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ORIGINAL RESEARCH ARTICLE

PHYSICAL PROPERTIES OF FOUR VARIETIES OF SORGHUM (Sorghum bicolor L. Moench) GRAIN AT DIFFERENT MOISTURE CONTENTS

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ABSTRACT

This study was undertaken to determine the physical properties of four varieties of sorghum grain and investigate their variation with moisture content. The properties studied include: axial dimensions, arithmetic mean and geometric mean diameters, one thousand grain weight, particle density, bulk density, porosity and angle of repose. Each property was investigated at four moisture levels in the range of 3.5-18.25% d.b (brown variety), 3.04-25.49% d.b (red variety), 3.5-20% d.b (reddish brown variety) and 3.4-25.49% d.b (white variety). The major, intermediate and minor dimensions all increased with increase in moisture content from 4.25-5.04mm, 4.10-4.76mm and 2.80-2.99mm for brown, 3.78-4.32mm, 2.96-3.43mm and 1.95-2.85mm for red, 4.25-5.21mm, 4.11-4.99mm, 3.61-3.77mm for reddish brown, 4.0-5.38mm, 3.20-4.99mm and 3.00-3.48mm for white variety. The arithmetic mean diameter had higher values for the four varieties than the geometric mean diameter. One thousand grain weight, bulk density, true density, porosity, and angle of repose of all the varieties of sorghum studied, increased linearly with increase in moisture content. Regression models with high coefficients of determination were used to express the relationship existing between the physical properties of the grains with moisture content.

1.0 Introduction

Sorghum *(Sorghum bicolor L.* Moench*)* also known as great millet Jurra, Jowani or Mib, is a grass species cultivated for its grain, which is used for food by humans and animals and for bioethanol production. Sorghum originated in Northern Africa and is cultivated widely in the tropical and sub-tropical regions. It is one of the world's most important cereals which could be processed into flour and used for making diverse food products such as pap, food, and porridge as well as livestock feed (Adinoyi *et al.,* 2017). The grain is known for its good source of protein and dietary energy (Belton and Taylor, 2004). Sorghum is also used in industries for the production of biscuits, beverages and pharmaceutical syrups (Adinoyi *et al.,* 2017). In developed countries of the world, particularly the United States, Ndirika and Mohammed (2005) reported that sorghum is grown mainly as feed crops for the production of starch, crystalline sugar and paper adhesive.

Sorghum can take many shapes and sizes from a tight-headed, wind panicle to an open, droopy panicle that can be short or tall. There are different varieties of sorghum available, and these include red, orange, bronze, tan, white, and black colored sorghum. Red, orange, or bronze sorghum is traditionally grown and is used in all segments of the sorghum industry. Tan cream and white colored sorghum varieties are typically made into flour for the food industry, while black and burgundy varieties contain beneficial antioxidant properties and are utilized in other food applications. In Nigeria the main varieties of sorghum are white, red, brown, and reddish brown (Figure 1) and there is a variety called "*masakwa*" which is grown in Southern part of Borno (between Gwoza and Bama Local Government Areas).

White variety | Brown variety

Red variety | Reddish Brown variety

Figure 1: Matured sorghum grains of different varieties

In order to develop equipment for the mechanisation of the handling and processing of sorghum gains, the engineering properties that include physical and thermal properties are needed. These properties determine not only the conveying characteristics of solid materials, but also the heating loads of food materials (Baryeh 2002, Poomsa-ad *et al.,* 2014).

