IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 12, Issue 6 Ser. I (June 2019), PP 73-86
www.iosrjournals.org

Effect of Moisture Content on the Physical Properties of Coffee Beans (Robusta)

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Abstract: *The effect of moisture content on the physical properties of robusta coffee beans was determined for moisture content levels of 6.0, 12.0, 18.0, 24.0 and 30.0 %(wb). For these moisture content levels, the length, width, thickness and geometric diameter increased linearly with increasing moisture content from 8.493mm to 10.223mm, 5.831mm to 7.163mm, 3.732mm to 4.715 and 5.696mm to 7.015mm for length, width, thickness and geometric mean respectively. Bean mass and 1000-bean mass increased linearly with increased moisture content from 0.1045grams to 0.1678 grams and 108.59 grams to 146.63 grams for bean and 1000-bean masses respectively. Both bulk and particle densities decreased with increasing moisture content of beans from 0.92* g/cm^3 *to 0.788* g/cm^3 *and from 1.187* g/cm^3 *to 0.960* g/cm^3 *for bulky and particle densities respectively. Porosity of the beans decreased with increasing moisture content from 33.61% to 21.92% whereas surface area of the beans increased with increase in moisture content of coffee beans. Sphericity was not significantly affected by changes in moisture content but angles of repose increased significantly with increase in moisture content from 29.8 to 45.44 degrees for filling angle of repose and from 24.00 to 40.54 degrees for emptying angle of repose. The co-efficient of static friction of coffee beans increased with increasing moisture content from 0.25 to 0.43, 0.21 to 0.37 and 0.12 to 0.34 for plywood, galvanized steel and rubber respectively. The effect of moisture content on the physical properties of the coffee beans like length, width, thickness, bean mass, 100-bean mass, 1000-bean mass, bulk density, surface area and co-efficient of static friction was significant (P<0.05) whereas the effect of moisture content on sphericity was not significant (P>0.05) as the change in sphericity with moisture content was very minimal.*

Key words; coffee beans, physical properties, moisture content, angle of repose, co-efficient of static friction

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Date of Submission: 22-05-2019 Date of acceptance: 08-06-2019

Nomenclatures

$\mathbf{M_c}$	Moisture content, %
$\mathbf{M_w}$	Mass of water to be added when rewetting, kg
$\mathbf{M_t}$	Final mass of sample to be dried, kg
$\boldsymbol{m_i}$	Initial moisture content of the sample, % w.b
$\boldsymbol{m_f}$	Final moisture content of the bean sample, % w.b
$\boldsymbol{M_i}$	Initial mass of the sample of to be rewetted, kg
L	Length of the bean, mm
W	Width of the bean, mm
T	Thickness of the seed, mm
$\boldsymbol{D_g}$	Geometric mean diameter, mm
$\boldsymbol{\phi}$	Sphericity
$\boldsymbol{\rho_b}$	Bulk density, kg/m3
$\boldsymbol{\rho_p}$	Particle density, kg /m3
$\boldsymbol{\theta_e}$	Emptying angle of repose, degrees
$\boldsymbol{\theta_f}$	Filling angle of repose, degrees
h	Height of conical bean heap in the filling angle of repose determination, mm
x	Horizontal distance of the bean heap
$\boldsymbol{\mu}$	Static coefficient of friction
$\boldsymbol{\theta}$	Angle of tilt in determination of static coefficient of friction, degrees
$\mathbf{R^2}$	Coefficient of determination
S	Surface area of the bean, mm^2
$\boldsymbol{\mu_{steel}}$	Static coefficient friction of the bean on galvanized steel surface
$\boldsymbol{\mu_{rubber}}$	Static coefficient of friction of the bean on rubber surface
$\boldsymbol{\mu_{p.wood}}$	Static coefficient of friction of the bean on plywood surface
Bean-mass	The mass of individual beans
1000-mass	The mass of 1000 beans

I. Introduction

Coffea is a genus of flowering plants whose seeds, called coffee beans, are used to make coffee. It is a member of the *Rubiaceae* family. They are shrubs or small trees native to tropical and southern Africa and tropical Asia. Coffee ranks as one of the world's most valuable and widely traded commodity crops and is an important export product of several countries, including those in Central and South America, the Caribbean and Africa [1].

Coffea canephora, commonly known as Robusta coffee, is a species of coffee that has its origins in central and western sub-Saharan Africa. It is a species of flowering plant in the Rubiaceae family. Though widely known as Coffea Robusta, the plant is scientifically identified as Coffea canephora, which has two main varieties, *robusta* and *nganda* [2].

Information on physical and aerodynamic properties of agricultural products is needed in design and adjustment of machines used during harvesting, separating, cleaning, handling and storing of agricultural materials and converting them into food, feed and fodder [3]. The geometric properties such as size and shape are two of most important physical properties considered during the separation and cleaning of agricultural grains. In theoretical calculations, agricultural seeds are assumed to be spheres or ellipse because of their irregular shapes [3].

Two important measurements used in determining the market grade of beans are, moisture content and test weight per bushel (bulk density). Information on both test weight and moisture content is used in management decisions relative to conditioning, storing, and marketing of beans. The basic physical properties of the beans depend on the variety and type of beans, the location and soil fertility where the crop is grown, and the cultural and harvesting practices used. Kernel size and shape, bulk density, true density, and porosity are parameters used in studying hydrodynamic, aerodynamic, and heat and mass transfer problems in grain [4].

Bulk density and porosity affect the structural loads. The coefficient of friction of seeds against various surfaces is also necessary in the design of conveying, transporting, and storing structures. The coefficient of friction between seed and wall is an important parameter in the prediction of seed pressure on walls. The coefficient of static friction also plays an important role in transporting (load and unload) of goods and design of storage facilities [5].

The purposes of this investigation were: To provide additional data on physical properties of robusta coffee; to study the changes in these properties caused by changes in moisture content of the coffee beans.

II. Theoretical Background

According to [6], the degree of sphericity can be expressed as follows;

$$\emptyset = \frac{(WLT)^{\frac{1}{3}}}{L} \quad \ldots\ldots\ldots 1$$

[7] have also stated that sphericity maybe given by;

$$\emptyset = [\frac{\beta(2L-\beta)}{L}]^{1/3} \quad \ldots\ldots\ldots 2$$

Where $\beta = (WT)^{0.5}$.

The geometric mean diameter is given by [8] and [9] as;

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

Therefore sphericity according to [6] can be expressed as;

$$\emptyset = \frac{D_g}{L} \quad \ldots\ldots\ldots 4$$

The surface area as stated by [7] maybe given by;

$$S = \frac{\pi\beta L^2}{2L-\beta} \quad \ldots\ldots\ldots 5$$

The surface area was also found by [10] to be given by;

$$S = \pi(D_g)^2 \quad \ldots\ldots\ldots 6$$

According to [6] and [11], the porosity is given by;

$$P = \left(\frac{\rho_p - \rho_b}{\rho_p}\right) \times 100 \quad \ldots\ldots\ldots 7$$

III. Materials and Methods

3.1 Sample preparation

Partially dry mature robusta coffee pods used in the experiments were obtained from the production year of 2014, and purchased from the local farmers during the season of 2014/2015 in Brong Ahafo Region in Ghana. The samples were then fully dried and manually de-shelled to obtain the beans. The initial moisture content of the samples was determined using the standard hot-air oven method at 105 ± 1°C for 24 h [12] and [13].

The beans at desired moisture levels were prepared by adding calculated amounts of distilled water, through mixing and sealing in separate polyethylene bags. The samples were kept at low temperature (5°C) in a refrigerator for 7 days to obtain uniform moisture distribution throughout the samples. The required quantities of the samples were taken out of the refrigerator, and allowed to warm up at room temperature for c. 2 hours. The wetting technique used to obtain the desired moisture content has frequently been reported [14], [15], [16], [17], [18].

The moisture contents were calculated from the following equation [19], [18].

$$M_w = \left[M_i [\frac{m_f - m_i}{100 - m_f}] \right] \dots\dots\dots\dots\dots\dots\dots\dots .8$$

Where M_w the mass of added water in kg, Mi is the initial mass of a sample in kg, m_i is the initial moisture content of a sample in % wet basis, and m_f is the final moisture content of the sample in percentage (wb).

The initial moisture content was 12.2% (wb) and the desired moisture for lower values were obtained by drying to obtain the desired moisture levels using the equation below according [6];

$$M_f = \frac{M_i(100 - m_i)}{100 - m_f} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. 9$$

Those of high moisture content were obtained adding distilled water of mass given by Eqn. 8 according to ([14]; [15]; [16]; [17]; [18]).

The physical properties of the beans were determined at five moisture levels in the range; 6.0%, 12.0%, 18.0%, 24.o% and 30.0% (wb), the design used was complete randomized block design with one factor, five levels and four replications of each moisture level.

