ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE, September 2019. Vol. 15(3):534-553
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

EFFECT OF MOISTURE CONTENT ON SOME ENGINEERING PROPERTIES OF AFRICAN MAHOGANY *(Afzelia africana)* SEED

N. A. Aviara[1*], S. Ekaso Jr.[1] and O. U. Nwanja[2]

([1]Department of Agricultural and Environmental Resources Engineering, University of Maiduguri, Maiduguri, Borno State, Nigeria

[2]Department of Agricultural Technology, Akanu Ibiam Federal Polytechnic, Unwana-Afikpo, Ebonyi State, Nigeria)

** Corresponding author's email address: nddyaviara@yahoo.com*

ARTICLE INFORMATION

Submitted 23 November, 2018
Revised 20 March, 2019
Accepted 25 March, 2019

Keywords:
Afzelia africana
physical properties
angle of repose
static and kinetic coefficients of friction
coefficient of restitution
specific heat

ABSTRACT

Some engineering properties of *Afzelia africana*, namely axial dimensions, one thousand seed mass, surface area, particle density, bulk density, porosity, angle of repose, static and kinetic coefficients of friction, coefficient of restitution and specific heat were determined as a function of moisture content in the moisture range of 6.1 – 32.3% (d.b). Results showed that in the above moisture range, major, intermediate and minor axial dimensions of the seed increased from 25.4 – 26.2mm, 13.2 – 13.95mm and 10.2 – 11.2mm, respectively. One thousand seed mass, surface area, particle density, porosity, angle of repose, static coefficient of friction, kinetic coefficient of friction and specific heat capacity of the seeds all increased with increase in moisture content. Seed bulk density decreased with increase in moisture content and coefficient of restitution decreased as drop height and moisture content increased. The relationship existing between the engineering properties and seed moisture content, established using regression analysis showed high coefficient of determination. These properties would be useful in the design of *Afzelia africana* seed handling, storage and processing equipment.

1.0 Introduction

Afzelia africana also known as African mahogany (Figure 1) is an economically valuable and drought resistant leguminous tree crop with its species widely distributed in the Continent of Africa. It is found from Senegal in West Africa to the Sudan, Uganda and Tanzania in the East. It is occasionally grown in other tropical countries as ornamental tree. Its uses range from foods to pharmaceuticals. In West Africa, the edible seed is used in soup making as thickening agent. The seed flour is used as a substitute for wheat flour in biscuits and doughnuts. *Afzelia africana* seeds (Figure 2) have been reported to contain 24% protein, 4.29% crude fibre, 3.43% ash and 21% lipid (Matouk et al., 2004), indicating good nutritional value. The seeds help in softening bulky stool and have been associated with protection against colon and rectal cancer.

Hydro gel is also found in the *Afzelia africana* seed and it is called Afzelia gum -a non starch polysaccharide- which is useful in the food and pharmaceutical industries (Builders et al., 2009).

With these numerous uses the popularity of this important seed has been limited because of lack of proper handling equipment to project its commercial value.

Figure 1: Afzelia africana tree

Figure 2: Afzelia africana seeds

In West Africa and Nigeria in particular, this important seed is subjected to such different processing operations as soaking, roasting, parboiling, de-hulling, grinding and drying, prior to utilization or storage. The present manual techniques of carrying out these operations are not only labour intensive and time consuming, but also tasky with low output in terms of quantity and quality of product. Therefore, there is the need to develop improved methods of handling processing and storing the seeds using suitable machines and equipment. The development of such machines and equipment require knowledge of the engineering properties of the seed. The performance and adjustment of such machines are also dependent on the moisture content of the produce (Aviara et al., 1999), therefore, the effect of moisture content on engineering properties of *Afzelia africana* seed is an important consideration in the design of its handling and processing equipment. No work however, appears to have been carried out of the engineering properties of *Afzelia africana* seed and their relationship with seed moisture content.

The objective of this study was to determine some engineering properties of *Afzelia africana* seed and investigate their relationship with moisture content. The properties include axial dimensions, one thousand seed mass, surface area, particle density, bulk density, porosity, angle of repose, static and kinetic coefficients of friction, coefficient of restitution and specific heat. Relevant literature was studied in order to select the appropriate method of determining each of the above properties. The selection of a method was based on simplicity, accuracy of results and wide acceptability.

2. Materials and Methods

The bulk quantity of *Afzelia africana* seeds used in this study were purchased from Onueke in Ebonyi State, and supplied by a marketer in Monday market, Maiduguri, Nigeria. The seeds were taken to the laboratory and cleaned manually to remove all foreign materials and damaged seeds. The market stable storage moisture of the seeds was determined by oven drying triplicate samples at 105°C for 6 hours (Aviara et al., 1999).

The bulk seed was divided into 5 batches and conditioned by soaking in water for 12, 36, 58 and 84 hours including the market stable storage to obtain samples at five moisture levels for the

Corresponding author's e-mail address: nddyaviara@yahoo.com

experiments. After conditioning, the seeds were poured separately into polyethylene bags and sealed before being kept in a curing room for the three days to make the moisture distribute uniformly throughout the grains. After the grains reached uniform moisture contents, the bags were placed in desiccators and stored at room temperature.

To determine the amount of moisture content of seeds in the differently conditioned lots, samples were collected and weighed using an electronic balance and placed in an oven set at 105°C with weight loss monitored on hourly basis until three consecutive weighing gave identical values of mass.

The moisture content was calculated from the relation used by Aviara (2005 b).

$$Mw.b = \left(\frac{Wi - Wf}{Wi}\right) \times 100 \qquad (1)$$

where: Mw.b = Wet basis moisture content (%), W_i = Initial weight (g) and W_f = Final weight (g)

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

$$M_{db} = \left(\frac{M_{wb}}{1 - M_{wb}}\right) \times 100 \qquad (2)$$

where: $M_{d.b}$ = Dry basis moisture content (%).

The axial dimensions of the seed, namely: the length (L), width (B), and thickness (T) were measured using the method of Ndukwu (2009). The dimensions of 100 randomly selected seeds at different moisture contents were measured using a Venier calliper of 0.01mm accuracy in order to determine the seed size. The average values of length, width and thickness of the seeds at each moisture content were recorded.

The geometric mean diameter was determined by applying the length, width and thickness of the seeds to Equation (3) (Joshi et al., 1993)

$$D_p = (LWT)^{1/3} \qquad (3)$$

where: D_p = Geometric mean diameter (mm), L= Length (mm), W= Width (mm) and T= Thickness (mm)

Arithmetic mean diameterwas determined by using Equation (4) (Mohsenin, 1986).

$$A_m = \frac{L + W + T}{3} \qquad (4)$$

where: A_m = Arithmetic mean diameter. (mm)

The aspect ratio was determined using Equation (5):

$$R_a = \frac{W}{L} \qquad (5)$$

where: R_a = Aspect ratio, W= Width (mm) and L= Length (mm)

The surface area of the seed was measured using the method of Ndukwu (2009). This involved carefully wrapping the seeds completely with a foil paper and cutting of the edges. The paper was then unwrapped and placed on a graph sheet. The outline covered by the foil paper on the graph sheet was traced with a pencil and the surface area of the seeds was determined by method of counting the squares. This was carried out at each moisture level using 30 seeds. The average surface area of the seeds at various moisture contents was then obtained.

The one thousand seed weight was determined using the method of Taimirat, (2011). It involved counting 1000 seeds and pouring them dockage free into a bucket of known weight.The seeds and bucket was weighed using an electronic balance of approximately 0.001g reading accuracy. The mass of the bucket was subtracted from the mass of the 1000 seeds plus bucket and the mass of the 1000 seeds at each moisture content was recorded.

The true density of Afzelia africana seeds was determined using the standard liquid displacement method as reported by Aviara et al. (1999).The samples were coated with epoxy resin around the ring, weighed individually on an electronic balance and tied with a thread before immersing them individually into a 25ml cylinder containing water to a known level. The volume of water displaced in the cylinder was noted and taken in order to obtain the volume of the seed. 30 trials were carried out at each moisture level.

