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ORIGINAL RESEARCH ARTICLE

EFFECT OF MOISTURE CONTENT ON SOME PHYSICAL PROPERTIES OF RED KIDNEY BEAN *(Phaseolus Vulgaris L.)* SEED GROWN IN NORTH EASTERN NIGERIA

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ABSTRACT

This study was aimed at determining some physical properties of red kidney bean seed as a function of moisture content. In the moisture range of 6.84-15.74% (d.b), seed length, width and thickness increased from 11.4-16.83mm, 6.2-8.87mm and 4.3-5.16mm, and Arithmetic and Geometric diameters increased from 8.6-10.29mm and from 8.3-9.14mm, respectively. In the above moisture range, one thousand seed weight, seed surface area, true density, and porosity increased linearly, while sphericity increased logarithmically, and angle of repose increased as a polynomial of the second order with moisture content. Bulk density decreased with increase in moisture content in the above moisture range. Static coefficient of friction on all the structural surfaces applied increased logarithmically with moisture content, and kinetic coefficient of friction on the surface all increased linearly with moisture content except on fiber glass where the increase was polynomial of the second order. Static and kinetic coefficients of friction were highest on Hessian bag material and lowest on fiber glass. Regression models that could be used to express the relationship between the physical properties and moisture content, with high coefficients of determination, were established. The data obtained in this study would be applicable in the design of red kidney bean seed handling and storage facilities.

1.0 Introduction

Beans are members of the Fabaceae family, which includes legumes. They are economically and nutritionally important food crops that are cultivated and consumed worldwide, (Sneh et al., 2020). Legumes are of *Leguminosae* plant family, and they constitute one of the World's most important groups of plants; second only to cereals in providing food crops for World agriculture. They represent an important source of dietary protein for large segment of the human population and domestic animals. Pulses as listed by the Food and Agricultural Organization (FAO), including French, Navy, Pinto, Field, Haricot, China, Marrow frijoles, Snap, String, Wax, Black and White kidney beans are the most widely produced and consumed food legumes in Asia, South America, Latin America and Africa, where they serve as good sources of protein with good nutritional and functional properties (Mundi, 2012).

The kidney bean is a variety of the common bean (*P. vulgaris L.*), so named because of its kidney-like shape and its color. The optimum moisture content of the seeds for their harvesting, shelling and storage ranges between 12 and 14%. The color of kidney beans ranges all the way from very light red to very dark, or almost purple. 'Hard seed' is a term reserved for those seeds that take up water slowly or not at all during soaking because of a relatively impermeable seed coat. 'Hard seeds' are often found after storage of dried beans in an atmosphere of very low humidity. A small percentage of hard seeds may be expected in kidney beans held under such conditions. These beans generally do not soak up completely and may remain undesirably hard, even after canning (Susan, 2016). The crop lacks biological Nitrogen fixation due to poor nodulation. Therefore, it needs good amount of Nitrogen of about 100 to 125 kg/ha. This crop also requires 60 to 70 kg of P205/ha and adding potassium hardly affects the yield.

Figure 1a and b show the red kidney bean pods and seeds, respectively.

Figure 1: (a) Red kidney bean seeds pods, **(b)** Red kidney bean seeds

To harvest the beans requires uprooting and pulling the entire bean plant out of the soil and hanging it upside down in a dark, dry, and warm spot for a few days (or in some cases weeks) to cure the beans. Once the plants become dried and hardened completely, the pods are plucked from the bean plant and arranged on a wooden rack or solid platform.

The harvested pods are then allowed in to dry in sun for 3 to 4 days after which they are shelled to obtain the seeds using bullocks or with sticks and or sickles. Seed bins are used to store the clean red kidney bean seeds (Singh and Chandra, 2020). The ever-increasing functional and utilization requirements of agricultural products together with the complexity of modern technology for their production, processing and storage necessitate better knowledge of their engineering properties so that machines, processes and handling operations can be designed for maximum efficiency and highest quality of end products. For instance, the application of physical properties such as shape which is an important parameter for stress distribution in materials under load is important in developing sizing and grading machines and for analytical prediction of drying behavior. The properties may be moisture dependent and this can affect the adjustment and performance of the agro-processing equipment. A range of moisture contents of the seed usually exist within which optimum performance is achieved therefore, the effect of moisture content on the physical properties of agricultural grains and seeds, is of important consideration in the design of the handling, processing and storage equipment (Aviara et al., 1999).