3.2 Dimension and Size

The length, width and thickness of the beans were determined using a digital micrometer screw gauge with 0.001mm accuracy. 10 beans each selected randomly [20]from 10 sub-samples each containing 100-beans and this was repeated 10 times for the various moisture levels. This is with regard to the method described by [7]. Three principal dimensions of the selected beans (length, Width and thickness) were measured and their averages taken.

Several investigators including [21], [6] and [22] have measured these dimensions for the other grains and seeds using a same approach. The sphericity and surface area were calculated from linear dimensions using equations 2 and 6 respectively.

Bean mass and 1000 bean mass

Five samples each of 100 beans at each moisture content level were randomly selected and weighed on an electronic digital mass balance with 0.01g accuracy. The mass of 1000 bean mass was obtained by counting five 1000 bean samples for each level of moisture content, weighed on an electronic balance of accuracy 0.01g and the weights were averaged. Similar methods have been used by other researchers including [23], [14], [22] and [15].

3.4 Bulk Density

To determine the bulk density of beans at each level of moisture content, 250 ml volume container was filled with coffee beans and the top levelled. No additional compaction was done, the electronic balance was used for weighing and the bulk density was calculated as the ratio of the mass to the volume of the beans. Several researchers including [24], [14] and [13] have employed this method for other grains and seeds.

3.5 Particle density

For the particle density, a sample of 100 beans selected randomly from 10-sub samples of 100 beans each was used. For each sub-sample, 10 beans were selected. The beans were used to displace methanol in a measuring cylinder after their masses were previously measured using an electronic digital mass balance with 0.01g accuracy, the particle density was found as the average ratio of their masses to the volumes of methanol displaced by the beans. This method has been used by [24] and [25] for Bambara groundnuts and cumin seeds respectively.

3.5 Porosity

The porosity of the beans was calculated from the values of the bulk and particle densities obtained using equation (7).

3.6 Surface Area(S)
The surface area of the beans was calculated from the geometric diameter of beans using the equation (6) and from linear dimensions of the beans (length, width and thickness) using the equation (5).

3.7 Sphericity
Two equations, (1) and (2) were used to determine the sphericity of the beans, both equations used linear dimensions of the beans (length, width and thickness).

3.8 Emptying angle of repose
The emptying or dynamic angle of repose was obtained using a plywood box of dimensions 0.2×0.2×0.2m with a front sliding panel. The box was filled with beans for each moisture content level and the front sliding panel was quickly slid upwards allowing all the beans to flow out and form a natural heap. The angle of repose was determined from measurement of height of bean heap at two points in the sloping bean heap and the horizontal distance between the two points using a relation.

$$\theta_e = \frac{h_2 - h_1}{x_2 - x_1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 10$$

This method has been used by other researchers for other grains and seeds [7], [26], [22] and [25].

3.9 Filling angle of repose
This is the angle the beans can make with respect to the horizontal plane when piled. This was determined by the aid of a topless and bottomless hollow cylinder of 10 cm diameter and 25 cm height. The cylinder was placed at the Centre of a raised circular wooden board having a diameter of 20cm and filled with the coffee beans. The cylinder was then raised slowly until it formed a conical heap of beans. The diameter (D) and height (h) of the conical heap were measured and recorded. Average value of four replications for each treatment was reported [27].The filling angle of repose (Θ_f) was then gotten from the equation (12) as given by [28].

$$\Theta_f = \mathrm{Arc}\tan\left[\frac{2h}{D}\right] \dots\dots\dots\dots\dots\dots\dots..11$$

3.10 Co-efficient of static friction
The co-efficient of static friction was obtained by filling a cylinder of diameter 100mm to and height 50mm with the beans and placed on the friction surface. The cylinder was pulled up slightly (about 2mm) to avoid contact between cylinder and friction surface. The friction surface was part of a special construct, which is hinged at one end so that it can be lifted gradually at the unhinged end by means of a bolt and nut arrangement.

The angle (θ) at which the beans just began to slide down was recorded as the static angle of friction between the beans and friction surface. (Baryeh. 2001, 2002), [21], [26], [25] and [13] have used this method for the other grains and seeds. The co-efficient of static friction was found as;

$$\mu = \tan\theta \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.12$$

The surfaces used where plywood, mild steel plate and rubber.

3.11 Statistical Analysis
The results obtained were subjected to analysis of variance (ANOVA) using GenStat-Tenth Edition, Version: 10.3.0.0 software to test for significance and the means were separated using Duncan multiple range test as shown in the tables 1 and2 and analysis of regression using Microsoft Excel 2013 (Microsoft Corp., USA).

IV. Results and Discussion

4.1 Dimension and Size
Generally, principal dimensions of the coffee beans (length, width and thickness) increased with increasing moisture content from 6.0% up to 30.0 % (wb). The length increased from 8.493 to 10.223mm for moisture content of 6.0 and 30.0 % (wb) respectively, the width increased from 5.831 to 7.163mm for moisture contents 0f 6 and 30.0 %(wb) respectively, the thickness of beans generally increased from 3.732 and 4.715mm for the moisture content levels of 6 and 30% respectively.

From the analysis of variance, the differences of means of length, width, thickness, bean-mass, Bean mass, 1000-bean mass, bilk density, surface area, geometric diameter, mean diameter and static co-efficient of friction were significant($P>0.05$) at different moisture content levels whereas for sphericity, the difference is not significant($P<0.05$).

The witnessed increase in the linear dimensions may be due to tendency of beans to swell due to moisture absorption as moisture content increases. Similar findings have been reported for millet(Jain & Bal, (1997)) and sweet corn(Sobukola, (2013)).

The trend between the linear dimensions and the moisture content is shown in the figure (1) shown below.

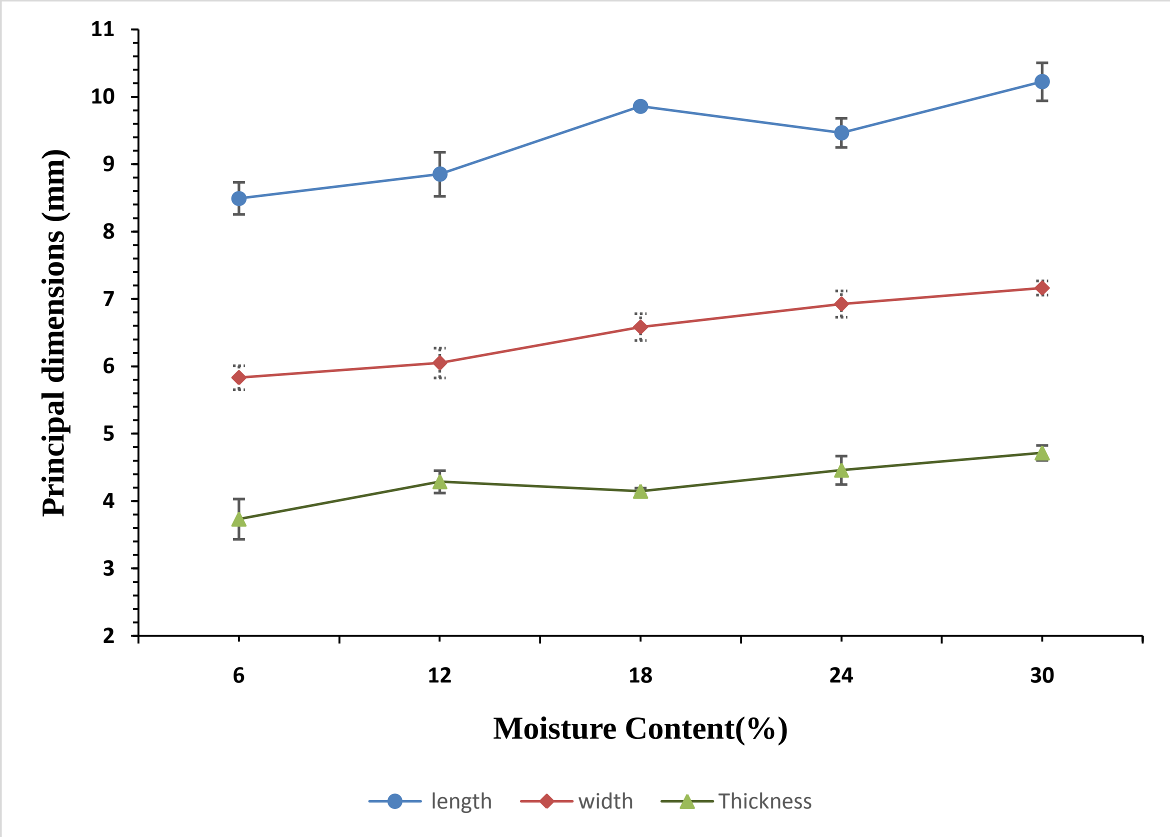

Figure 1 Variation of moisture content with principal dimensions of length, width and thickness