Many researchers have reported that moisture content has marked effect on the engineering properties of grains, seeds, and kernels. These include Verma and Prasad (2000) on mechanical and thermal properties of maize, Aviara and Haque (2001) on moisture dependence of thermal properties of sheanut kernel, Poomsa-ad *et al.* (2014) on physical and aerodynamic properties of sorghum, Kara *et al.* (2012) on thermal properties of red lentil seeds, Aviara *et al.* (2008) on thermal properties of guna seeds, and Tang *et al.* (1991) on specific heat capacity of lentil seeds. Simonyan *et al*. (2007) determined the physical properties of Samaru sorghum 17 grains within the moisture range of 8.89-16.5% (wb), Kenghe *et al*. (2015) studied the physical properties of a new variety of sorghum (cv. Phule Suchitra) grown in India, as a function of moisture content in the moisture rage of 10.94-2.22% (db), while Masane *et al*. (2016) investigated the effect of moisture content on the physical properties of tender sorghum grains in the moisture rage of 68.5-73.5% (db). In some other studies, Shashikumar *et al.* (2018) and Surpam *et al*. (2019) determined some physical and engineering properties of sorghum grain at the moisture content of 11.69% (wb) and 9.15%, respectively, while Sabar *et al*. (2020) investigated the moisture dependence of physical and engineering properties of a sorghum variety grown in India, in the moisture range of 10-21.8% (wb). From literature, it can be seen that little information appears to be available on the effect of moisture content on the physical properties of sorghum grain varieties grown in Nigeria. Therefore, the objective of this study was to investigate the moisture dependence of the physical properties (size, one thousand grain mass, bulk density, particle density, porosity, and angle of repose) of four sorghum varieties grown in Nigeria.

2. Materials and Methods

Bulk quantities of different varieties in terms of color of sorghum (brown, white, red and reddish brown) used in this study were obtained from of the Monday market, Maiduguri, Borno State, Nigeria. The grains were first cleaned to remove foreign matters, broken, and immature grains. Samples at different moisture contents were obtained in moisture range of 3-26% (db) using the method of addition of calculated amount of water (Aviara et al., 1999). The samples were kept in air tight polythene bags and stored in a cold environment. One hundred seeds were randomly selected at each moisture level for the measurement of the length, width and thickness using a micrometer screw gauge of 0.01mm accuracy. The arithmetic mean diameter was determined by applying Equation (1) as given by Mohsenin (1986). Twenty (20) seeds were used for the determining of this parameter. The average value at each moisture level was recorded and used in analysis.

$$\mathrm{AMD} = \frac{a+b+c}{3} \quad (1)$$

where a = major diameter, mm; b = intermediate diameter, mm and c = minor diameter, mm

The geometric mean diameter (GDM) was calculated using the expression given by Mohsenin (1986) as follows:

$$GDM = (LWT)^{1/3} \quad (2)$$

where L is length (mm), W is width (mm) and T is thickness (mm) of the grain. According to Baryeh (2002), the grain sphericity, ∅ can be determined as follows:

$$\emptyset = \frac{(LWT)^{1/3}}{L} \quad (3)$$

One thousand grain weight was determined using a digital electronic weighing balance of 0.001g reading accuracy. This involved random counting of 3 sets of 100 seeds from each variety and placing same on the weighing balance. The average was multiplied by 10 to obtain the required 1000 grain weight. The porosity, ε, of the four varieties of sorghum was determined using the formulae (Mohsenin, 1986).

$$\varepsilon = (1 - \rho b/\rho t) \times 100 \quad (4)$$

where: ρb and ρt are bulk and true density (g/cm^3) respectively. The angle of repose was determined according to Mohsenin (1986). The value is expressed by the equation:

$$\theta = tan^{-1}(2H/D) \quad (5)$$

where: H is the height from base to peak (mm) and D is the diameter of the base (mm). Angle of repose was determined at different moisture contents using the method of specially constructed wooden box with removeable front panel (Dutta *et al*., 1988). Each measurement was carried out five times at specific moisture content and the average value was reported.

3. Results and Discussion

The initial moisture content of grain sorghum for brown, red, reddish brown and white varieties was found to be 3.5, 3.04, 3.5 and 3.41% (db), respectively. The moisture contents obtained after conditioning the grains were 13.55, 16.5 and 18.65 %(db) for brown, 11.65, 16.8 and 25.13%(db) for red, 14.21, 15.76, 16.28% and 20% (db) for reddish brown and 12.56, 16.17, and 25.49%(db) for white variety, respectively. The investigations were carried out at the above moisture levels to determine the effect of moisture content on the physical properties of the four varieties of sorghum grains.

