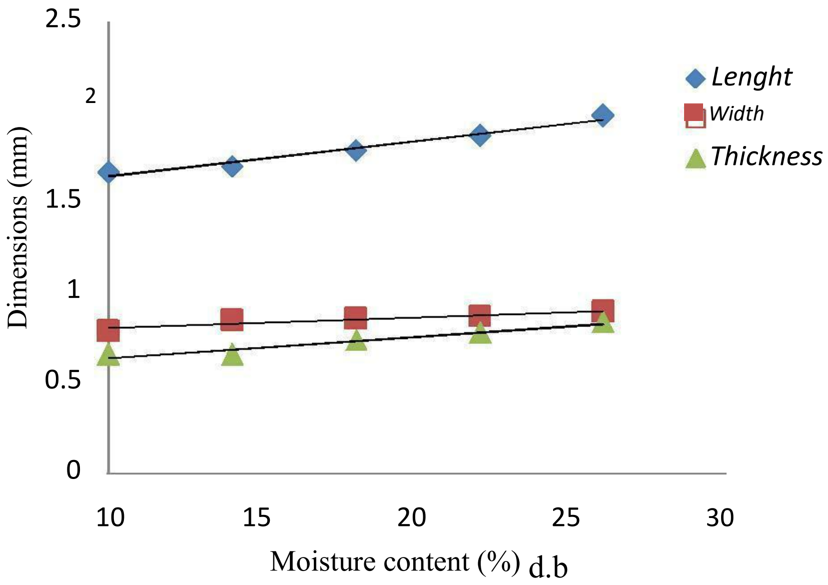

Figure 10. Effect of moisture content on axial dimension of *Digitaria exilis.*

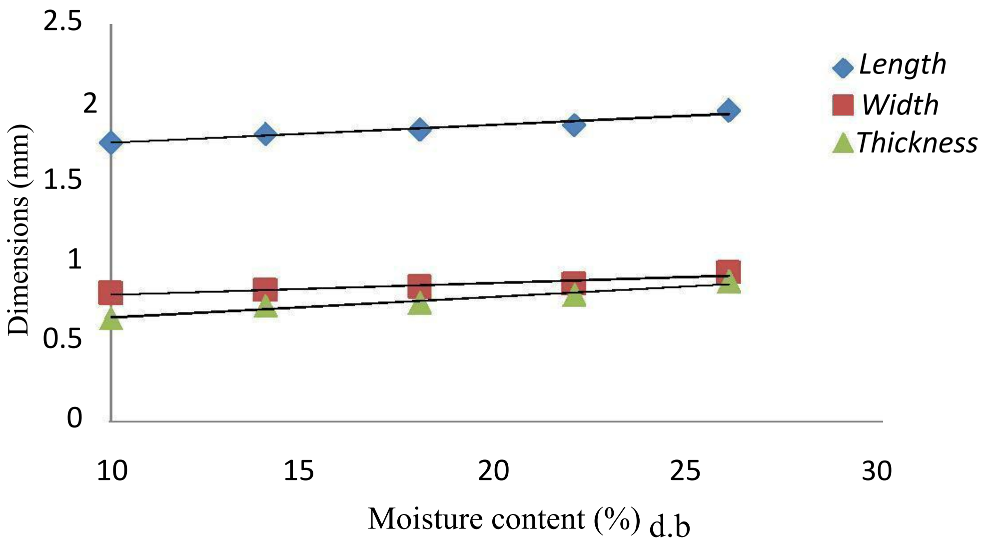

Figure 11. Effect of moisture content on axial dimension of *Digitaria iburua.*

$$\mu_{ib.wd} = 0.405MC + 39.67\ (R^2 = 0.920) \quad (29)$$

$$\mu_{ib.ms} = 0.835MC + 26.33\ (R^2 = 0.952) \quad (30)$$

$$\mu_{ib.gs} = 0.75MC + 24.66\ (R^2 = 0.940) \quad (31)$$

Figures 10 and 11 are the effect of moisture content on axial dimensions of *D. exilis* and *D. iburua,* respectively.