The relationships are described by the linear models below.
Length; $Y = 0.4075M_c + 8.1557\ (R^2 = 0.8237)$ ……….13
Width; $Y = 0.3539M_c + 5.4483\ (R^2 = 0.981)$ …………..14
Thickness; $Y = 0.2137M_c + 3.6257(R^2 = 0.848)$ …………..15

Table 1; Means of principal dimensions of coffee beans

Moisture content (%)	Length (mm)	Width (mm)	Thickness (mm)	Arithmetic diameter(mm)	Geometric diameter(mm)
6.0	8.49^{a}	5.831^{a}	3.623^{a}	5.982a	5.626^{a}
12.0	8.85^{ab}	6.048^{ab}	4.144^{b}	6.347b	6.042^{b}
18.0	9.86^{bc}	6.582^{bc}	4.33^{bc}	6.924c	6.547^{c}
24.0	9.46^{c}	6.924^{c}	4.457^{bc}	6.949c	6.627^{c}
30.0	10.22^{c}	7.16^{c}	4.715^{c}	7.367d	7.011^{d}
Standard error difference(S.e.d)	**0.3580**	**0.2666**	**0.2330**	**0.1501**	**0.1356**

In each column, the means with a common letters are not significantly different at α= 5%.

The geometric diameter and arithmetic diameter of the coffee beans increased gradually with the increase in the moisture content of the beans as shown in figures 2 and 3 respectively. It increased from 5.696 to 7.015 mm and from 6.019 to 7.367mm for geometric and arithmetic diameters respectively for moisture 6.0 and 30.0 percentage on wet basis levels respectively. The Comparison of means using Duncan Multiple Range revealed significant difference (P>0.05) between the mean values of geometric diameter at different levels of moisture content.

The relationship between moisture content and geometric diameter of the coffee beans is described by the linear equation.

$D_g = 0.3151M_c + 5.4395\ (R^2 = 0.9847)$ ……………………….16

Similar patterns have been observed for Guna seeds, soybean, cumin seeds, neem seeds, Bambara ground nuts and category B cocoa beans by Aviara et al., (1999), Sreenarayan et al., (1985); Visvanathan et al., (1996), Baryeh., (2001) and Ato Bart-Plange & Baryeh., (2003) respectively

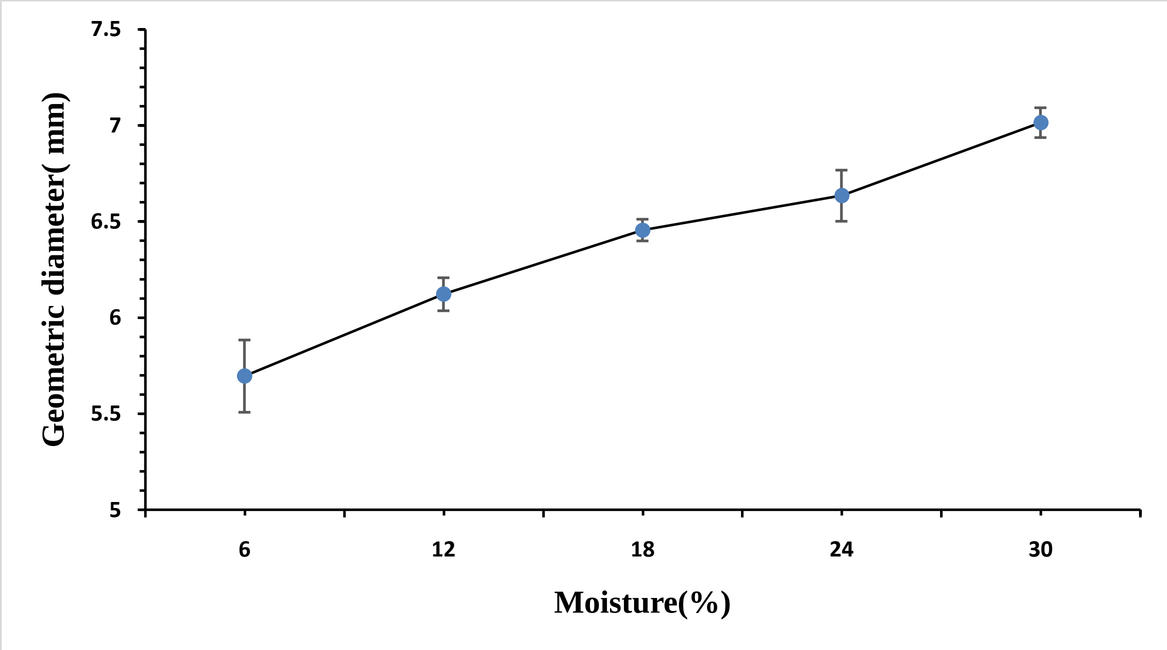

Figure 2. Effect of moisture content on the geometric diameter of coffee beans

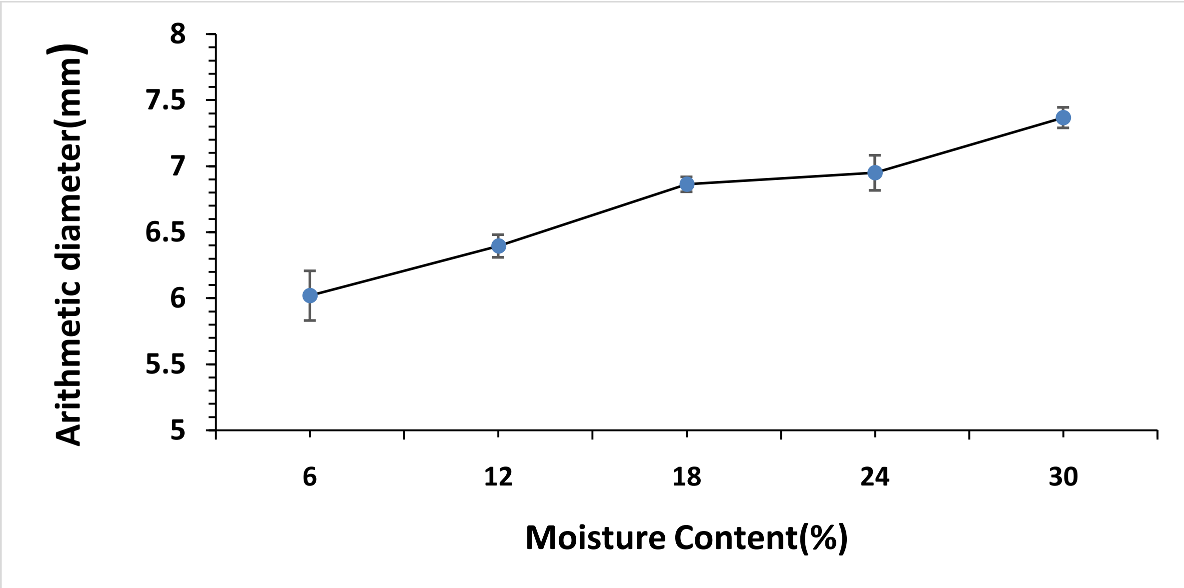

Figure 3 Effect of moisture content on Arithmetic diameter of coffee beans

4.2 Bean mass and 1000 bean mass

For the bean mass and 10000-bean mass, the mass increased steadily with increasing moisture content as shown in figure 3 and 4. The bean mass increased from 0.105 to 0.16 grams for moisture content of 6.0 and 30.0 % (wb) respectively.