The dimensions of sorghum grains measured at different moisture levels for the four varieties are presented in Table 1. The Table shows that the axial dimensions were variety dependent and that they increased with increase in moisture content in the range of 3.5 – 18.65% (db) for brown, 3.04 -25.12% (db) red, 3.5 – 20% (db) for reddish brown and 3.41 – 25.49% (db) for white, variety, respectively. The major axis increased from 4.25 to 5.04mm, 3.78 to 4.32mm, 4.25 to 5.21mm and 4.00 to 5.38mm for brown, red, reddish brown, and white sorghum, respectively. The corresponding intermediate axis increased from 4.10 to 4.76, 2. 96 to 3.43, 4.11 to 4.99 and 3.20 to 4.49mm respectively, while minor axis increased from 2.80 to 2.99, 1.95 to 2.85, 3.61 to 3.77 and 3.00 to 3.48mm, respectively.

The arithmetic mean and geometric mean diameters of the four varieties of sorghum grain at different moisture contents are also presented in Table 1. The Table shows increase in arithmetic and geometric mean diameters with increase in moisture content. The arithmetic mean diameter however, had higher values than geometric mean diameter of the grains at a specified moisture level. The increase in axial dimensions of the grains indicated that upon moisture absorption, the grains expanded in length, width and thickness thereby increasing the average dimensions. These could be of important consideration in the determination of seed volume and size of the chute through which the grains could be discharged at different moisture levels. Similar results of increase have been reported by Tavakkoli *et al.* (2009) for soybean grains. Also, this is in line with the findings of Sobukola *et al.* (2013) on maize grains. The results of the axial dimension can be used in designing of machines for mechanical separation and grading of sorghum grain.

The variation of one thousand grain weight of the sorghum varieties with moisture content is presented in Figure 1. The Figure shows that one thousand grain weight is variety dependent. It increased from 35.05 – 42.85g, 25.8 – 29.00g, 35.00 – 40.11g and 35.6 – 43.5g respectively, in the moisture ranges of 3.5 – 18.65% (db), 3.04 – 25.12% (db), 3.5 – 20% (db) and 3.41 – 25.49% (db) respectively, for brown, red, reddish brown and white sorghum varieties. The positive trend of one thousand seed weight with moisture content may have been due to increase in weight gained at higher moisture contents.

The relationship between moisture content and mass of the one thousand grains of the four varieties of sorghum was found to be linear, and can be expressed with the following equations

$$W_b = 0.3085M + 36.816,\ R^2 = 0.974 \quad (6)$$
$$W_r = 0.1506M + 25.124,\ R^2 = 0.942 \quad (7)$$
$$W_{rb} = 0.4091M + 33.195,\ R^2 = 0.931 \quad (8)$$
$$W_w = 0.4015M + 34.966,\ R^2 = 0.951 \quad (9)$$

where: W is one thousand seed weight of the four sorghum varieties (g), M is the moisture content, R^2 is coefficient of determination and subscripts b, r, rb and w represent brown, red, reddish brown, and white varieties, respectively.

Similar trend was reported by Irtwange and Igbeka (2002) for African yam bean, Kaleemullah and Gunasekar (2002) for a sheanut, Aviara *et al.* (2005) for sheanut, Isik (2007) for round red lentil grain and Simonyan *et al.* (2007) for Samaru sorghum. Brown and white varieties had the highest values of one thousand grain weight, while the red variety has the lowest values. The one thousand seed weight can be used to estimate the overall bulk weight and equivalent sphere effective diameter of sorghum grains necessary in the design of the handling equipment.