The aim of this study is to investigate the effect of moisture content on the physical properties of red kidney bean (*Phaseolus vulgaris L.*) seed. The properties addressed are axial dimensions (length, width and thickness), surface area of the seed 1000 seed weight, particle/true density, bulk density, angle of repose, porosity, sphericity, arithmetic mean diameter and geometric mean diameter at different moisture contents, as well as coefficients of static and kinetic friction of the seed on different structural surfaces and moisture levels.

2. Materials and Method

The bulk quantity of red kidney beans used in this study was obtained from a local market in Jalingo, Taraba State. The seeds were brought to the laboratory and cleaned manually to remove all foreign and other fine materials as well as damaged seeds. The bulk seeds were divided into five batches, four of the batches were conditioned to raise their moisture content to different moisture levels using the addition of calculated amount of water method according to Tamirat (2012). The remaining batch was used for experiment at the market storage moisture level. After conditioning, the seeds were stored in separate polyethylene bags which were sealed and kept in a refrigerator for 24 hours to enable the moisture to be uniformly distributed throughout the seeds. After the attainment of uniform seed moisture content, the bags were stored at room temperature. The market storage moisture of the seeds the four higher moisture levels obtained after the conditioning operation were determined by oven drying at 105°C for 8 hours, as recommended for proteinous crops by Aviara *et al.* (1999). This was carried out in three replicates and the average values were recorded.

The axial dimensions of the seeds, namely: the length (L), width (W), and the thickness (T) were measured using the method of Ndukwu (2009). This involved counting of 100 seeds selected randomly from the bulk material and using Micrometer screw gauge of 0.01mm accuracy to measure the different dimensions of each of the seeds. This method was preferred due to simplicity, accuracy and availability of material.

The arithmetic mean diameter was determined using Equation (1) (Mohsenin, 1986). Twenty (20) seeds were used for the determination of this parameter. The average values were recorded and used in the analysis.

$$A_m = \frac{L+W+T}{3} \tag{1}$$

where: A_m = Arithmetic mean diameter (mm), L = Length (mm),

W= Width (mm), T = Thickness (mm).

Geometric mean diameter was determined using Equation (2) (Joshi et al., 1993).

$$D_g = (LWT)^{1/3} \tag{2}$$

where: D_g = Geometric mean diameter (mm)

The sphericity was determined using Equation (3) (Aviara et al., 1999).

$$\varphi = \frac{D_g}{L} \tag{3}$$

where: φ = Sphericity

The one thousand seed weight of the seeds was determined using the method of Aviara et al. (2014). This involved counting 1000 seeds at each moisture level and pouring them dockage free into a container of a known weight, then weighing the seeds and the container using a digital electronic balance of approximately 0.001g reading accuracy. The weight of the container was subtracted from weight of the 1000 seeds + container to obtain the weight of the 1000 seeds. This experiment was replicated three times and the average value recorded.

The surface area of the seed was measured using the method of Aviara *et al.* (1999). This involved carefully wrapping the seeds with a foil paper, and cutting of the excess paper, then unwrapping the papers and spreading them carefully on a graph sheet and tracing the boundary

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formed using a pencil. The surface area of the seeds was then determined by counting the number of square boxes the traced boundary covered on the graph. This was repeated for all the four other moisture levels and at 20 trials each.

The true or particle density of the seeds was determined using the standard liquid displacement method as reported by Aviara *et al.* (2005). In this experiment, water was used as the liquid. The samples were coated with thin layer of epoxy resin, weighed individually on an electronic weighing balance and tied with a thread before immersing them individually into a 10ml cylinder containing a known volume of water and the volume of water displaced in the cylinder was noted and taken in order to obtain the volume of the seed. Twenty trials were carried out at each moisture level.