True density was then calculated from the obtained values using the formula:

$$\rho_t = \frac{M}{Vf - Vi} \qquad (6)$$

where: ρ_t = True density (kgm^{-3}), M = Mass of individual seed (kg), Vi = Initial volume of water in the cylinder (m^3) and Vf = Final volume of water in the cylinder after submergence of seed (m^3).

The bulk density was determined using the AOAC (1980) method. Samples were poured from a height of 15cm into a 500ml cylinder of known mass. The cylinder containing samples was weighed on abalance and weight of the seeds was obtained by subtracting the mass of the cylinder from the final mass of seeds and cylinder, while the volume of the cylinder was taken as the volume occupied by the seeds.

Bulk density was then determined using the expression:

$$\rho_b = (Ms / Vs) \qquad (7)$$

where: ρ_b = Bulk density (kg/m^3), Ms = Mass of seeds alone (kg) and V_s = Volume of seeds (m^3)

The porosity of Afzelia Africana seeds were determined using the formula (Mohsenin, 1986)

$$\varepsilon = \left(1 - \frac{\rho b}{\rho t}\right) \times 100 \qquad (8)$$

where: ε = Porosity (%), ρb = Bulk density (kg/m^3) and ρ_t = True density (kg/m^3)

In determining the angle of repose, the cylindrical pipe method reported by Zewdu and Solomon (2007) was used. A topless and bottomless cylinder placed on a flat surface was filled with seeds at specified moisture content and slowly raised until it completely gets lifted off from the seeds leaving them to pile in form of a cone. The diameter and height of the cone were measured using a Venier calliper and used to calculate the angle of repose. The formula (Equation 9) given by Zewdu and Solomon (2007) was applied to determine the angle of repose.

$$\theta = \tan^{-1}\left(\frac{h}{r}\right) \qquad (9)$$

Corresponding author's e-mail address: nddyaviara@yahoo.com

where: θ = Angle of repose in degrees, h = height of piled seeds (mm) and r = Radius of base of cone formed by seeds (mm)

Static coefficient of friction of the seeds on different structural surfaces (steel sheet, wood, hessian bag and glass)was determined using the inclined plane method as described by Dutta et al. (1988) and Suthar and Das (1996). This involved the placing of an open-ended box (50mm × 100mm × 100mm) on an adjustable tilting surface which was formed with structural surface. The box was filled with seeds at specified moisture content and the structural surface with the box and its content on top was gradually raised using a screw device until the box started to slide down and the corresponding tilting angle, α was recorded.

The value of static coefficient of friction was calculated using Equation (10) due to Mahapatra et al. (2002).

$$\mu = \tan \alpha \qquad (10)$$

where: μ = static coefficient of friction and α = tilting angle

For the kinetic coefficient of friction, the open-ended box was used as described by Aviara et al., (2000). In this method, the box was placed on a horizontal surface. The box was filled with seeds and connected by means of a string, parallel to the surface and passed over a pulley to a pan hanging down from it. Weights were placed in the pan subsequently until the box and its content moved uniformly when given a gentle push. The kinetic coefficient of friction of the seeds on a given structural surface was determined using Equation (11). Four different surfaces were used for each moisture level of the seeds namely and these were plywood, fibre glass, hessian bag material and steel sheet.

$$\mu = \frac{Wp + Wi}{Wb + Ws} \qquad (11)$$

where: μ = Kinetic coefficient of friction, W_p = Weight of pan (g), W_i = Weight placed in pan to move the box (g), W_b = Weight of box (g) and W_s = Weight of sample (g).

Coefficient of restitution of the seeds was determined using the method described by Kumar (1995). The nuts were dropped from a height of 50, 90, 120, and 150 cm on four structural surfaces namely: wood, galvanised steel sheet, hessian bag and fibre glass. A graduated scale was kept at the background and the maximum height of rebound was recorded using a video camera. This was replicated three times at each moisture content level for seed fall on both axial and longitudinal orientation. The coefficient of restitution was calculated using Equation (12) as given by Aviara et al. (2010):

$$C.R = \sqrt{\frac{h}{H}} \qquad (12)$$

where: C.R is the coefficient of restitution, h = Height of rebound (cm) and H = Height of drop (cm).

Coefficient of restitution on each surface for different drop heights was regressed against moisture content.

The specific heat of the seeds was determined using a copper calorimeter placed inside a flask by method of mixtures as described by Ogunjimi et al., (2002). A sample of known weight and temperature was poured into calorimeters containing water of known weight and temperature.

The final temperature was noted and the specific heat of the sample was calculated using Equation (13):

$$C_s = \frac{(McCc + MwCw)(Te - Tw)}{Ms(Te - Ts)} \quad (13)$$

where: C_c = Specific heat of calorimeter (J/kgK), C_s = Specific heat of sample (J/kgK), C_w = Specific heat of water (J/kgK), M_c = Mass of calorimeter (kg), Ms = Mass of sample (kg), Te = Equilibrium temperature of seed (K), T_s = Initial temperature of sample (K) and T_w = Initial temperature of water (K).

The experiments were replicated thrice at each moisture content except in cases otherwise stated and the average values of the properties were recorded. The relationship existing between the properties and seed moisture content as well as the coefficient of determination of the equation used to express the relationship were determined using regression procedure. The variation of the engineering properties with moisture content was also expressed graphically.

3. Results and Discussion

3.1 Seed Moisture Content

The initial moisture content of *Afzelia africana* seeds was found to be 6.1% (d.b). The four other moisture levels obtained after conditioning the seeds were 7.9, 12.8, 25.4 and 32.3% (d.b), respectively. The investigations were carried out at the above moisture levels to determine the effect of moisture content on the physical, frictional and thermal properties of Afzelia africana seeds.

3.2 Axial Dimensions

The variation of the Afzelia africana seed size measured at different moisture content levels is presented in Figure 3.

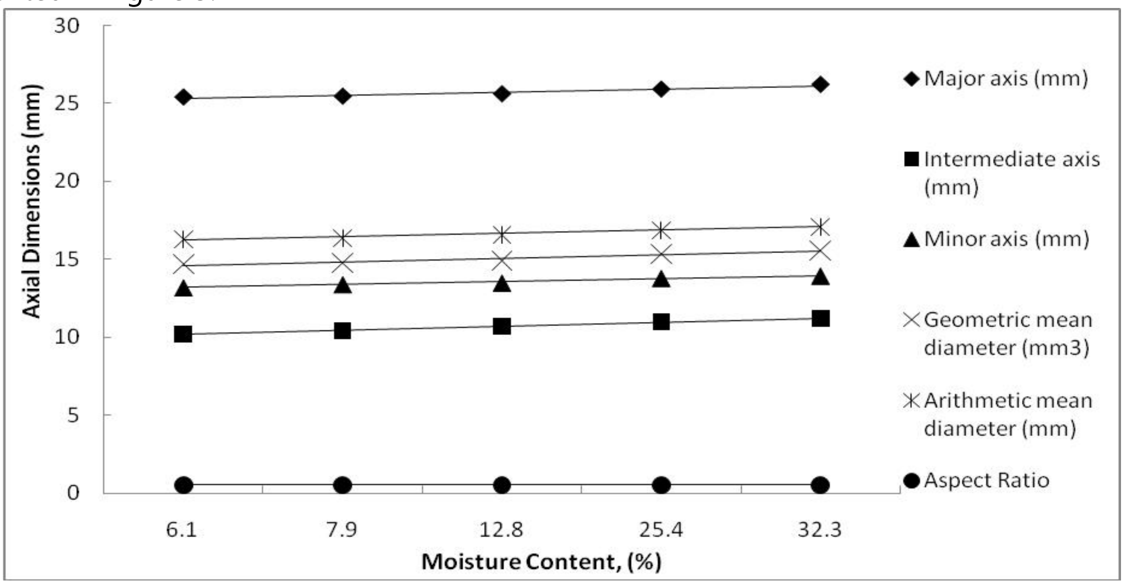

Figure 3: Effect of moisture content on the axial dimensions of Afzelia africana seed

The Figure shows that the three axial dimensions increased with increase in moisture content in the moisture range of 6.1 – 32.3% d.b. Major axis increased from 25.4 – 26.2mm, the intermediate axis increased from 13.2 – 13.95mm and the minor axis from10.2 – 11.2mm. The arithmetic and geometric mean axial dimensions also increased with increase in moisture content. The arithmetic mean had higher values than the geometric mean axial dimensions of the seeds. The aspect ratio which is the ratio of the intermediate axis to the major axis also

Corresponding author's e-mail address: nddyaviara@yahoo.com

increased with increase in moisture content. The increase in axial dimensions indicates that upon increase in moisture contents, the seeds expand in length, width and thickness thereby increasing their average dimensions.