The length, width and thickness increased from 1.67 to 1.98 mm and 1.76 to 1.96 mm for length, 0.79 to 0.90 mm and 0.81 to 0.94 mm for width and from 0.66 to 0.84 mm and 0.65 to 0.88 mm for thickness as the moisture was increased from 10 to 26% for *D. exilis* and *D. iburua,* respectively. The linear relationship between axial dimensions (length, width and thickness) and moisture content for *D. exilis* and *D. iburua* are given by Equations 32 to 37, respectively.

$$L_{ex} = 0.019MC + 1.446\ (R^2 = 0.970) \quad (32)$$

$$W_{ex} = 0.006MC + 0.746\ (R^2 = 0.883) \quad (33)$$

$$T_{ex} = 0.012MC + 0.52\ (R^2 = 0.947) \quad (34)$$

$$L_{ib} = 0.011MC + 1.641\ (R^2 = 0.949) \quad (35)$$

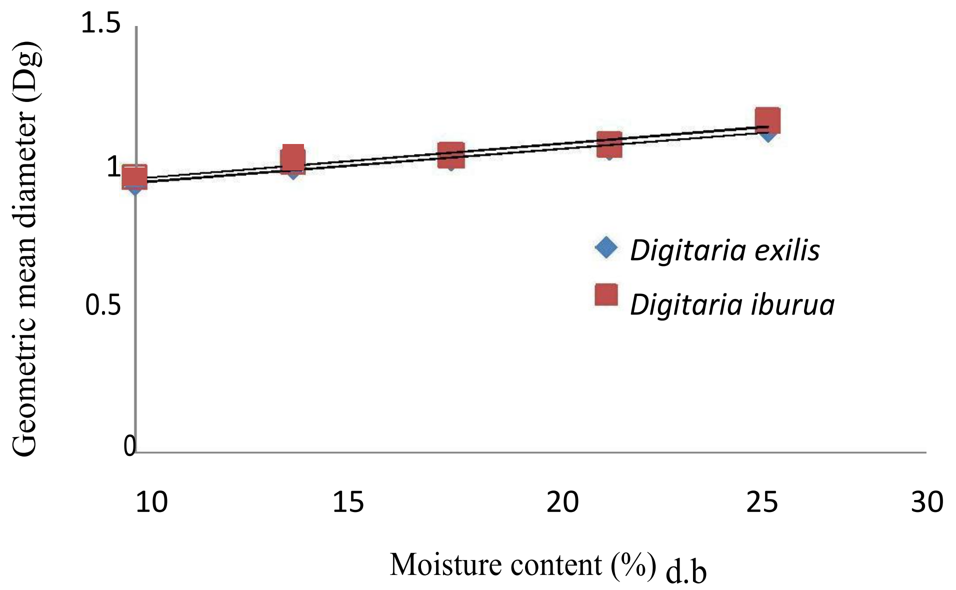

Figure 12. Effect of moisture content on geometric mean diameter.

$$W_{ib} = 0.007MC + 0.725\ (R^2 = 0.9) \quad (36)$$

$$T_{ib} = 0.013MC + 0.523\ (R^2 = 0.966) \quad (37)$$

The mean values of geometric mean diameter were found to be 0.955 to 1.144 mm for *D. exilis* and 0.975 to 1.175 mm for *D. iburua* as moisture content was increased (Figure 12). The linear relationships that exist between the geometric mean diameter with moisture content for *D. exilis* and *D. iburua* are given by Equations 38 and 39, respectively. The increase in dimension of various seeds were also reported by Sahoo and Srivastava (2002) for okra seed, Abalone et al. (2004) for Amaranth seed and Ndirika and Oyeleke (2006) for millet as moisture content increased.