Table 1: Seed size of different varieties of sorghum grain at several moisture contents

AXIAL DIMENSION	MOISTURE CONTENT (%) db			
(a) Brown variety	3.5	13.55	16.5	18.65
Major axis (mm)	4.25	4.85	4.87	5.04
Intermediate axis (mm)	4.10	4.45	4.49	5.04
Minor axis (mm)	2.80	2.98	2.79	2.99
Arithmetic mean diameter mm	3.72	4.09	4.18	4.26
Geometric mean diameter	3.65	4.00	3.91	4.15
Aspect ratio (b/a)	0.97	0.91	0.92	0.94
(b) Red variety	3.04	11.65	16.8	25.12
Major axis (mm)	3.87	3.78	4.23	4.32
Intermediate axis (mm)	2.96	2.96	3.41	3.43
Minor axis (mm)	1.95	1.95	2.52	2.85
Arithmetic mean diameter mm	2.89	2.89	3.38	3.53
Geometric mean diameter	2.79	2.79	3.31	3.48
Aspect ratio (b/a)	0.78	0.78	0.80	0.79
(c) Reddish brown variety	3.5	14.21	15.6	16.28
Major axis (mm)	4.25	5.05	5.10	5.21
Intermediate axis (mm)	4.11	4.74	4.82	4.99
Minor axis (mm)	3.61	3.25	3.38	3.77
Arithmetic mean diameter mm	3.99	4.34	4.43	4.65
Geometric mean diameter	3.98	4.28	4.36	4.61
Aspect ratio (b/a)	0.96	0.93	0.94	0.95
(d) White variety	3.41	12.56	16.17	25.49
Major axis (mm)	4.00	4.75	5.27	5.38
Intermediate axis (mm)	3.20	3.99	4.97	4.49
Minor axis (mm)	3.00	3.55	3.31	3.48
Arithmetic mean diameter mm	3.4	4.09	4.51	4.45
Geometric mean diameter	3.37	4.06	4.42	4.38
Aspect ratio (b/a)	0.8	0.84	0.94	0.83

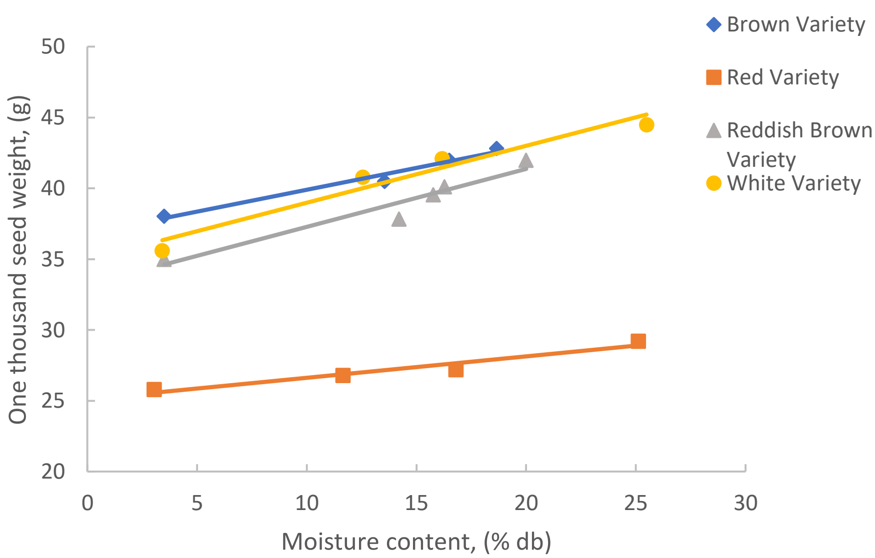

Figure 1: One thousand-grain weight of sorghum varieties at different moisture contents

The effect of moisture content on bulk density of the four varieties of sorghum is shown in Figure 2. The bulk density of the grains was found to increase with increase in moisture content. This increase in bulk density of the seeds may have resulted from increased in mass with moisture content. The relationship between bulk density of the various varieties of sorghum and moisture content was found to be linear and can be represented by the following equations.

$\rho_{bb} = 0.6882M + 697.47, \quad R^2 = 0.997$ (10)

$\rho_{br} = 0.4299M + 751.22, \quad R^2 = 0.964$ (11)

$\rho_{brb} = 0.8028M + 712.44, \quad R^2 = 0.935$ (12)

$\rho_{bw} = 0.3315M + 737, \quad R^2 = 0.994$ (13)

where ρ_b is the bulk density of sorghum, (kg/m^3).