The relationship between moisture content and the axial dimensions of the seeds was found to be linear with the following equations:

$$a = 0.26M + 9.92 \quad (14)$$

$$b = 0.205M + 25.095 \quad (15)$$

$$c = 0.19M + 13 \quad (16)$$

$$A_m = 0.214M + 16.022 \quad (17)$$

$$D_p = 0.237M + 14.373 \quad (18)$$

$$R_a = 0.0032M + 0.5181 \quad (19)$$

with values of coefficient of determination R2 = 0.9298, 0.9941, 0.981, 0.9745, 0.9454 and 0.9063 respectively.

where: a = Major axis (mm), b = Intermediate axis (mm), c = Minor axis (mm), A_m = Arithmetic mean dimension (mm), D_p = Geometric mean dimension (mm), R_a = Aspect ratio and M = Moisture content (%, db).

Similar results of increase are reported by Tavakkoli et al., (2009) for the soybean grains and Al-Mahasneh and Rababah, (2007) for green wheat. The results of the axial dimensions can be used in sizing, mechanical separation and grading of *Afzelia africana* seeds from similar sized materials such as stones. Irtwange and Igbeka (2002) and Aviara et al., (2005b) observed similar trend of arithmetic and geometric mean dimensions for African yam bean and sheanut respectively.

3.3 One Thousand Seed Weight

The variation of one thousand seed weight of *Afzelia Africana* with moisture content is presented in Figure 4.

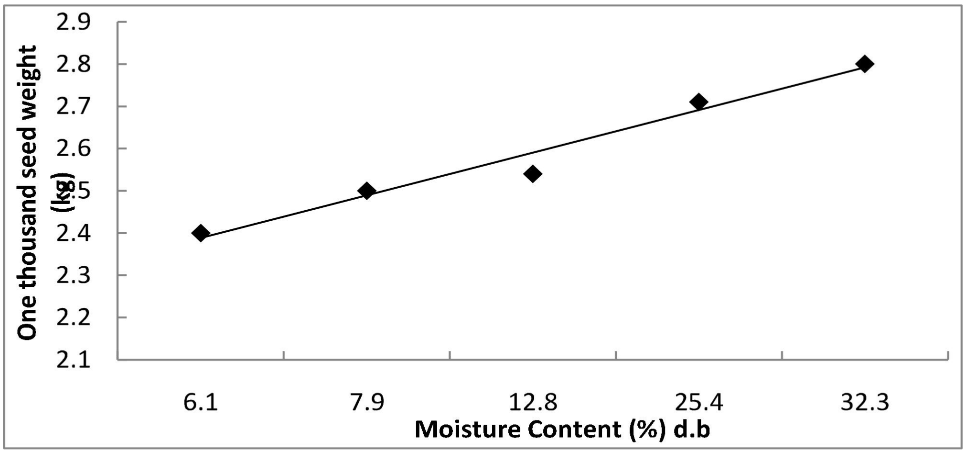

Figure 4: The effect of moisture content on the one thousand seed weight of Afzelia africana seed

Figure 4 shows that one thousand seed weight increased from 2.4 – 2.8kg in the moisture range of 6.1 – 32.3% d.b. This positive trend of one thousand seed weight with moisture content was due to increase in weight gained by the presence of more water thereby producing a heavier seed.

The relationship between moisture content and mass of one thousand seeds was seen to be linear and can be expressed with the following equation:

$$W1000 = 0.101M + 2.287 \quad (20)$$

with value of coefficient of determination R^2 = 0.9697, where W1000 is the one thousand seed weight (kg).

Similar trend was reported by Irtwange and Igbeka, (2002) for African yam bean, Kaleemullah and Gunasekar, (2002) for arecanut, Aviara et al., (2005b) for sheanut, Isik, (2007) for round red lentil grain and Simoyan et al., (2007) for Samaru sorghum. This result on seed mass can be applied practically in the design of equipment for cleaning, separation, conveying and elevating unit operations. It can also be used to estimate the overall bulk weight of *Afzelia africana* seeds during bulk handling.

3.4 Particle Density

The effect of moisture content on particle density of *Afzelia africana* seeds is presented in Figure 5.

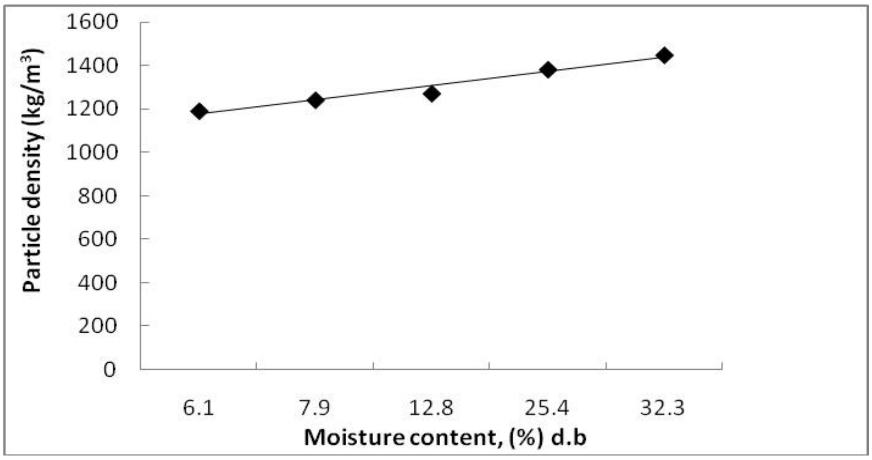

Figure 5: Effect of moisture content on the particle density of Afzelia africana seed

The Figure shows that particle density increased from 1190 – 1446kg/m3 as the moisture content increases from 6.1 – 32.3% d.b. The increase in particle density of Afzelia africana seeds with increase in moisture content may be due to the higher rate of increase in mass of the individual seeds than its volume as the moisture content increased. The relationship existing between particle density and moisture content was found to be linear and can be represented by the regression equation:

$$\rho t = 65.2M + 1109.6 \quad (21)$$

with correlation coefficient of R^2 = 0.9622, where: ρt = Particle density (kg/m^3).

Baumler et al., (2006) and Coskuner and Karababa (2007) reported polynomial relationship between particle density and moisture content for safflower and coriander seeds respectively. An increase in particle density had also been reported by Perez-Alegria et al., (2001) for parchment coffee bean, Ozarslan, (2002) for cotton seed, Aviara et al., (2005 a) for *Balanites aegyptiaca* nuts, Aviara et al., (2005 b) for sheanut and Isik (2007) for round red lentil grain. The particle density of agricultural products have been reported to play significant importance in the design of silos and storage bins, maturity and quality evaluation of products which are essential to grain

Corresponding author's e-mail address: nddyaviara@yahoo.com

marketing (Irtwange and Igbeka, 2002) and also could prove useful in the separation and transport of the seeds by hydrodynamic means (Omobuwajo et al., 2003).

3.5 Bulk Density

The effect of moisture content on the bulk density of Afzelia africana seeds is shown in Figure 6.