$$Dg_{ex} = 0.011MC + 0.846\ (R^2 = 0.986) \quad (38)$$

$$Dg_{ib} = 0.011MC + 0.858\ (R^2 = 0.957) \quad (39)$$

As moisture content was increased, the sphericity also increased from 0.806 to 0.912 and from 0.808 to 0.947 for *D. exilis* and *D. iburua,* respectively. Figure 13 shows the graph of the linear relationship between the varieties and moisture content levels with a high positive correlation for both varieties. The relationships between sphericity and moisture content are given by Eqns. 40 and 41 for *D. exilis* and *D. iburua* respectively. A linear increase in sphericity as the moisture content was increased was reported by Deshpande et al. (1993) for soya bean, and Sahoo and Srivastava, (2002) for okra seed. Sphericity values are used in the design of hopper, conveyors and storage structures.

$$\phi_{ex} = 0.006MC + 0.752\ (R^2 = 0.960) \quad (40)$$

$$\phi_{ib} = 0.008MC + 0.726\ (R^2 = 0.947) \quad (41)$$

Conclusions

The moisture-dependence of some physical properties of *D. exilis* and *D. iburua* seeds in the moisture range of 10 to 26% was determined. The physical properties of the two acha varieties were affected by the various moisture content levels of 10, 14, 18, 22 and 26%. The bulk density (kg/m^3), solid density (kg/m^3), porosity (%) and specific gravity decreased with increase in moisture content. *D. exilis* gave the highest mean values of bulk density, solid density, porosity and specific gravity of 1167.2 kg/m^3, 1733.6 kg/m^3, 32.7% and 1.734, respectively while the least values at 26% of 1035.8 kg/m^3, 1169.3 kg/m^3, 11.4% and 1.169, respectively were obtained from *D. iburua*.

The angles of repose and friction on mild steel, wood and glass surfaces increased with increase in moisture content for both varieties of acha. Wood gave the highest value for angle of repose of 38.1° at 26% moisture content for *D. iburua* while glass surface gave the least angle of repose of 27.6° at 10% moisture content for *D. exilis*. Geometric mean diameter, axial dimensions (length, width and thickness), 1000 grain mass and sphericity of both varieties increased with increase in moisture content for both acha varieties studied.

Results from this research work will provide useful information to engineers, food scientists and other scientists involved in handling, processing (such as transportation, drying, threshing, cleaning, aeration, grading) and design of post–harvest machines for acha and other related cereal grains.

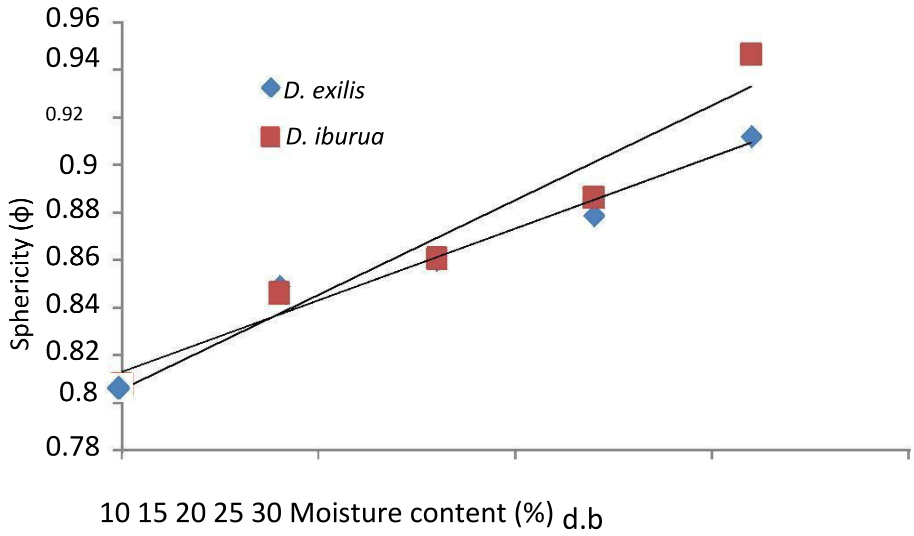

Figure 13. Effect of moisture content and variety on acha sphericity.

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