True density was calculated from the obtained values using Equation (4):

$$\rho_t = \frac{M}{V_f - V_i} \quad (4)$$

where: ρ_t = True density (g/cm^3), M = Mass of individual seed (g), Vi = Initial volume of water in the cylinder (ml), V_f = Final volume of water in the cylinder after submergence of seed (ml).

The bulk density was determined using the AOAC method as reported by Aviara et al, (1999). This method was used for accuracy and better understanding. Samples were poured from a height of 15cm into a 500ml cylinder of known mass. The sample was weighed on the balance and weight of the seeds was calculated by subtracting the mass of the cylinder alone from the final mass of seeds and cylinder, while the volume of the cylinder was taken to be the volume occupied by the seeds.

Three trials were carried out with their average calculated for each of the moisture levels.

The bulk density was then determined using the expression in Equation (5):

$$\rho_b = \frac{M_S}{V_S} \quad (5)$$

where: ρ_b = Bulk density (g/cm^3), Ms = Mass of seeds (g), Vs = Volume of seeds (cm^3).

The porosity of red kidney beans was determined using the formula (Singh and Chandra, 2014):

$$\varepsilon = (1 - \frac{\rho b}{\rho t}) \times 100 \quad (6)$$

where: ε = porosity (%), P_b = bulk density (kg/m^3), ρ_t = true density (kg/m^3)

In determining the angle of repose, the cylindrical pipe method was used as reported by Zewdu and Solomon (2007) and Aviara et al. (2014). A topless and bottomless cylinder was filled with seeds and slowly raised on a surface to leave the seeds piling to form a cone. The diameter of the cone was measured using a meter rule in order to obtain the radius and the height of the cone was also measured using a meter rule and these were used to calculate the angle of repose. Equation (7) due to Aviara *et al.* (2017) was applied to determine the angle of repose.

$$\theta = \tan^{-1} \left(\frac{h}{r} \right) \quad (7)$$

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

The static coefficient of friction was evaluated on plywood structural surface with wood gain parallel to direction of movement and plywood with wood grain perpendicular to the direction of movement. Other structural surfaces used were hessian bag material and fiber glass. The incline plane method as described by Dutta et al. (1988) and Aviara et al. (1999) was applied. This involved placing of an open ended box (150mm x 150mm x 150mm) on an adjustable tilting surface which was formed with structural surface. The box was filled with seed 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. The angle of tilt was read from a graduated scale and the tangent of the angle was taken as the static coefficient of friction. This was done for four samples of different moisture content.

For the kinetic coefficient of friction, the open-ended box used in determining the static coefficient of friction was placed on a horizontal surface. Plywood with wood grain parallel to the direction of movement and plywood with wood grain perpendicular to the direction of movement were employed (Aviara et al., 2013). The box was filled with seeds. It was connected by means of a string, parallel to the surface and passed over a pulley to a pan hanging from it. Weights were placed in the pan until the box and it content moved uniformly when given a gentle push. The kinetic coefficient of friction of product on a given structure surface was Calculated using Equation (8) (Aviara et al., 2013).

$$\lambda = \frac{W_p + W_m}{W_b + W_s} \qquad (8)$$

where: λ is the kinetic coefficient of friction of seed on a structural surface, Wp is the weight of pan (kg), Wm is weight placed in the pan to move the box and content (kg), Wb is weight of the box (kg) and Ws weight of sample (kg).

Measurements were replicated five times at each moisture level with different samples. The average value at each moisture level was plotted against moisture content. The relationship existing between the properties and seed moisture content was determined using regression analysis.