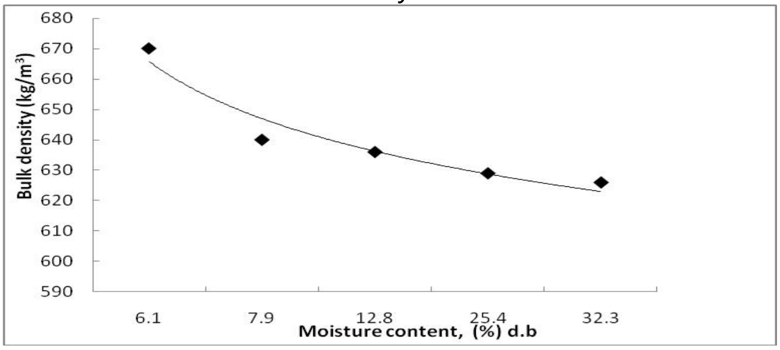

Figure 6: Effect of moisture content on the bulk density of Afzelia africana seed

Bulk density was found to decrease from 670 – 626kg/m^3 as the moisture content increased from 6.1 – 32.2% (d.b). It was seen that as the moisture content increased, the size of the seeds increased resulting in less mass and amount of seeds occupying equal bulk volume. Therefore, the decrease in bulk density of the seeds resulted from increase in size with moisture content. Also, the resistance of the seeds to consolidation may have increased with moisture content as a result of increase in internal pressure. The relationship existing between moisture content and bulk density was observed to be a power law relationship and it's further represented by the equation:

$$\rho b = 665.78M \, -0.041 \qquad (22)$$

with the coefficient of determination R^2 = 0.9379, where: ρb = Bulk density (kg/m^3).

Carman (1996), Gupta and Das (1998), and Visvanathan et al., (1996) found the bulk density of lentil seeds, sunflower seeds and neem nuts, respectively, to decrease as the seed moisture content increases. Bulk density is applied practically in the calculation of thermal properties in heat transfer problems, in determining Reynold's number of materials and in predicting pressures in storage structures as well as chemical composition.

3.6 Porosity

The porosity of Afzelia africana seeds calculated from relevant experimental data in the moisture range of 6.1 – 32.2% (d.b) increased from 43.7 – 56.6%. The effect of moisture on porosity is presented in Figure 7.

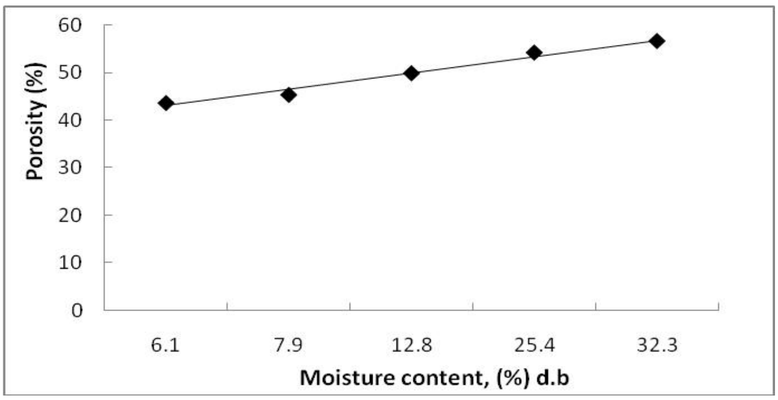

Figure 7: Effect of moisture content on the porosity of *Afzelia africana* seed

The increase in porosity may bedue to decrease in compaction and increase in void spaces within the grain mass as bulk density decreased, invariably increasing the porosity of the seed in bulk. This may be expected because the larger the size of an object, the more loosely packed it becomes. The relationship existing between moisture content was found to be linear and can be represented with the equation:

$$\varepsilon = 3.46M + 39.58 \qquad (23)$$

with coefficient of determination R^2 = 0.9809, where: ε = Porosity (%).

The dependence of porosity on true and bulk densities are definitely different for each seed or grain with increasing moisture content. A decrease in porosity with moisture content was reported by Irtwange and Igbeka (2002) for African yam bean. Chowdhury et al., (2001) and Konak et al., (2002) reported a linear increase in porosity with increase in moisture content for gram and chick pea seed. Baryeh (2002) and Coskuner and Karababa (2007) reported a polynomial relationship between porosity and moisture content for millet seeds and coriander seeds. These results indicate that porosity of seeds of different crops could respond differently in manner, which could be dependent on their morphological characteristics.

3.7 Surface Area

The effect of moisture content on the surface area of *Afzelia africana* seeds is presented in Figure 8.

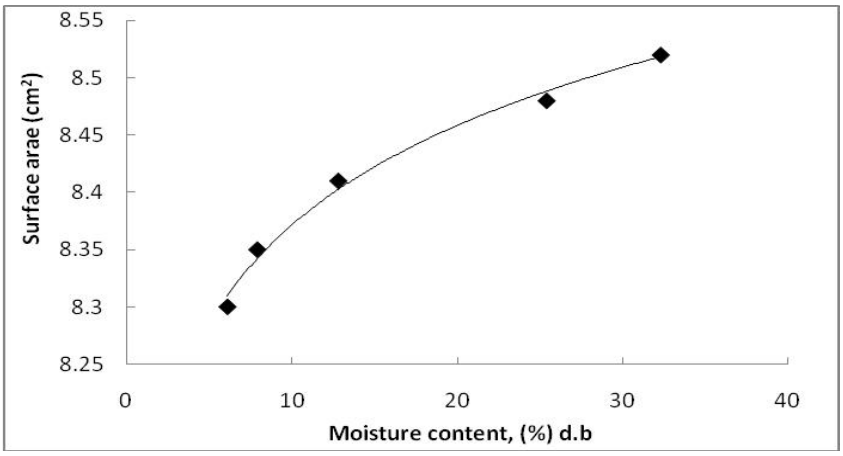

Figure 8: Effect of moisture content on the surface area of Afzelia africana seed

The surface area of *Afzelia africana* seeds increased from 8.3 – 8.52cm^2 in the moisture range of 6.1 – 32.3% (d.b). The increase in surface area is mainly due to the increase in the linear dimensions with increase in moisture content thereby resulting in increased volume causing the seeds to occupy a larger area. The relationship found between moisture content and surface area of the seeds was logarithmic and can be expressed using the equation:

$$S_a = 0.1248\ln(M) + 8.0841 \qquad (24)$$

with the coefficient of determination R^2 = 0.9913, where: S_a = Surface area (cm^2).The trend of increasing surface area with moisture content have been reported by Fatholahzadeh et al. (2008) for Apricot kernel from 282.35 – 297.24mm^2, and Isik (2007) for soybean grains from 118.756 – 197.654 mm^2. Aviara et al. (2014) reported the seed surface area of Brachystegia eurycoma seeds

Corresponding author's e-mail address: nddyaviara@yahoo.com

to increase from 7.67 – 8.48cm^2. Also, Tavakoli et al. (2009) reported the surface area for barley grains to increase linearly from 56.66 – 71.09mm^2.

3.8 Angle of Repose

The variation of angle of repose with moisture content is shown in Figure 9.

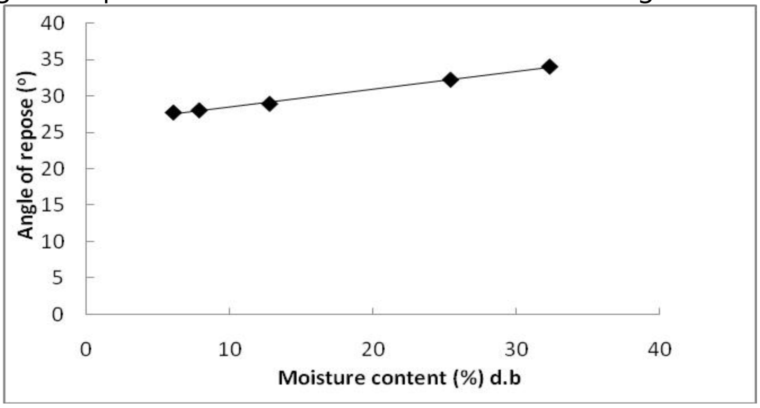

Figure 9: Effect of moisture content on angle of repose of *Afzelia africana* seed

From the Figure, it was observed that the angle of repose increased from 27.7 – 34° as the moisture content increased from 6.1 – 32.3% (d.b). It was also observed that at higher moisture content within the above range, seeds tend to stick together resulting in better stability and less flowability, which must have resulted in increases in the value of θ. The relationship between moisture content and the angle of repose of the seeds was found to be linear with the equation:

$$\theta = 0.2437M + 26.042 \quad (25)$$

with the coefficient of determination R^2 = 0.9966, where: θ = Angle of repose (°).