The relationship is described by a linear model given below;

$Bean\ Mass = 0.0156M_c + 0.0884\ (R^2 = 0.9974)$ … … … … … . .17

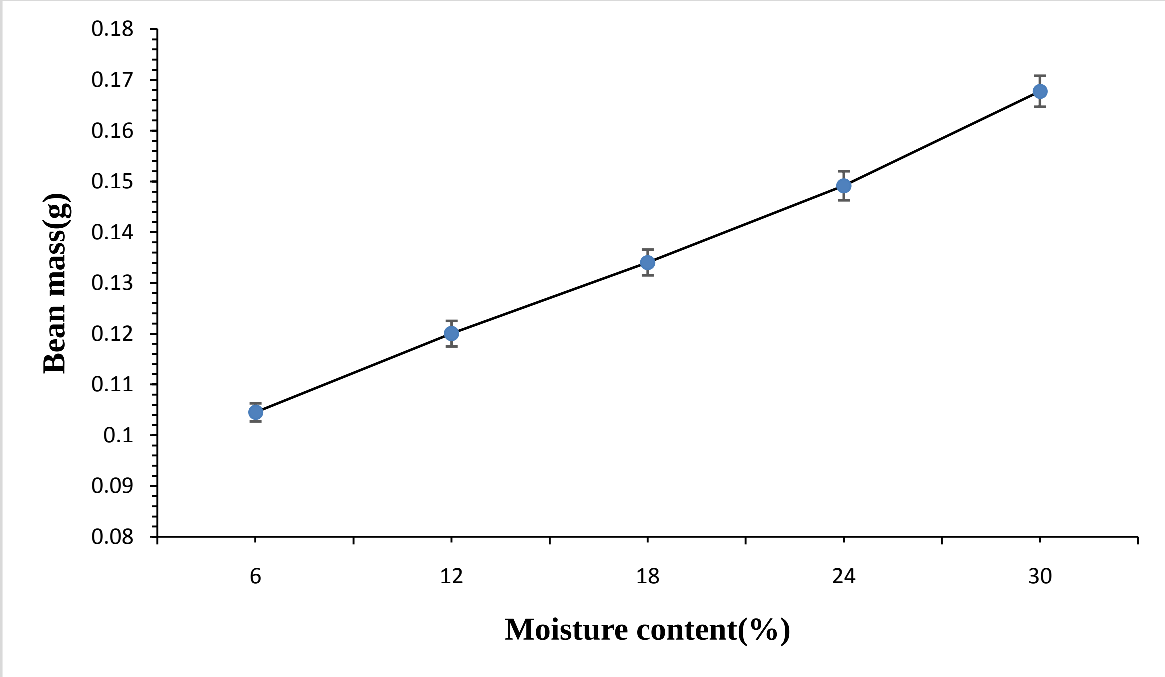

Figure 4. Effect of moisture content on bean mass of coffee

The 1000-bean mass increased steadily from 108.59 to 146.63 grams for moisture content levels of 6.0 and 30.0 percentages (wb) respectively as shown in figure 4. The relationship is described by a linear model shown below.

$$1000 - bean\ mass = 9.35M_c + 98.769 \ \ (R^2 = 0.9966) \ldots\ldots\ldots\ldots\ldots\ldots\ldots..18$$

The separation of means using Duncan Multiple Range showed a significant difference (P>0.05) between the mean values of 1000-bean mass at different levels of moisture content.

The linear relationship between the masses and moisture content has been reported for sorghum (Mahapatra, Patrick, & Diau, (2002)), large and medium size cocoa beans (A Bart-Plange, Dzisi, & Addo, (2011)) and green gram [17].

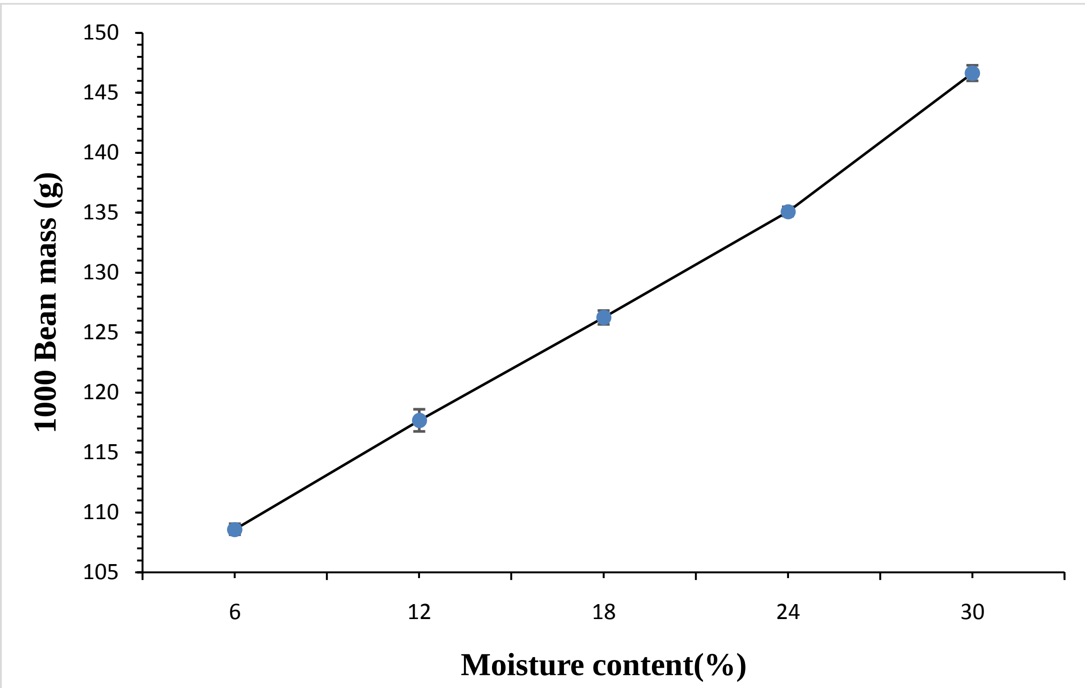

Figure 5 Effect of moisture content on the 1000-bean mass of coffee beans

4.3 Bulk density

Bulk density of the coffee beans gradually reduced with increasing moisture content. The relationship between moisture content and bulk density of beans is linear as shown in the figure 5 below, the density reduced from 0.788 to 0.692 g/cm^3 for moisture content of 6.0 and 30.0 % (wb) respectively. The Comparison of means using Duncan Multiple Range revealed a significant difference (P>0.05) between the mean values of bulky density at different levels of moisture content.

The relationship is described by a linear model shown below;

$\rho_b = -0.0214M_c + 0.8062\ (R^2 = 0.9354) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 19$

Similar findings have been made for Guna seeds, lentil seeds, soybean, pigeon pea and neem seeds by Aviara et al., (1999), Carman, (1996), Deshpande et al., (1993), Shepherd & Bhardwaj, (1986) and Visvanathan et al., (1996). However, for grains like pumpkin and karingda seeds were found to show a linear increase with increasing moisture content [26] and [13]. The difference could be due to the nature of the cell structure, and the volume and mass characteristics of different grains and seeds as moisture content increases [31].

Table 2; Means of bulky density, bean masses, friction, Sphericity and surface area of coffee beans

\`Moisture content (%)	Bulk density(kg/m^3)	Bean mass(g)	1000 bean mass(g)	Coefficient of static friction	Sphericity	Surface area(mm^2)
6.0	0.7889^a	0.1045^a	109.18^a	0.245^a	0.9239^a	84.049^a
12.0	0.7512^b	0.12^b	118.54^b	0.276^b	0.9329^a	96.931^b
18.0	0.7619^c	0.134^c	125.85^c	0.293^b	0.9249^a	113.334^c
24.0	0.7275^c	0.1492^d	135.53^d	0.343^c	0.9398^a	116.814^c
30.0	0.6925^d	0.1678^e	146.12^e	0.404^d	0.9340^a	130.484^d
Standard error difference(S.e.d)	**0.00678**	**0.00345**	**0.80400**	**0.00800**	**0.0095**	**4.3458**

In each column, the means with a common letters are not significantly different at α= 5%

4. 4 Particle density

Figure (5) shows the variation of both particle density and bulk density of the coffee beans with increase in moisture content. The particle density decreases linearly with increase in moisture content of the beans from 1.187 to 0.960 g/cm^3 for moisture contents of 6.0 and 30.0 % (wb) respectively.

The relationship between particle density and moisture content of the coffee beans is described by model below;

$\rho_p = 0.0282{M_c}^2 - 0.2222\mathrm{M}_c + 1.373\ (R^2 == 0.9857) \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 20$

The variation could be due to a higher increase in volume of the coffee beans compared to their masses as the moisture content increases.

Similar findings have reported for pigeon pea, karingda seeds, soybean, pumpkin seeds and Bambara ground nuts [22], [13], [14], [26] and [24] respectively. However, on the contrary to the findings are the neem seeds, cumin seeds, category B cocoa beans and Guna seeds [15], [25], [31] and [23] respectively. The results suggest that the beans are likely to have a low terminal velocity making pneumatic separation from lighter particles less feasible.