3. Results and Discussion

3.1 Seed moisture content and axial dimensions

The initial (market storage) moisture content of red kidney beans seed was found to be 6.84% (d.b), the four other moisture level obtained after conditioning the seeds were 7.5, 10, 12, and 15.74%, respectively. The investigations were carried out at the above moisture levels to determine the effect of moisture content on the physical properties of red kidney beans. The mean values of the axial dimensions of the red kidney bean seed at different moisture contents are presented in Table 1. All three axial dimensions namely length, width and thickness increased with increase in moisture content. The average diameters also increased with increase moisture content as axial dimensions. The arithmetic and geometric mean diameter ranged from 8.6 to 10.284 mm and 8.3 to 9.137 mm as the moisture content increased from 6.84 to 15.74% db, respectively. The values of dimensions of a single red kidney bean were higher than those for lentils, cotton seeds, sweet corn and pea, respectively.

Table 1: Axial dimensions of red kidney bean seed at different moisture contents

Moisture content d.b%	Axial dimension (mm) Length, L	Width, W	Thickness, T	Average dimension (mm) Arithmetic mean, D_a	Geometric, mean, D_g
6.84	11.4	6.2	4.3	8.6	8.3
7.5	11.5	6.5	4.5	8.9	8.2
10	16.75	8.64	4.96	10.12	8.93
12	16.45	8.44	5.21	10.2	9.01
15.74	16.83	8.87	5.16	10.29	9.14

3.2 Sphericity

The variation of sphericity of red kidney beans with moisture content is presented in Figure 2. The Figure shows that the sphericity of the seed increased logarithmically from 0.546 to 0.689 as the moisture content increased from 6.84% to 15.74% (db). The relationship existing between sphericity and moisture content can be expressed with Equation (9):

$$\varphi = 42.387 + 9.572 \text{Ln}(M), \quad R^2 = 0.9721 \qquad (9)$$

where φ = sphericity.

The sphericity of red kidney bean shows that the seed is not perfectly spheroidal in shape.

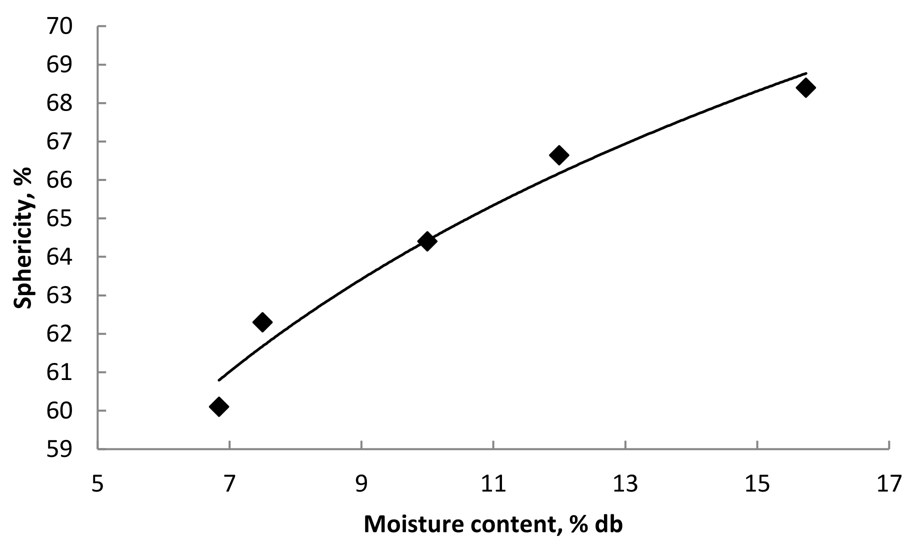

Figure 2: Effect of moisture content on sphericity of red kidney beans

3.3 One thousand seed weight

The variation of one thousand seed weight (M_{1000}) is presented in Figure 3. From the Figure, it can be seen that the M_{1000} of red kidney beans increased linearly from 3.3 to 4.1 kg when the moisture content increased from 6.84 – 15.74 % d.b. Increase of 47.3% in the one thousand grain mass was recorded within the above moisture range. The relationship between one thousand seed weight and moisture content can be represented with the following regression equation:

$$M_{1000} = 2.8059 + 0.0885M, \quad R^2 = 0.9325 \qquad (10)$$

where: M_{1000} = one thousand seed weight (kg), M = moisture content (% db), R^2 = coefficient of determination.

Red kidney bean has a relatively big grain size, compared with other commonly grown legume crops.