A linear relationship between angle of repose and moisture content was also observed for cumin seed and coriander seed (Singh and Goswani, 1996; Yalcin and Ersan, 2007). However, a logarithmic relationship was observed for okra seed and sheanut (Sahoo and Srivastava, 2002; Aviara et al., 2005) respectively. This property is used in the design of discharging equipment for particulate solids.

3.9 Static Coefficient of Friction

The static coefficient of friction obtained experimentally on four structural surfaces against moisture content in the range of 6.1 – 32.3% (d.b) is presented in Figure 10.

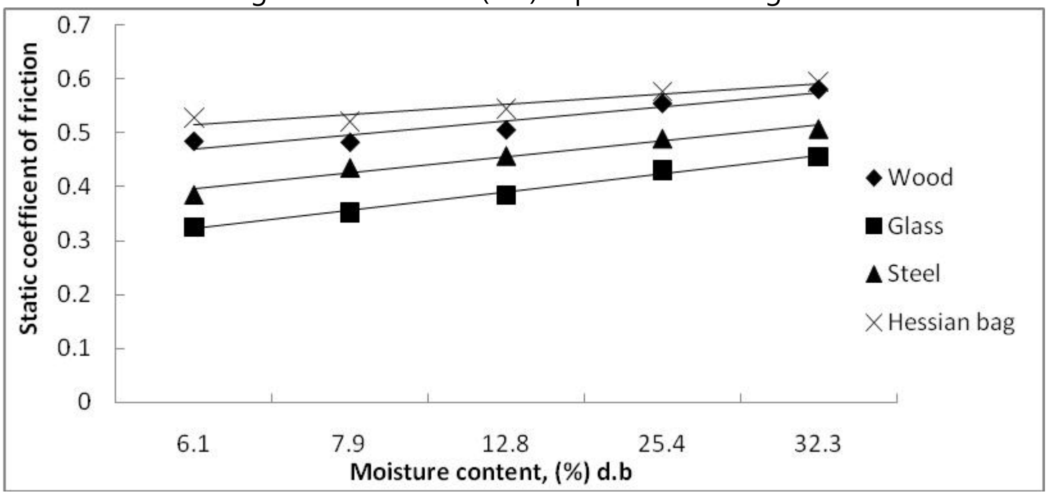

Figure 10: Effect of moisture content on the static coefficient of friction of *Afzelia africana* seed

It was seen that the static coefficient of friction of *Afzelia africana* seeds initially decreased with increase in moisture content for wood and hessian bag but later increased at higher moisture content of the experimental range, while it completely increased on galvanised steel sheet and fibre glass. The static coefficient of friction varied according to the surface. It could be said that at higher moisture content, the seeds became rough thereby increasing friction characteristics. The static coefficient of friction was maximum on hessian bag (0.528 – 0.595), followed by wood (0.485 – 0.581), galvanised steel sheet (0.385 – 0.507) and was minimum on fibre glass (0.325 – 0.456).

The relationship existing between moisture content and the static coefficient of friction of *Afzelia africana* seeds for different structural surfaces were found to be linear and can be expressed with the following equations:

$$\mu_{hb} = 0.019M + 0.4962 \quad (26)$$

$$\mu_{w} = 0.0264M + 0.4428 \quad (27)$$

$$\mu_{gs} = 0.0298M + 0.3652 \quad (28)$$

$$\mu_{fg} = 0.0341M + 0.2873 \quad (29)$$

with values of coefficient of determination R^2 = 0.8907, 0.9033, 0.9691, and 0.9904 respectively.

where: μ_{hb} = Static coefficient of friction on hessian bag, μ_{w} = Static coefficient of friction on wood, μ_{gs} = Static coefficient of friction on galvanised steel sheet, μ_{fg} = Static coefficient of friction on fibre glass.

Singh and Goswani (1996), Milani et al., (2007) and Kheiralipour et al., (2008) reported linearly increasing trends on the static coefficient of friction for cumin seed, cucurbit seed and wheat respectively. This property is very useful in the product movements during processing. In the design of silos, bins and other storage facilities for the seed, the vertical load on the walls of the structure or equipment is determined by the friction coefficient.

3.10 Kinetic Coefficient of Friction

The kinetic coefficient of friction obtained experimentally on four structural surfaces against moisture content in the range of 6.1- 32.3% (d.b) is presented in Figure 11

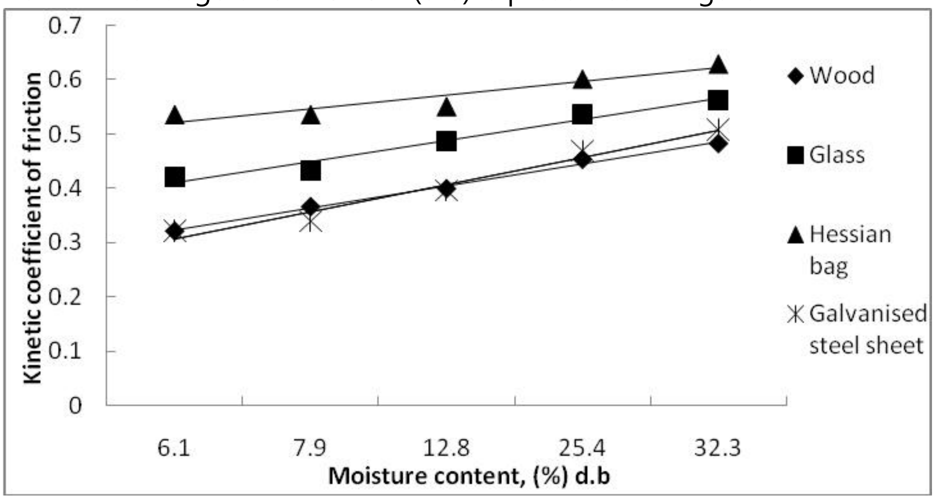

Figure 11: Effect of moisture content on the kinetic coefficient of friction of *Afzelia africana* seed

The Figure shows that the kinetic coefficient of friction increased with increase in moisture content and well varied with structural surface.The highest friction coefficient was recorded on hessian bag (0.536 – 0.63), followed by fibre glass (0.42 – 0.563) and galvanised steel sheet

Corresponding author's e-mail address: nddyaviara@yahoo.com

(0.321 – 0.509), while the least was recorded for wood (0.321 – 0.482). This could be due to the surface characteristics of the seeds with increasing moisture content.

The relationship existing between moisture content and the kinetic coefficient of friction of *Afzelia africana* seeds for different structural surfaces were found to be linear and can be expressed with the following equations:

$$\mu_{hb} = 0.0254M + 0.4948 \quad (30)$$

$$\mu_{w} = 0.0409M + 0.2815 \quad (31)$$

$$\mu_{gs} = 0.0506M + 0.255 \quad (32)$$

$$\mu_{fg} = 0.0389M + 0.3711 \quad (33)$$

with values of coefficient of determination R^2 = 0.8848, 0.9932, 0.9702, and 0.9713 respectively.

where: μ_{hb} = Kinetic coefficient of friction on hessian bag, μ_{w} = Kinetic coefficient of friction on wood, μ_{gs} = Kinetic coefficient of friction on galvanised steel sheet, μ_{fg} = Kinetic coefficient of friction on fibre glass.

Carman (1996), Ebubekir et al. (2004) and Sessiza et al. (2007) reported linear increase of kinetic coefficient of friction for lentil seed, fenugreek seeds and capper fruit seeds, respectively.