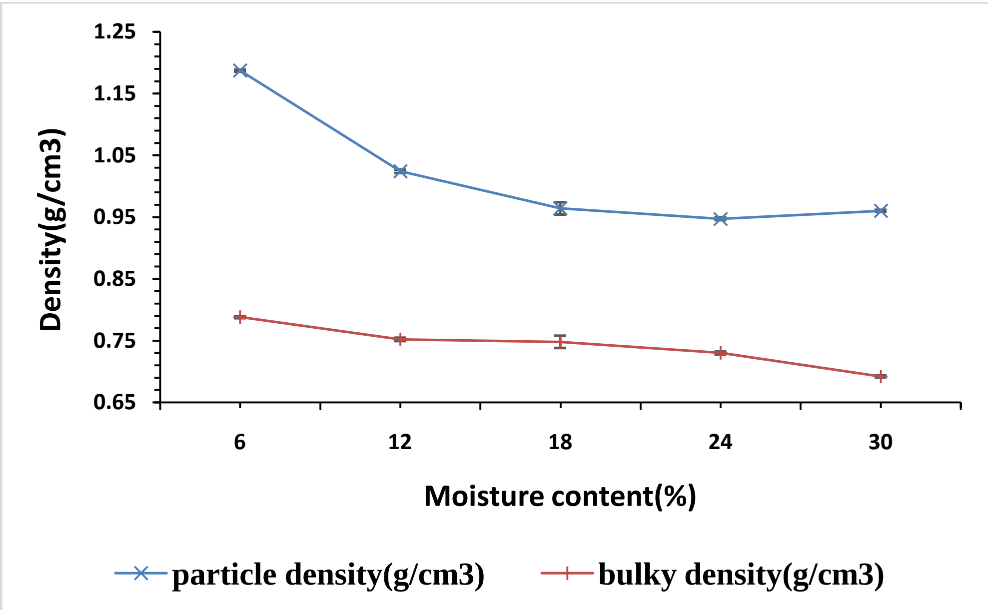

Figure 6 Effect of moisture content on the densities of coffee beans

4. 5 Porosity

Figure 6 shows the variation of percentage porosity with moisture content of the beans. The porosity decreases linearly with increase in moisture content from 33.61 to 21.92 for moisture contents of 6 and 30 % (wb). The decrease is probably due to an increase in cohesion of the cell structure of the coffee beans as a result of an increase in moisture content.

The relationship between porosity and moisture content of coffee beans is described by a mathematical model given by;

$Porosity = 1.1979M_c^{\ 2} - 9.8901\mathrm{M}_c + 41.976\ (R^2 = 0.9707)$ ……………..21

Chandrasekar & Visvanathan, (1999), Deshpande et al., (1993), Joshi et al., (1993), Suthar & Das, (1996), Visvanathan et al., (1996) have found out that porosity decreases with moisture content for coffee, soybean, pumpkin, karingda and neem seeds respectively while Aviara et al.,(1999), Carman, (1996), Gupta & Das, (1997), Shepherd & Bhardwaj, (1986), Singh & Goswani, (1996) and Ato Bart-Plange & Baryeh., (2003) found out that porosity increases with increase in moisture content for Guna seeds, lentil seeds, sunflower seeds, pigeon pea, cumin seeds and Category B cocoa beans respectively.

Low porosity at high moisture content indicates that more beans of coffee can be stored at high moisture content than at low moisture content due to reduction in inter-bean voids when porosity is low.

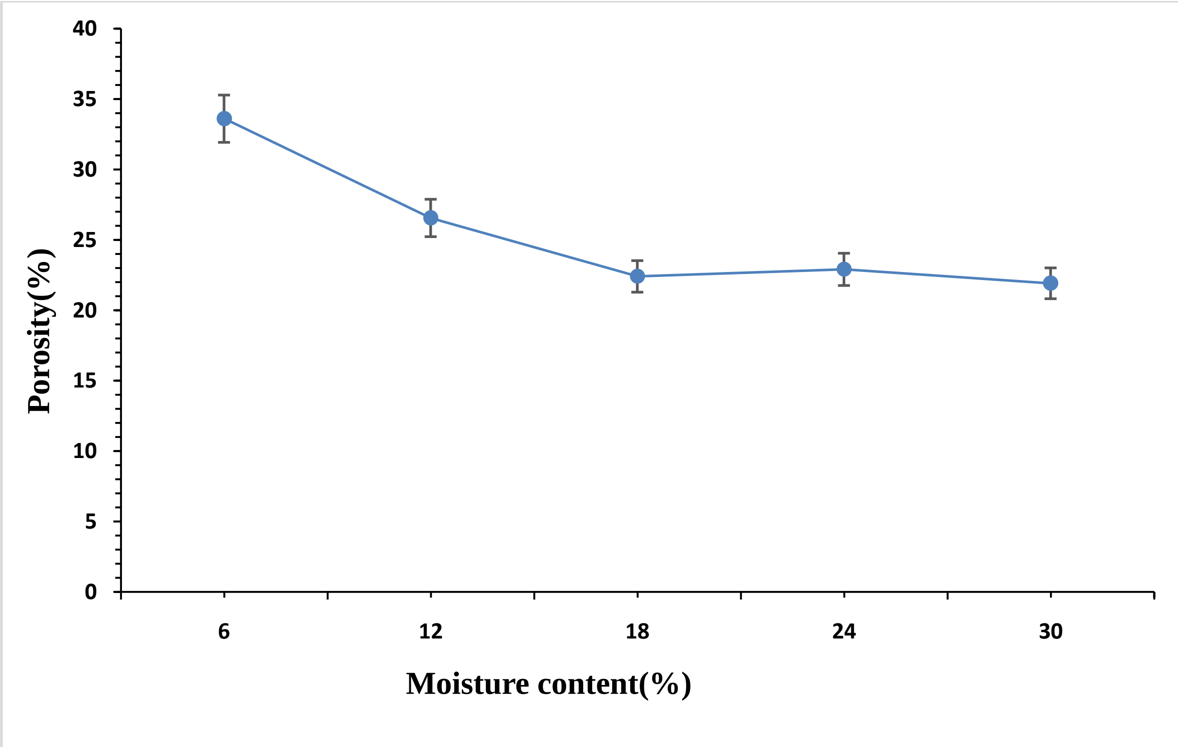

Figure 7 Effect of moisture content on the porosity of coffee beans

4. 6 Sphericity

The sphericity variation with moisture content is shown in figure 7. The sphericity of coffee beans was determined using two equations, 1 and 2, the sphericity given by equation 2 gave higher values compared to equation 1, and this is due to the shape assumption for the two equations.

For equation 1, the sphericity of coffee beans ranges from 0.6515 to 0.674 for moisture content levels of 6.0 and 30.0% (wb) respectively, for equation 2, the sphericity values range from 0.9239 to 0.934 for moisture contents of 6.0 and 30.0% (wb) respectively. The Comparison of means using Duncan Multiple Range revealed no significant difference (P>0.05) between the mean values of sphericity at different levels of moisture content. The mathematical models showing the relationship between moisture content and sphericity of coffee beans were;

$\emptyset(Eqn.1) = -0.0052M_c^{\ 4} - 0.2611M_c^{\ 3} + 0.4338M_c + 0.6935\ (R^2 = 1))$ ………………22

$\emptyset(Eqn.2) = -0.0122M_c^{\ 4} + 0.147M_c^{\ 3} - 0.6133M_c^{\ 2} + 1.0189M_c + 0.1105(R^2 = 1)$ ….23