Bulk density was found to be variety dependent with the highest values obtained on the red variety, while the lowest values were from the brown variety.

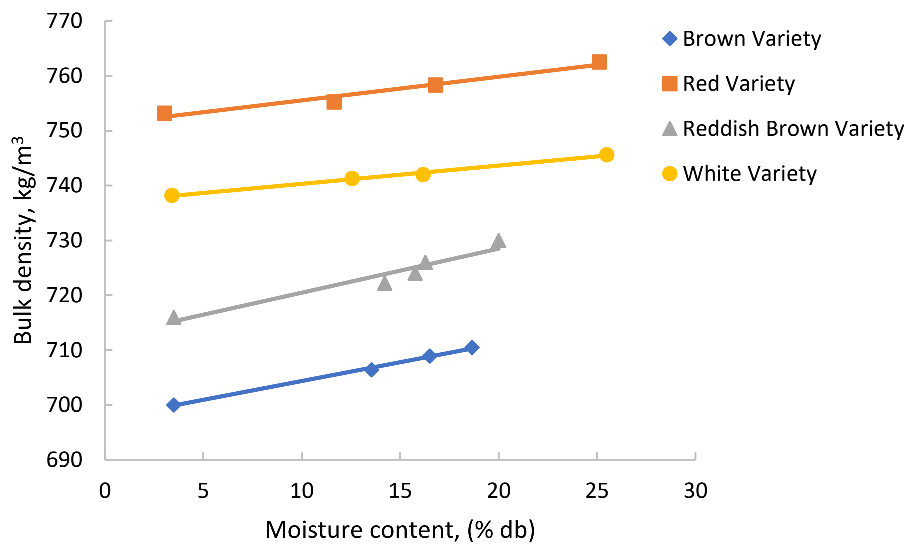

Figure 2: Variation of bulk density of sorghum varieties with moisture content

The true density of the sorghum varieties increased linearly with increased in moisture content as can be seen in Figure 3. The relationship between the true density and moisture content of the grain was found to be represented by the following equations.

$\rho_{tb} = 4.0255M + 909.22, \quad R^2 = 0.982$ (14)

$\rho_{tr} = 1.2108M + 867.68, \quad R^2 = 0.996$ (15)

$\rho_{trb} = 2.7066M + 906.24, \quad R^2 = 0.990$ (16)

$\rho_{tw} = 1.7919M + 882.68, \quad R^2 = 0.944$ (17)

where ρ_t is the true density of sorghum, (kg/m^3).

A similar trend with moisture content has been reported for the particle density of cumin seed by Singh and Goswami (1996) and for sheanut by Aviara *et al.* (2005). True density was also found to be variety dependent. The brown variety had the highest values, while the red variety had the lowest.