Kinetic coefficient of friction is needed before the power requirements for continued flow of granular or unconsolidated materials can be estimated.

3.11 Coefficient of Restitution

The variation of the coefficient of restitution of *Afzelia africana* seeds with moisture levels in the range 6.1 – 32.3% (d.b), drop heights between 50 – 150cm and different structural surfaces namely Hessian bag, wood, fibre glass and galvanised steel sheet are presented in Figures 12 – 15.

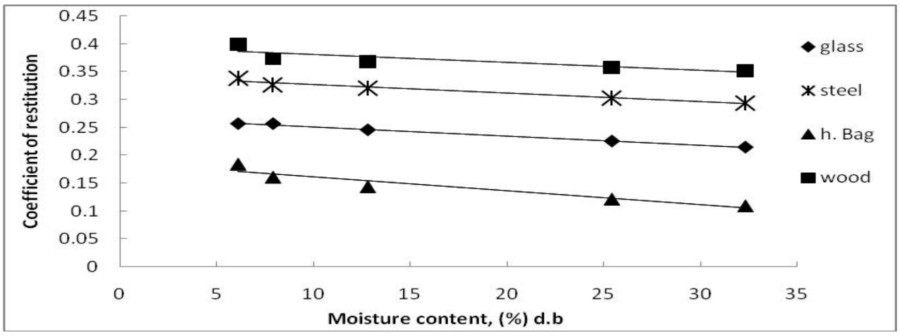

Figure 12: Effect of moisture content on the coefficient of restitution of *Afzelia africana* seed from a drop height of 50cm

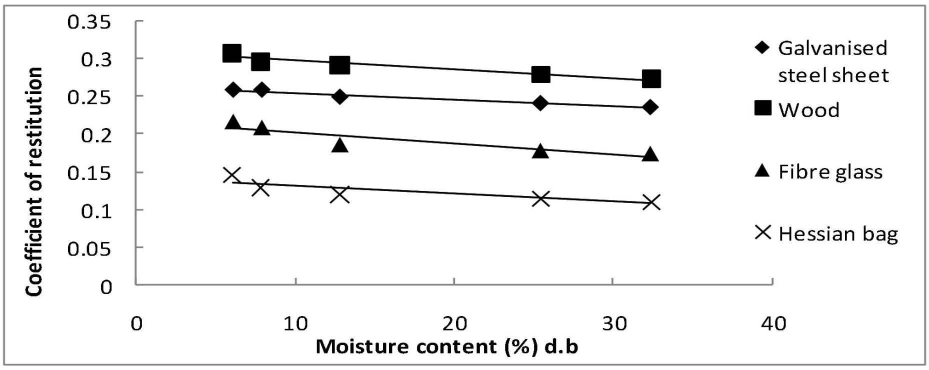

Figure 13: Effect of moisture content on the coefficient of restitution of *Afzelia africana* seeds from a drop height of 90cm

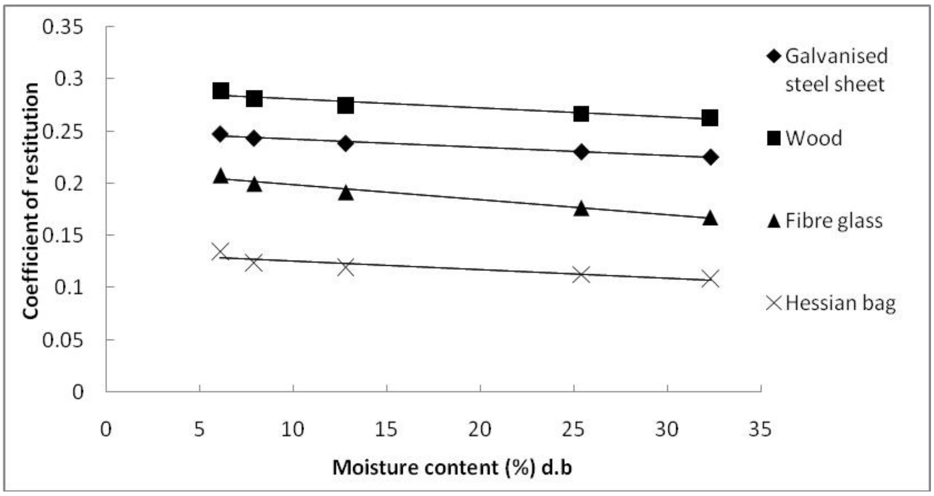

Figure 14: Effect of moisture content on the coefficient of restitution of *Afzelia africana* seeds from a drop height of 120cm

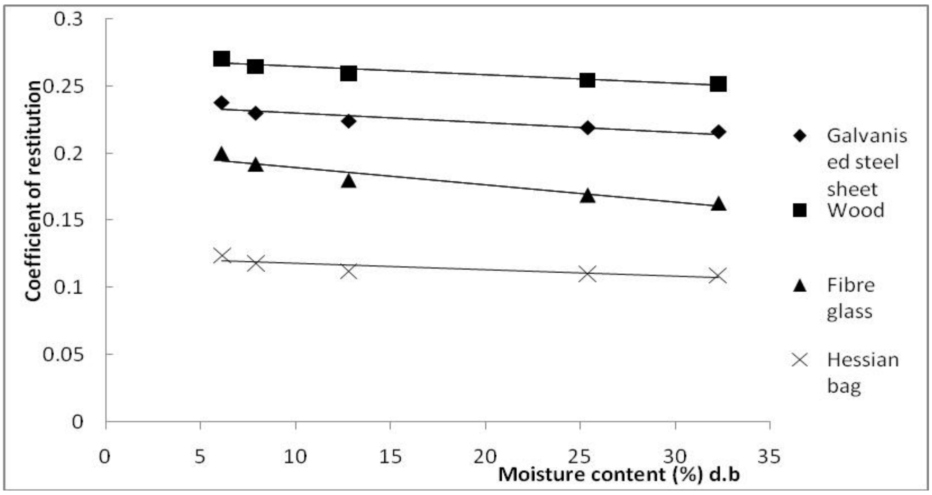

Figure 15: Efect of moisture content on the coefficient of restitution of *Afzelia africana* seeds from a drop height of 150cm

Coefficient of restitution decreased with increase in drop height and also decreased with increase in moisture content and exhibited a linear relationship with moisture content on all the surfaces. The decrease in the coefficient of restitution appeared to be almost entirely as a result of increased impact velocity at increased drop heights. The non-spherical seed's impact on a point increased the local stress in the material, thus causing reduction in coefficient of restitution. The relationship between coefficient of restitution and moisture content on all surfaces at various heights can be expressed using linear equations of the form:

$$C.R = xM + y \tag{34}$$

where: C.R = Coefficient of restitution, x and y are constants and M = Moisture content (%).

The constants in Equation (34) obtained for the seeds on different structural surfaces and drop heights with the coefficients of determination are presented in Table 1.

It was also observed that coefficient of restitution depends not only on the impact velocity but also on the seed composition and structural surface roughness as the highest coefficient of restitution was observed on wood, followed by galvanised steel sheet, fibre glass and least on

Corresponding author's e-mail address: nddyaviara@yahoo.com

hessian bag at all drop heights. Aviara et al. (2010) and LoCurto et al. (1997) reported decrease in the coefficient of restitution with increase in moisture content and drop height for Mucuna flagellipes and Soy bean respectively. Decrease in coefficient of restitution was also reported by Jayan and Kumar (2004) for maize and red gram and by Ozturk et al. (2010) for chickpea and lentil seeds.