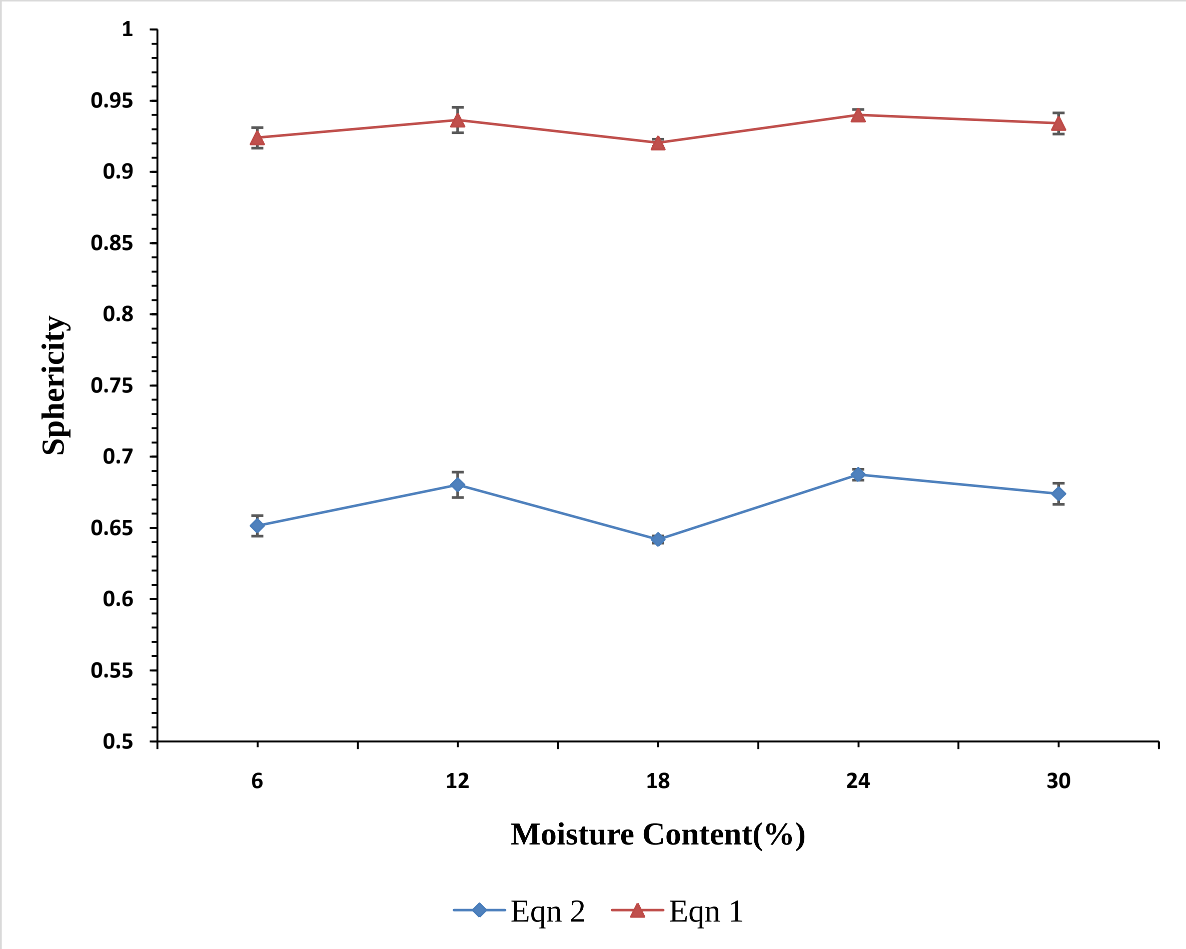

Figure 8 Effect of moisture content on the sphericity of beans

The sphericity of the beans was closer to one for equation 2 than equation 1, this was because for grains which are elongated like ellipse are better described by equation 2 while equation 1 is for non-elongated ones which supports the shape of the bean used as being close to an ellipse. This indicates that sieving or separating machine with circular holes will not easily let the beans through and during unloading; the beans will not roll away from the intended unloading point.

The linear change is in accordance with reported results for Amaranth seeds[36], fenugreek seeds [37] and vetch seed [38].

4. 7 Surface area

The variation of the bean surface area with moisture content is shown in figure 8. The relationship is described by two linear models for the two formulas used.

The surface area of the coffee beans was calculated from the linear dimensions of length, width and thickness using equation 5 and equation 6. The values of surface area for equation 6 are higher than the values of equation 5. The trend for both equations shows a gradual increase in surface area with increasing moisture content as described by the following mathematical models.

$S(Eqn.\ 6) = 12.592M_c + 90.944\ (R^2 = 0.9877) \dots\dots\dots\dots\dots\dots .24$

$S(Eqn. 5) = 10.671M_c + 76.496(R^2 = 0.9895) \dots\dots\dots\dots\dots . 25$

The results suggest that it is better to store coffee beans at low moisture content to maximize storage area. Similar findings have been observed by [29] for millet seeds and [39] for edible squash seeds.

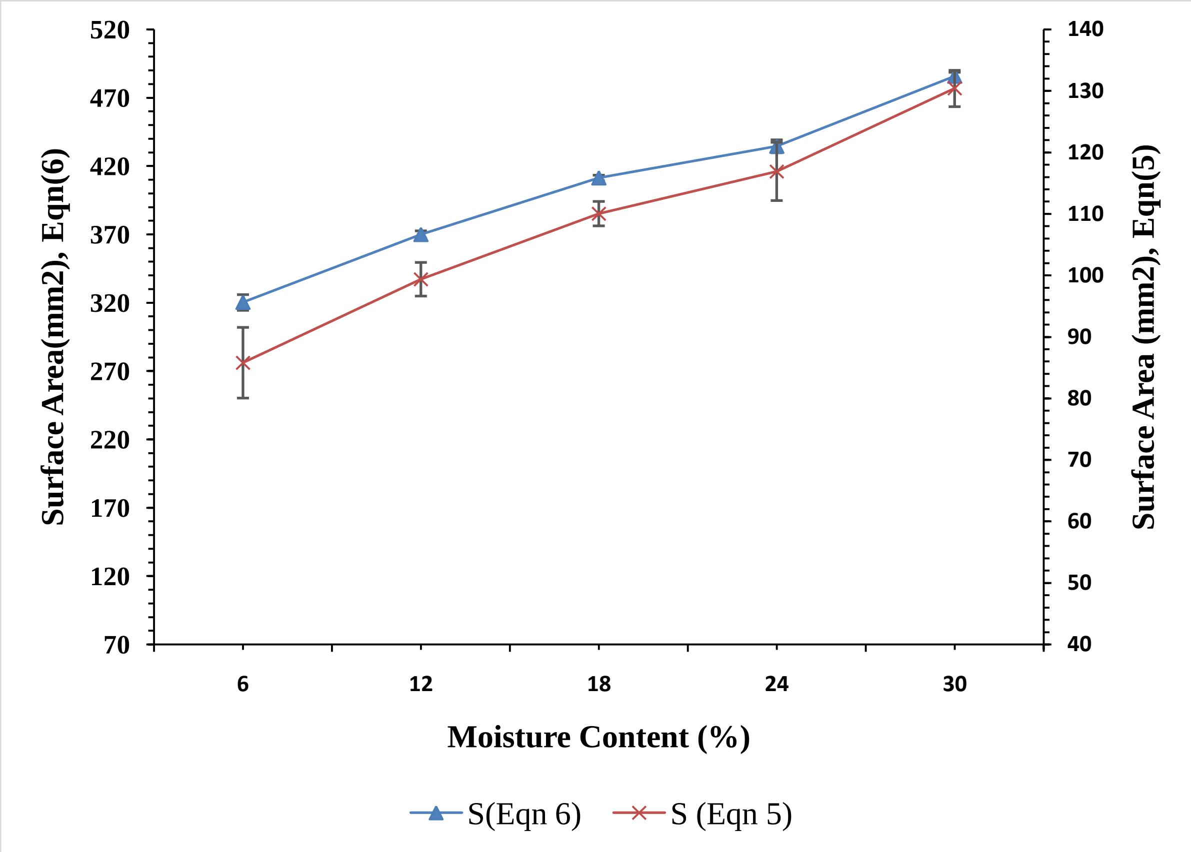

Figure 9 Effect of moisture content on the surface area of coffee beans

4. 8 Angles of repose

Figure 9 shows variation of the angles of repose with moisture content. The filling angle of repose increased linearly with increasing moisture content from 29.80 to 45.44 degrees for moisture content of 6.0 and 30.0 % (wb) respectively.

The emptying angle of repose also increased linearly from 24.00 to 40.54 degrees for 6.0 and 30.0 %(wb) respectively. It was generally observed that the filling angle of repose values are higher than emptying angle of repose values for all levels of moisture content. The linear models for filling and emptying angles of repose were found to be;

$\theta_f = 3.605M_c + 25.727\ (R^2 = 0.9442) \dots\dots\dots\dots\dots..26$

$\theta_e = 4.096M_c + 18.816\ (R^2 = 0.9661) \dots\dots\dots\dots\dots\dots.27$

Similar linear relationship for angles of repose have been found for cumin seeds, neem seeds, karingda seeds, pumpkin seeds, pigeon pea, sun flower seeds and millet [25], [13], [15], [26], [22], [16] and [29] respectively.

However a non-linear relationship between the angle of repose and moisture content has been found out for Guna seeds, Bambara seeds and category B cocoa beans by Aviara et al., (1999), Baryeh., (2001) and Ato Bart-Plange & Baryeh., (2003) respectively. Low angle of repose makes coffee beans spread out wider on a plane surface compared to high angles of repose, low angle of repose is suitable for belt conveying while high angle of repose is desirable when unloading onto a horizontal surface. Thus low moisture content is advisable for belt conveying while high moisture content is advisable when beans need to be unloaded unto a horizontal plane.