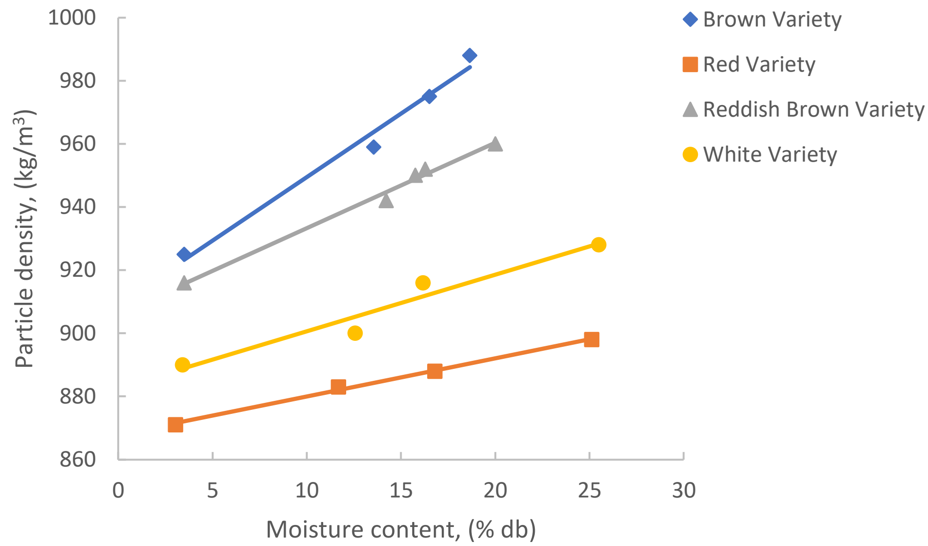

Figure 3: True density of sorghum varieties at different moisture contents

The porosity calculated from relevant experimental data on true density and bulk density for each variety of sorghum was found to increase with increase in moisture content as shown in Figure 4. In the moisture range of 3.5 – 18.65% (db) for brown, 3.04 – 25.12% (db) red, 3.5 – 20% (db) reddish brown and 3.41 – 25.49% (db) for white grains, the porosity increased from 24.29-28.10%, 13.52-17.67%, 21.78-25.12% and 15.55-19.95%, respectively. The relationships between porosity and moisture content for the four varieties of sorghum were expressed as shown in Equations (18) – (21).

$P_b = 0.252M + 23.37, \quad R^2 = 0.998$ (18)

$P_r = 0.1893M + 12.635, \quad R^2 = 0.9622$ (19)

$P_{rb} = 0.1897M + 22.898 \quad R^2 = 0.9097$ (20)

$P_w = 0.2086M + 14.534, \quad R^2 = 0.9190$ (21)

where P is the porosity of sorghum (%) and subscript denotes the variety

Similar trend of porosity with moisture content was reported by Carman (1996) for lentil seed and Aviara *et al.,* (1999) for guna seed. Porosity was also variety dependent. The varieties that had highest and lowest true densities also had the highest and lowest porosity, respectively.

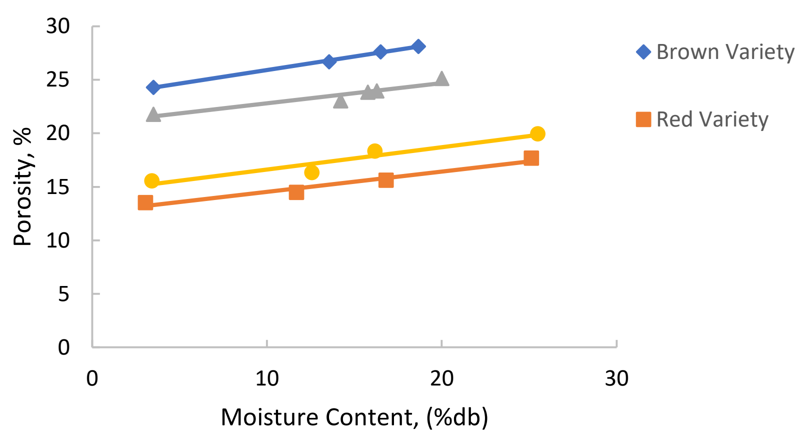

Figure 4: Porosity of sorghum varieties at different moisture contents

The angle of repose of four sorghum varieties determined at different moisture contents is presented in Figure 5. It was observed that the angle of repose increased as the moisture content increased for all the sorghum varieties considered in the study. The angle of repose ranged from 24.58-27.11° for brown, 25.6-28.15° for red, 23.12-29.41° for reddish brown and 22.5-26.4° for white variety. It was also observed that angle of repose was not variety dependent and that at higher moisture contents within the experimental range the grains tend to stick together resulting in lower flowability and increase in angle of repose. The relationship between angle of repose and moisture content of the four varieties was found to be linear and it can be represented with the following equations.

$$\theta_b = 0.1635\text{M} + 23.881, \quad R^2 = 0.8940 \tag{22}$$
$$\theta_r = 0.1137\text{M} + 25.212, \quad R^2 = 0.9913 \tag{23}$$
$$\theta_{rb} = 0.3697\text{M} + 21.711, \quad R^2 = 0.9921 \tag{24}$$
$$\theta_w = 0.1823\text{M} + 22.084, \quad R^2 = 0.9443 \tag{25}$$

where θ is angle of repose for sorghum varieties

The trend was found to be similar to the one reported by Dutta *et al.* (1988) on gram seed and Gupta and Das (1997) on other sorghum grains. The information obtained on angle of repose is used in the design of hopper and conveyors in the handling and processing industries.