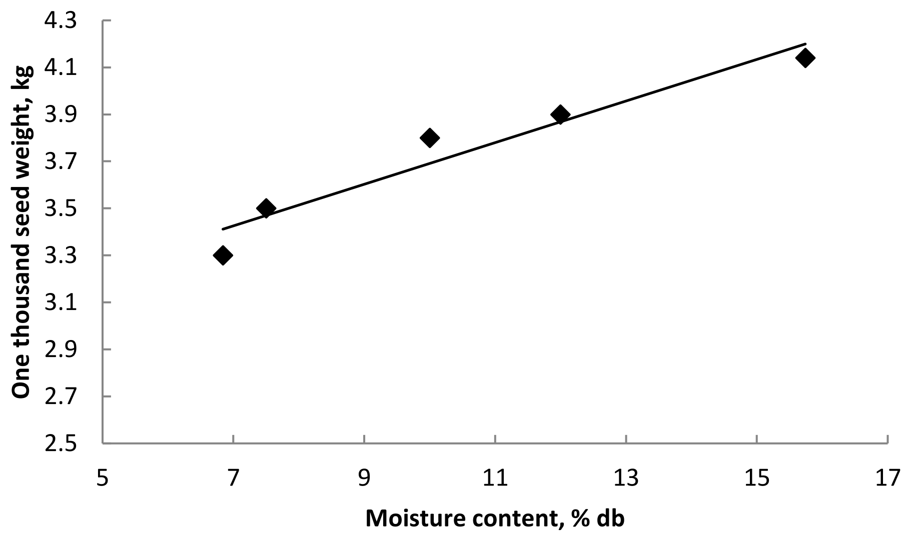

Figure 3: Effect of moisture content on one thousand seed weight of red kidney beans

3.4 Surface area of seeds

The variation of the surface area of red kidney with moisture content, % db of bean grains, is shown in Figure 4. Surface area of the bean grains increased linearly from 7.4-7.7mm² in the moisture range of 6.84-15.74 (d.b). The regression equation that adequately expressed the relationship existing between surface area and seed grain moisture content is presented as Equation (11).

$$As = 7.1942 + 0.0322M, \qquad R^2 = 0.9922 \qquad (11)$$

where: As = seed surface area (cm^2).

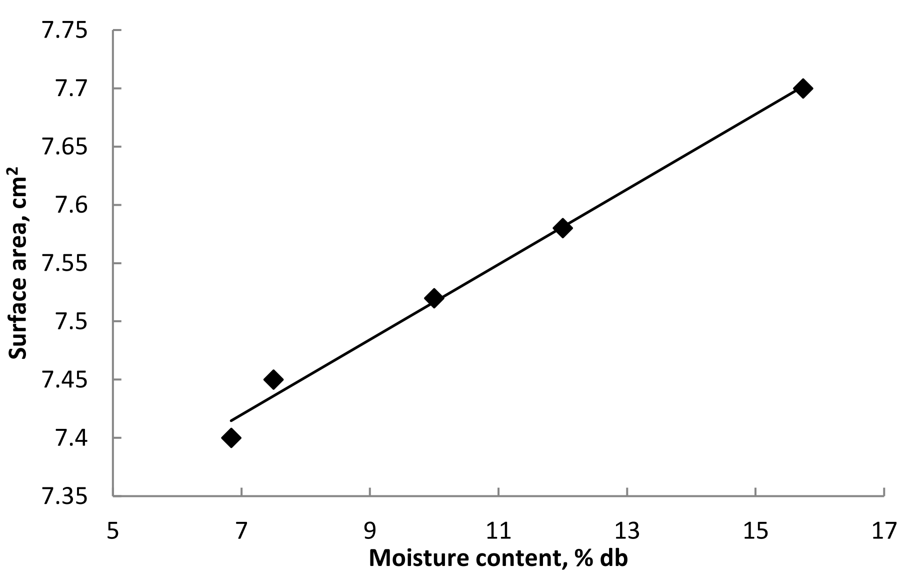

Figure 4: Effect of moisture content on surface area of red kidney beans

3.5 Bulk density

The bulk density of red kidney beans decreased from 679.14 to 563.04 kg/m³ when the moisture content increased from 6.84-15.74% db, (Figure 5). The decrease in bulk density with increase in moisture contents indicates that the increase in volume due to moisture gain in the sample is greater than the accompanying increase in the mass of the bulk seeds. Bulk density (ρ_b) was found to decrease linearly with the moisture content and the relationship existing between them was represented by Equation (12).