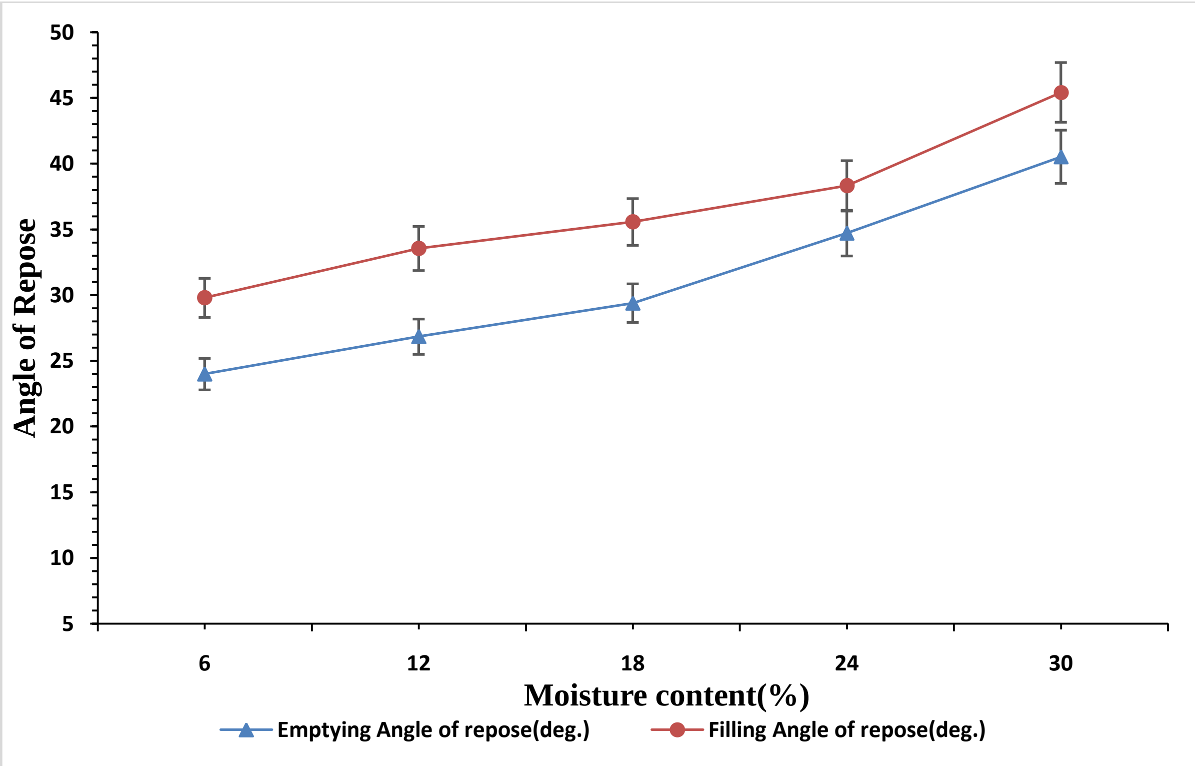

Figure 10 Effect of moisture content on the angle of repose of coffee beans

4. 9 Co-efficient of static friction

The variation of co-efficient of static friction with moisture content is shown in Fig 10. For the three frictional materials, it was observed that co-efficient of static friction increased linearly with increasing moisture content. The values for plywood ranged between 0.25 and 0.43 for moisture content of 6.0and 30.0 %(wb) respectively, the values for galvanized steel ranged between 0.21 and 0.37 for moisture content of 6.0 and 30.o % (wb) respectively while values for rubber ranged between 0.12and 0.31 for moisture content of 6.0 and 30.0 % (wb) respectively.

The highest co-efficient of friction was for plywood followed by galvanized steel and by rubber. The linear models describing the relationship between co-efficient of static friction and moisture of beans are;

$\mu(P.wood) = 0.045M_c + 0.193\ (R^2 = 0.9698) \ldots\ldots\ldots\ldots\ldots..28$

$\mu(G.steel) = 0.042M_c + 0158\ (R^2 = 0.9844) \ldots\ldots\ldots\ldots\ldots\ldots.329$

$\mu(Rubber) = 0.057M_c + 0.071\ (R^2 = 0.9763) \ldots\ldots\ldots\ldots\ldots\ldots..30$

Aviara et al., (1999), Baryeh. (2002; 2001), Carman, (1996), Shepherd & Bhardwaj, (1986), Visvanathan et al., (1996) and Ato Bart-Plange & Baryeh., (2003) have found out that co-efficient of static friction is higher on plywood than galvanized steel for Guna seeds, millet, Bambara ground nuts, lentil seeds, pigeon pea, neem seed and category B cocoa beans respectively.

The co-efficient of static friction is important in the design of conveyors because friction is necessary to tract coffee beans onto the conveyor surface without sliding or slipping back. If rubber is to be used as a conveying surface, it is advisable to make the rubber surface rough to increase the friction between the beans and the surface. However discharging require less friction to enhance discharging process and reduce energy requirement for discharging.

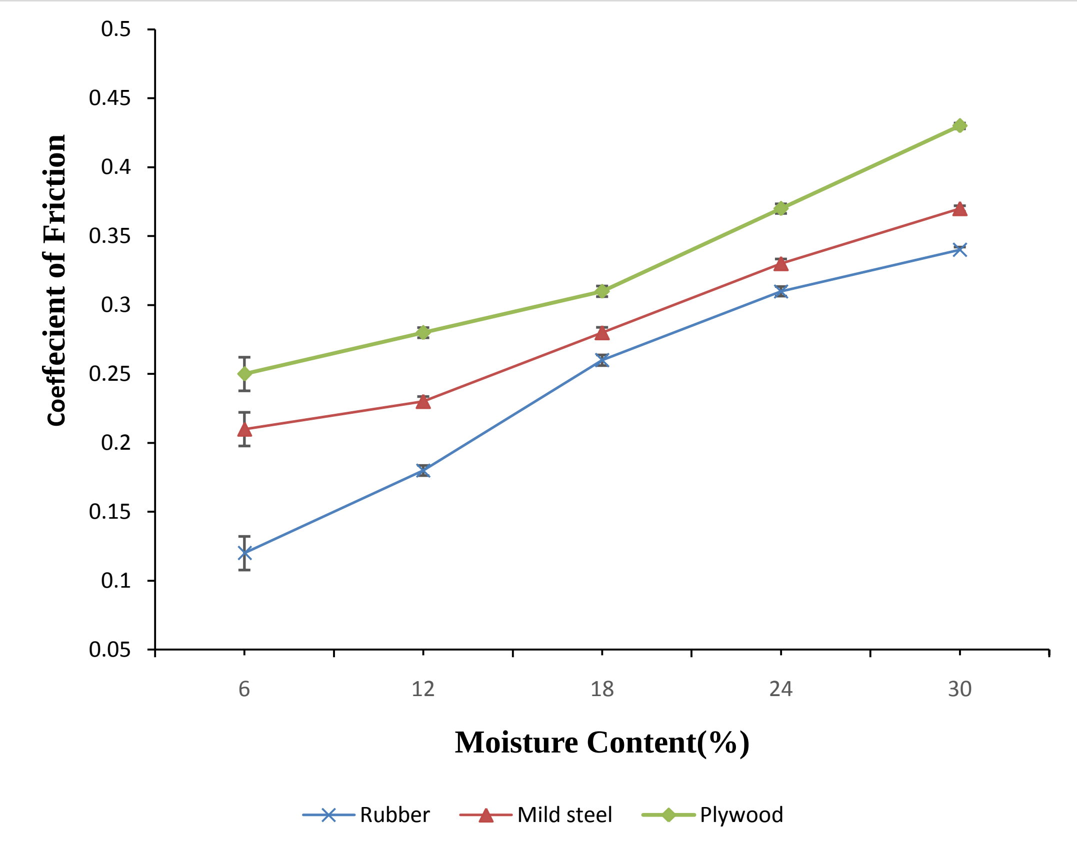

Figure 11 Effect of moisture content on the co-efficient of static friction of coffee beans

V. Conclusion

This experiment to determine the effect of moisture content on the physical properties of coffee found out the following;

1. All linear dimensions like length, width and thickness of the coffee beans increased with increasing moisture content, the length increased from 8.493mm at moisture content of 6.0 %(wb) to 10.223mm at moisture content of 30.0% (wb), width increased from 5.831mm at 6.0 % (wb) moisture content to 7.163 at 30.0 % (wb) moisture content while the thickness increased from 3.732mm at moisture content of 6.0% (wb) to 4.715mm for moisture content of 30.0 % (wb) respectively. The geometric diameter of coffee beans also increased with increasing moisture content from 5.696mm to 7.015 for moisture content of 6.0 and 30.0 % (wb) respectively.
2. Both the bean mass and 1000-bean mass increased linearly with increasing moisture content of coffee beans. The bean mass increased from 0.1045 grams to 0.1678grams and 1000-bean mass increased from 108.59 grams to 146.63 grams for moisture content of 6.0 and 30.0% (wb) respectively.
3. Bulk density and particle density of coffee beans decreased with increase in moisture content. Bulk density decreased from 0.788 g/cm^3 to 0.692 g/cm^3 while particle density decreased from 1.187 g/cm^3 to 0.960 g/cm^3 for moisture content of 6.0 and 30.0% (wb) respectively.
4. Porosity of the beans decreased linearly with increasing moisture content from 33.61 to 21.92 % for moisture contents of 6.0 and 30.0 % (wb) respectively.
5. Sphericity was least affected by changes in the moisture contents of the coffee beans. Coffee beans approximate a shape of an ellipse more than the sphere.
6. Surface area of coffee beans increased with increased moisture content of coffee beans and coffee beans should be stored at a low moisture content since surface area is low thus maximizing storage area.
7. Both the filling and emptying angles of repose increased linearly with increased moisture content, the filling angle is generally higher than emptying angle of repose for beans at the same moisture content.
8. Co-efficient of static friction increased gradually with increased moisture of the coffee beans and for the three frictional materials used, plywood had highest values of co-efficient of friction followed by galvanized steel and then rubber.