Table1: Values of the constants in Equation (34) expressing the coefficient of restitution of Afzelia africana seeds as a function of moisture content at different drop heights on different structural surfaces

Structural surfaces	Drop Heights (cm)	Constants		R^2
		x	y	
Hessian bag	50	-0.0025	0.186	0.908
	90	-0.0011	0.1415	0.7593
	120	-0.0008	-0.134	0.8469
	150	-0.0005	-0.1226	0.7304
Fibre glass	50	-0.0017	0.2681	0.9959
	90	-0.0015	0.2174	0.8217
	120	-0.0014	0.2129	0.9765
	150	-0.0013	0.2027	0.9264
Galvanised steel sheet	50	-0.0016	0.3424	0.965
	90	-0.0009	0.2628	0.9674
	120	-0.0008	0.2508	0.9767
	150	-0.0007	0.2374	0.8438
Wood	50	-0.0014	0.3943	0.7457
	90	-0.0011	0.3085	0.9284
	120	-0.0009	0.2898	0.91
	150	-0.0006	0.2712	0.8887

3.12 Specific Heat

The variation of specific heat of *Afzelia africana* seeds with moisture content in the range of 6.1 – 32.3% (d.b) is presented in Figure 16.

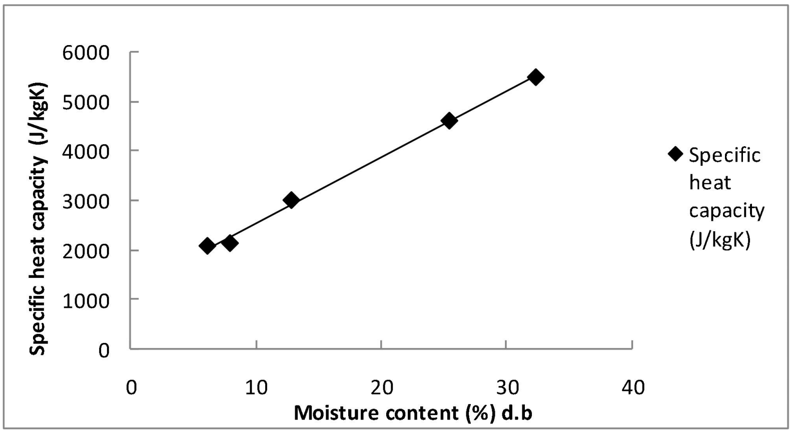

Figure 16: Effect of moisture content on the specific heat capacity of *Afzelia africana* seeds

It was observed that the specific heat of *Afzelia africana* seeds increased linearly with increase in moisture content from 2080.3 – 5488.2J/kgK. The relationship between moisture content and the specific heat capacity of the seeds can be further expressed using the linear equation:

$$C_s = 133.03M + 1215.2 \qquad (35)$$

with the value for the coefficient of determination R^2 = 0.997, where: C_s = Specific heat capacity of the seeds (J/kgK) and M = Moisture content (%, db).

Desphande and Bal (1999), Aviara and Haque (2001) and Aviara et al., (2008) reported a similar trend of linear increase in specific heat for cumin seeds, sheanut kernel and guna seeds and kernel, respectively. Knowledge of the specific heat of seeds as well as the effect of moisture content and temperature on it value is essential for the design of thermal processing systems, as varying moisture content and temperature could form some of the process conditions. The thermal properties of the seed are also essential in the development of processes and equipment needed in drying and storage.

4.0 Conclusion

This study investigated the moisture dependence of some engineering properties of *Afzelia africana* seeds (axial dimensions, arithmetic mean diameter, geometric mean diameter, aspect ratio, one thousand seed weight, surface area, particle density, bulk density, porosity, angle of repose, static and kinetic coefficient of friction, coefficient of restitution and specific heat)in the moisture range of 6.1 – 32.3% d.b. The outcome of the study revealed that the major, intermediate and minor axial dimensions, the arithmetic and geometric mean diameters as well as the aspect ratio of *Afzelia africana* seed increased linearly with moisture content. One thousand seed weight, particle density, porosity and angle of repose also increased linearly as the moisture content increased. Surface area of the seed increased logarithmically with increase in moisture content, while bulk density decrease at a trend that had power relationship with increase in moisture content. Static coefficient of friction increased linearly with moisture content and varied with structural surfaces with the highest values being on hessian bag, followed by wood, steel and the least on glass. Kinetic coefficient of friction also increased linearly with moisture content and its highest values were on hessian bag, followed by glass, galvanised steel sheet and the least was on wood. Coefficient of restitution decreased with increase in drop height as well as increase in moisture content and varied with surface. Specific heat of the seeds increased linearly with moisture content and ranged from 2080.3 – 5488.2J/kgK.

References

Atlantus, E. and Yaldiz, M. 2007. Effect of moisture content on some physical properties of faba bean grain. Journal of Food Engineering, 78:174-183.

Amin, MN., Hossani, MA. and Roy, KC. 2004. Effects of moisture content on some physical properties of lentil seeds. Journal of Food Engineering, 65(1): 83-87.

AOAC, (1980). Official Methods of Analysis (13th ed.). Washington, DC: Association of Official Analytical Chemists.

Aviara, NA., Haque, MA. and Ogunjimi, LAO. 2008. Thermal properties of guna seed. International Agrophysics, 22:291-297.

Aviara, NA., Haque, MA. and Izge, IA. 2000. Physical and frictional properties of sheanut. Agro Science, 2(1):19-34.

Corresponding author's e-mail address: nddyaviara@yahoo.com

Aviara, NA. and Haque, MA. 2001. Moisture dependence of thermal properties of sheanut kernel. Journal of Food Engineering, 47(2):109-113.

Aviara, NA. and Haque, MA. 2000. Moisture dependence of densities, coefficient of friction and angle of repose of guna seed and kernel. Journal of Engineering Application, 2:44-53.

Aviara, NA., Ajibola, OO. and Oni, SA. 2003. Effect of moisture content and temperature on the specific heat of soybean TGX 1440-IE. Proceedings of the 4th International Conference of the Nigeria Institution of Agricultural Engineers, 25:183-193.

Aviara, NA., Gwandzang, MI. and Haque, MA. 1999. Physical properties of guna seeds. Journal of Agricultural Engineering Research, 73:105-111.

Aviara, NA. and Haque, MA. 2002. Processing and storage of guna crop in the North East Arid Region of Nigeria. Agricultural Mechanization in Asia, Africa and Latin America, 33:49-54.

Aviara, NA., Onuh, OA. and Ehiabhi, SE. 2010. Phyisical properties of *Mucuna Flagellipes* nuts. GSB seed Science and Biotechnology, 4(1): 59-68.

Aviara, NA., Oluwole, FA. and Haque, MA. 2005. Effect of moisture content onsome physical properties of sheanut (Butyrosperm Paradoxum). International Agrophysics, 19:193-198.

Aydin, C., Ogut, H. and Konak, M. 2002. Some physical properties of Turkish Mahaleb. Biosystems Engineering, 82(2):231-234.

Barbosa-Canovas, GV., Juliano, P. and Palag, M. 2004. Engineering property of Foods, in Food Engineering (Ed. Gustavo V. Barbosa-Canovas). In Encyclopaedia of the Support Systems (EOLSS), developed under the auspices of the UNESCO, EOLLAS publishers, OXFORD, UK, (http://www.eolass.net).

Baryeh, EA. 2002. Physical properties of millet. Journal of Food Engineering, 51:39-46.

Brenan, JPM. 1967. Leguminosae, subfamily Caesalpnoideae In: Milne-Redhead, E. and Polhill, RM. (Eds). Flora of tropical east Africa: crown agents for Overseas Governments and Administrations, London, United Kingdom. 230 pp.

Burkill, HM. 1995. The useful plants of west tropical Africa. 2nd Edition. Volume 3, families J – L. Royal botanic gardens, Kew, Richmond, United Kingdom. 857 pp.

Burubai, W., Akor, AJ., Igoni, AH. and Puyate, YT. 2007. Some physical properties of African nutmeg (Monotora Mystica). International Agrophysics, 21:123-126.

CAB 2005. CAB InternationalForestry Compendium:Afzelia Africana. [Internet]

http://www.cabicompendium.org/fc/datasheet.asp? Downloaded 14/6/2015.

Carman, K. 1996. Some physical properties of Lentil seeds. Journal of Agricultural Engineering Research, 63:87-92.