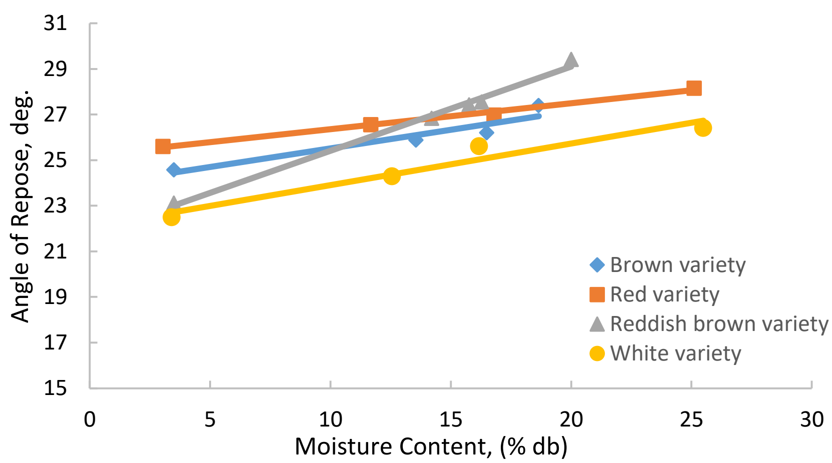

Figure 5: Angle of repose of sorghum varieties at different moisture contents

4. Conclusion

The investigation of physical properties of four sorghum varieties at four moisture levels revealed that in the moisture ranges of 3.5 – 18.65 %(db), 3.04 – 25.12%(db), 3.5 – 20%(db) and 3.41 25.49% (db) for the brown, red, reddish brown and white variety, respectively:

i) The major, intermediate and minor axial dimensions of the grains all increased with increased in moisture content from 4.25 – 5.04mm, 4.10 – 4.76mm and 2.80 – 2.99mm (brown), 3.78 – 4.32mm, 2.96 – 3.43mm and 1.95 – 2.85mm (red), 4.25 – 5.21mm, 4.11 – 4.99mm and 3.61 – 3.77mm (reddish brown) and 4.00 – 5.08mm, 3.20 – 4.49mm, 3.00 – 3.48mm (white), respectively. The arithmetic and geometric means diameter increased from 3.72 -4.26mm for brown, 2.89 – 3.5mm for red, 3.99 – 4.68mm for reddish brown and 3.4 – 4.45mm for white which the geometric means increased from 3.65 – 4.15mm for brown, 2.77 -3.84mm for red, 3.98 – 4.6mm for reddish brown and 3.37 – 4.38mm for white respectively.

ii) One thousand grain weight of sorghum grain increased from38.5 – 42.85g for brown, 25.8 – 29.22g for red, 35.00 - 40.11g for reddish brown and 35.6 – 43.5g white varieties.

iii) Bulk density of the grains increased with increased in moisture content from700.3 – 7103.5kgm^3, 753 – 758kgm^3, 718 – 728kgm^3 and 738.2 – 745.6kgm^3 respectively for brown, red, reddish brown and white.

iv) The true density increased with increase in moisture content from 925 – 988kgm^3 for brown, 871 -889kgm^3 for red, 918 – 934kgm^3 for reddish brown, and 890 – 899kgm^3 for white sorghum grains.

v) The porosity of the grains of sorghum investigated as a function of moisture content increased from 24.29- 28.10% for brown, 13.52 – 14.67% for red, 21.78 – 22.26% for reddish brown and 10.55 – 19.95% for white variety.

vi) The angle of repose increased linearly with increased in moisture content from24.8 – 27.11° for brown, 25.6 – 27.15° for red, 25.1 – 27.55° for reddish brown and 22.5 – 26.4° for white variety.

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