$$\rho_b = 775 - 12.592M, \qquad R^2 = 0.9699 \qquad (12)$$

where: ρ_b = bulk density (kg/m^3).

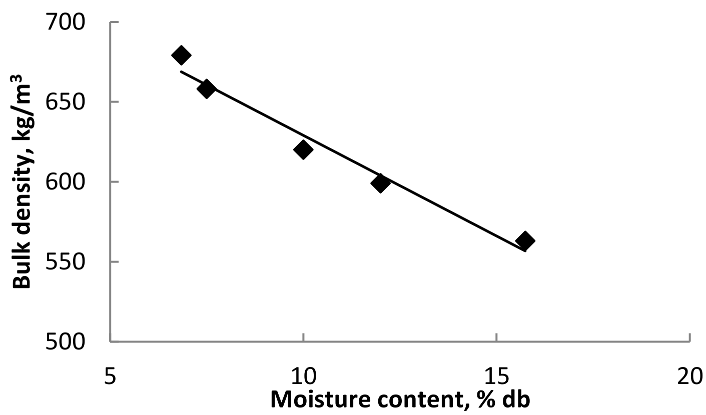

Figure 5: Effect of moisture content on bulk density of red kidney beans

3.6. True density

The variation of true density with moisture content is presented in Figure 6. True density increased from 1128-1290 kg/m^3 as the moisture content of red kidney bean seed increased from 6.84-15.74% (db). The increase of true density with increase in moisture content may have been due to higher rate of increase of mass of the individual seed than the rate of increase of the volume. The relationship between true density and moisture content was found linear and can be represented by the following regression equation.

$$\rho_t = 1042.8 + 15.703M, \qquad R^2 = 0.9879 \qquad (13)$$

where: ρ_t = true density (kg/m^3)

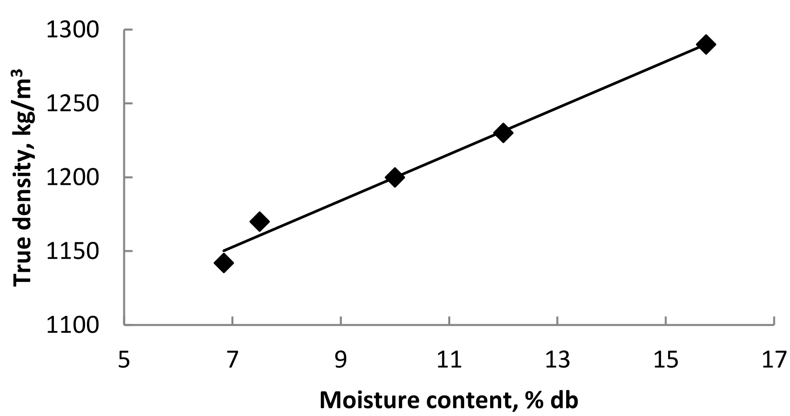

Figure 6: Effect of moisture content on true density of red kidney beans

3.7 Porosity

Porosity was evaluated using mean values of bulk density and true density of red kidney beans and found to increase with increase in moisture content, as shown in Figure 7. From the Figure, porosity was found to increase linearly from 39.79 to 56.38 % in the moisture range of 6.84-15.74% (db). The relationship between porosity and moisture content could be adequately expressed with Equation (14).

$$\varepsilon = 28.113+1.8824M, \qquad R^2 = 0.9279 \qquad (14)$$

where: ε = porosity (%).