References

[1] a. Pui, C. Tanase, D.-G. Cozma, and T. Balaes, “Assessment of macromycetes using fourier Transform Infrared spectroscopy and chemometrics,” *Environ. Eng. Manag. J.*, vol. 12, no. 3, pp. 527–534, 2013.

[2] W. Contributors, “Coffea canephora See also,” *Wikipedia, The Free Encyclopedia*, 2015. [Online]. Available: http://en.wikipedia.org/w/index.php?title=Coffee&oldid=647768449.

[3] S. Gürsoy and E. Güzel, “Determination of Physical Properties of Some Agricultural Grains,” *Res. J. Appl. Sci. Eng. Technol.*, vol. 2, no. 5, pp. 492–498, 2010.

[4] D. S. Chung and H. H. Converse, “Effect of Moisture Content on Some Physical Properties of Grains,” *Trans. ASAE*, vol. 14, no. 4, pp. 0612–0614, 1971.

[5] E. Altuntas and H. Demirtola, “Effect of moisture content on physical properties of some grain legume seeds,” *New zealandJournal Crop Hortic. Sci.*, 2007.

[6] N. N. Mohsenin, *Physical properties of plant and animal materials*. New York: Gordon & Breach Science Publishers, 1970.

[7] R. K. Jain and S. Bal, “Physical properties of pearl millet,” *J. Agric. Eng. Res.*, vol. 66, no. 2, pp. 85–91, 1997.

[8] S. K. Sharma, R. K. Dubey, and C. K. Techandani, “Engineering properties of black gram, soybean and green gram,” *J. Agric. Eng. Res.*, vol. 3, pp. 118–185, 1985.

[9] V. V. Sreenarayan, V. Subramanian, and R. Visvanathan, “Physical and thermal properties of soybean,” *Proc. Indian Soc. Agric. Eng.*, vol. 3, no. 2, pp. 161–169, 1985.

[10] W. L. McCabe and P. Harriott, *Unit operations of chemical engineering*. New York: McGraw-Hill, 1986.

[11] R. A. Thompson and G. W. Isaac, “Porosity determination of grains and seeds with air comparison pyconometer,” *Am. Soc. Agric. Eng.*, vol. 10, no. 5, pp. 693–696, 1967.

[12] Brusetwitz. G.H, “Density of rewetted high moisture grains.,” *Trans. ASAE*, vol. 18, pp. 935–938, 1975.

[13] S. . Suthar and S. K. Das, “Some physical properties of karingda (Citrus lanatus (thumb) mansf) seeds.,” *J. Agric. Eng. Res.*, vol. 65, no. 1, p. 15–22., 1996.

[14] S. Deshpande, S. Bal, and T. Ojha, “Physical properties of soybean seeds,” *J. Agric. Eng. Res.*, vol. 56, no. 2, pp. 89–98, 1993.

[15] R. Visvanathan, P. T. Palanisamy, L. Gothandapani, and V. V Sreenarayanan, “Physical properties of neem nut,” *J. Agric. Eng. Res.*, vol. 63, no. 1, pp. 19–25, 1996.

[16] R. Gupta and S. Das, “Physical properties of sunflower seeds,” *J. Agric. Eng. Res.*, vol. 66, no. 1, pp. 1–8, 1997.

[17] P. Nimkar and P. Chattopadhyay, “‘PH—Postharvest Technology: some physical properties of green gram.,’” *J. Agric. Eng. Res.*, vol. 80, no. 2, pp. 183–189, 2001.

[18] K. Sacilik, R. Öztürk, and R. Keskin, “Some physical properties of hemp seed,” *Biosyst. Eng.*, vol. 86, no. 2, pp. 191–198, 2003.

[19] D. Balasubramanian, “Physical properties of raw cashew nut,” *J. Agric. Eng. Res.*, vol. 78, no. 3, pp. 291–297, 2001.

[20] R. Murray, *statistics*. New York: McMillan Publishers, 1992.

[21] S. K. Dutta, V. K. Nema, and R. K. Bhardwaj, “Physical properties of gram,” *J. Agric. Eng. Res.*, vol. 39, no. 4, pp. 259–268, 1988.

[22] H. Shepherd and R. K. Bhardwaj, “moisture dependent physical properties of pigeon pea,” *J. Agric. Eng. Res.*, vol. 35, no. 4, pp. 227–234, 1986.

[23] N. A. Aviara, M. I. Gwandzang, and M. A. Hague, “Physical properties of guna seeds,” *J. Agric. Eng. Res.*, vol. 73, no. 2, pp. 105–111, 1999.

[24] E. A. Baryeh., “Physical properties of bambara groundnuts,” *J. Agric. Eng. Res.*, vol. 47, no. 4, pp. 321–326, 2001.

[25] K. K. Singh and T. K. Goswani, “Physical properties of cumin seed,” *J. Agric. Eng. Res.*, vol. 64, no. 2, pp. 93–98, 1996.

[26] D. C. Joshi, S. K. Das, and R. K. Mukherji, “Physical properties of pumpkin seeds,” *J. Agric. Eng. Res.*, vol. 54, no. 3, pp. 219–229, 1993.

[27] A. Koocheki, S. Razavi, E. Milani, T. Moghadam, M. Abedini, and S. Alamatiyan, “Physical properties of watermelon seed as a function of moisture content and variety.,” *Int. Agrophysics*, vol. 21, no. 4, pp. 349–359, 2007.

[28] S. Razavi, A. Mohammad, A. Rafe, and Z. B. Emad, “The physical properties of pistachio nut and its kernel as a function of moisture content and variety,” *J. Food Eng.*, vol. 81, no. 1, p. 226–235., 2007.

[29] E. A. Baryeh., “Physical properties of millet,” *J. Agric. Eng. Res.*, vol. 51, no. 1, pp. 39–46, 2002.

[30] S. Sobukola, “Physical properties of high quality maize (Swam 1 variety) seeds (Zea mays) as affected by moisture levels,” *African J. Food Sci.*, vol. 7, no. 1, pp. 1–8, Jan. 2013.

[31] A. Bart-Plange and E. A. Baryeh., “The physical properties of category B Cocoa beans,” *J. Food Eng.*, vol. 60, no. 3, pp. 219–227, 2003.

[32] A. Mahapatra, C. Patrick, and P. Diau, “Effect of moisture content on the physical properties of sorghum (mahube variety) seeds,” *J. Agric. Eng.*, vol. 11, no. 1, pp. 1–10, 2002.

[33] A. Bart-Plange, A. Dzisi, and A. Addo, “A Comparative Study of Some Physical Properties of Large and Medium Size Cocoa Beans from Ghana,” *Small (Category …*, vol. 2, no. 3, pp. 135–141, 2011.

[34] K. Carman, “Somephysical properties of lentil seeds,” *J. Agric. Eng. Res.*, vol. 63, no. 2, pp. 87–92, 1996.

[35] V. Chandrasekar and R. Visvanathan, “Physical and thermal properties of coffee,” *J. Agric. Eng. Res.*, vol. 73, no. 3, pp. 227–234, 1999.

[36] R. Abalone, A. Cassinera, A. Gastón, and M. A. Lara, “Some physical properties of amaranth seeds,” *Biosyst. Eng.*, vol. 89, no. 1, pp. 109–117, 2004.

[37] E. Altuntaş, E. Özgöz, and Ö. F. Taşer, “Some physical properties of fenugreek (Trigonella foenum-graceum L.) seeds,” *J. Food Eng.*, vol. 71, no. 1, pp. 37–43, 2005.

[38] I. Yalçin and C. Özarslan, “Physical properties of vetch seed,” *Biosyst. Eng.*, vol. 88, no. 4, pp. 507–512, 2004.

[39] M. Paksoy and C. Aydin, “Some physical properties of edible squash seeds,” *J. Food Eng.*, vol. 65, no. 2, pp. 225–231, 2004.

Joseph Niwagaba. " Effect of Moisture Content on the Physical Properties of Coffee Beans (Robusta). "IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) 12.6 (2019): PP- 73-86.