Cetin, M. 2007. Physical properties of barbunian bean (Phaseolus Vulgaris L.Cv. 'Barbunia') seed. Journal of Food Engineering, 80:353-358.

Chung, JH. and Verma, LR. 1989. Determination of friction coefficients of peanuts. Transactions of the ASAE. 745-750.

Coskun, MB., Yalcin, I. and Ozarslan, C. 2006. Physical properties of sweet corn seed (Zea mays Saccharastasturt). Journal of Food Engineering, 74:523-528.

Desphande, SD. and Bal, S. 1999. Specific heat of soybean. Journal of Food Processing Engineering, 22:469-477.

Desphande, SD., Bal, S. and Ojha, TP. 1993. Physical properties of soybean. Journal of Agricultural Engineering Resources, 56:89-98.

Dursun, E., and Dursun, I. 2005. Some physical properties of caper seed. Biosystems Engineering, 92(2):237-245.

Dutta, SK., Nema, VK. and Bhardwaj, RK. 1988a. Physical properties of gram. Journal of Agricultural Engineering Research, 39:269-275.

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

Ebubekir, N., Eugin, O. and Faruk, OT. 2004. Some physical properties of Fenugreek seeds. Journal of Food Engineering, 71:37-43.

Eke, CNU., Aseogwu, SN. and Nwandikom, GI. 2007. Physical properties of Jackbean (Carnavatia Ensiformis). Agricultural Engineering International: The CIGR e-journal, manuscript of FP 07 014.

Garnayaka, DK., Pradhana, RC., Narka, SN. and Bhatnagar, N. 2008. Moisture dependent physical properties of Jatropha seed. Industrial Crops and Products, 27(1):123-129.

Gupta, RK. and Das, SK. 1997. Physical properties of sunflower seed. Journal of Agricultural Engineering Research, 66:1-8.

Igbozulike, AO. and Aremu, AK. 2009. Moisture dependent physical properties of Garcinia kola seeds. Journal of Agricultural Technology, 5(2):239-248.

Irtwange, SV. and Igbeka, JC. 2002. Selected moisture dependent frictional properties of two African yam bean accessions. Applied Engineering in Agriculture, 18(5):559-565.

Joshi, DC., Das, SK. and Mukherjee, RK. 1993. Physical properties of pumpkin seed. Journal of Agricultural Engineering Research, 54:219-229.

Kazarian, EA. and Hall, CW. 1965. The thermal properties of grains. Transactions of the ASAE, 31:33-37/40.

Keranmat, JM., Jafari, A., Rafiee, S., Keyhani, AR. and Mirasheh, R. 2007. Somephysical properties of date fruit (Cv. Lasht). Agricultural Engineering International: The CIGR e-journal manuscript FP 019, Vol. IX. August, 2007.

Kheirahipour, K., Karimi, M., Tabatabaeefar, A., Nadari, M., Khoubaht, G. and Heidarbeigi, K. 2008. Moisture dependent physical properties of wheat (triticum aestivum L.). Journal of Agricultural Technology, 4(1):53-64.

Kocabiyik, HA., Kayisoglu, BB. and Tezer A. 2009. Effect of moisture content on the thermal properties of pumpkin seed. International Journal of Food Properties, 12(2):277-285.

Louppe, D. 2000. Afzelia Africana: une essence precieuse et plastique. Poster abstract. In: UFRO. Forests and Society: the role of research. Vienna, Austria.

Oteng-Amoako, AA. 2006. 100 Tropical African Timber Trees from Ghana: tree description and wood identification with notes on distribution, ecology, silviculture, ethnobotany and wood uses. 304 pp.

Madubike, FN., Ojimedukwe, PC. and Ajah, PO. 1994. Proximate composition, energy content of Afzelia Africana and Brachystegia Eurycoma seeds. Plant Foods for Human Nutrition, 46(4):339-344, Dol:10.1007/BF 010884304.

Corresponding author's e-mail address: nddyaviara@yahoo.com

Milani, E., Seyed, M., Razavi, A., Koocheki, A., Nikzadeti, V., Vahedi, N., Moeinfard, M., and Gholanhosseinpour, A. 2007. Moisture dependent physical properties of curcubit seeds. International Agrophysics, 21:157-168.

Moshenin, NN. 1986. Physical properties of plant and animal materials. Gordon and Breach press. New York.

Ndukwu, MC. 2009. Determination of selected physical properties of Brachystegia eurycoma seeds. Journal of Agricultural Engineering Research, 55:165-169.

Nimkar, PM. and Chattopadhyay, PK. 2001. Some physical properties of green gram. Journal of Agricultural Engineering Resources, 80(2):183-189.

Ogunjimi, LAO., Aviara, NA. and Aregbesola, OA. 2002. Some engineering properties of locust bean seed. Journal of Food Engineering, 55:95-99.

Oje, K. 1994. Moisture dependence of some physical properties of cowpea. Ife Journal of Technology, 4:23-27.

Oje, K. and Ugbor, EC. 1991. Some physical properties of oil bean seed. Journal of Agricultural Engineering Research, 50:305-313.

Power, PP. 2006. Effects of moisture content on the engineering properties (physical) of Moringa Africana seeds. B.Eng. University of Maiduguri, Maiduguri, Nigeria.

Sacande, M. 2007. Afzelia Africana. Seed leaflet, (118). Millennium bank seed project. Forest and Landscape Denmark. 2 pp.

Sacilik, K., Ozturk, R. and Keskin, R. 2002. Some physical properties of thrump seed. Biosystems Engineering, 86(2):191-198.

Sahoo, PK. and Srivastava, AP. 2002. Physical properties of Okra seed. Biosystems Engineering, 83(4):441-448.

Selvi, KC., Pinar, Y. and Yesilobglu, E. 2006. Some physical properties of linseed.Biosystems Engineering, 95(4):607-612.

Sessiz, A., Esgici, R. and Kizli, S. 2007. Moisture dependent physical properties of caper (capparis spp.) fruit. Journal of Food Engineering, 79(4):1426-1431.

Shepherd, H. and Bhardwaj, RK. 1986. Thermal properties of pigeon pea. Cereal Foods World, 31:466-470.

Simonyan, KJ., El-Okene, AM. and Yiljep, YD. 2007. Some physical properties of Samaru sorghum 17.Agricultural Engineering International:The CIGR e-journal, manuscript FP07 008. Vol. IX.

Simonyan, KJ., Yijep, YD., Oyatoyan, OB. and Bawa, GS. 2009. Effects of moisture content on some physical properties of LabLabpurpureus (L.) seeds. Agricultural Engineering International: The CIGR ejournal, Manuscript 1279. Vol. XI., July 2009.

Singh, KK. and Goswami, TK. 1999. Thermal properties of cumin seed. Journal of Food Engineering, 54(4):181-187.

Singh, KK. and Goswami, TK. 1996. Physical properties of cumin seed. Journal of Agricultural Engineering Research, 64:93-98.

Suthar, SH. and Das, SK. 1996. Some physical properties of Karinga seed. Journal of Agricultural Engineering Research, 54:219-229.

Tabatabaeefar, A. 2003. Moisture dependent physical properties of wheat. International Agrophysics, 17:207-211.

Timbers, GE. 1975. Properties of rapeseed: Thermal conductivity and specific heat. Canadian Agricultural Engineering, 17:81-84.

Tunde-Akintunde, TY. and Akintunde, BO. 2007. Effect of moisture content and variety on selected physical properties of beniseed.Agricultural Engineering International: The CIGR ejournal, Manuscript FP 07 021. Vol. IX.

Yalcin, C. and Ersan, K. 2007. Physical properties of Coriander seeds. Journal of Food Engineering, 80(2):408-416.

Zewdu, A. and Solomon, W. 2008. Moisture dependent physical properties of grass pea (Lathyrus sativus L.) seeds. Agricultural Engineering International. The CIGR ejournal. Manuscript FP 06 027. Vol.X

Corresponding author's e-mail address: nddyaviara@yahoo.com