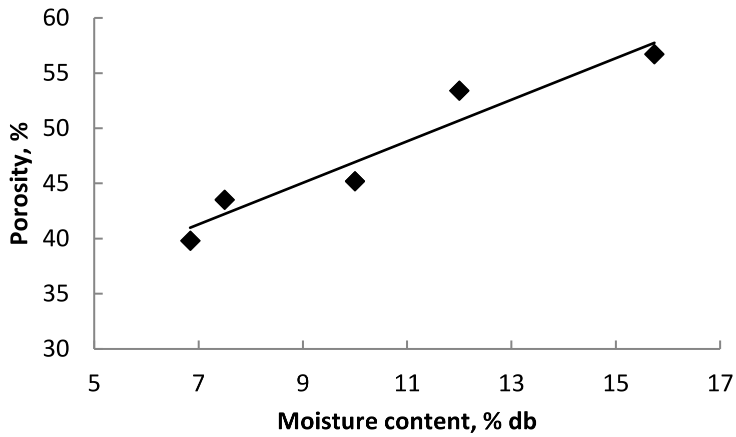

Figure 7: Effect of moisture content on porosity of red kidney beans

3.8 Angle of Repose

The variation of Angle of repose of red kidney bean seed with moisture content is shown in Figure 8. From this Figure, it was observed that the angle of repose increased from 25.1 to 29.4° as the moisture content increased from 6.84 to 15.74% (db). The increase in angle of repose with moisture content was found to be polynomial of the second order. The relationship existing between angle of repose and moisture content can be expressed using the Equation (15).

$$\theta = 14.512 + 1.9628M - 0.0647M^2, \quad R^2 = 0.9825 \qquad (15)$$

where θ = angle of repose (degree).

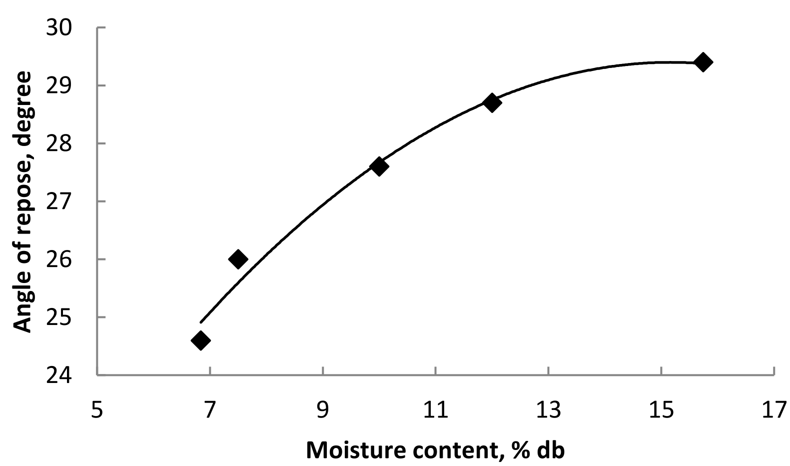

Figure 8: Effect of moisture content on angle of repose of red kidney beans

3.9 Static coefficient of friction

The static coefficient of friction of red kidney bean seed obtained experimentally at different moisture contents in the range of 6.84– 15.74% (db) on four structural surfaces are presented in Figure 9. The Figure shows that the static coefficient of friction of red kidney beans increased with increase in moisture content and varied according to the surface. Static coefficient of friction was maximized on hessian bag material (0.403-0.530) followed by plywood with wood grain perpendicular to the direction of movement (0.390-0.540), followed by plywood with wood grain parallel to the direction of movement (0.341-0.500) and was minimum on fibre glass (0.295-0.400). The relationship existing between static coefficient of friction and moisture content was found to be logarithmic on all the structural surfaces employed and it can be expressed for the different structural surfaces using Equations (16) to (19), respectively.

$$\mu_h = 0.0889 + 0.1695Ln(M), \quad R^2 = 0.9754 \quad (16)$$

$$\mu_{pp} = 0.0634 + 0.1713Ln(M), \quad R^2 = 0.9841 \quad (17)$$

$$\mu_{pl} = 0.0041 + 0.17744Ln(M), \quad R^2 = 0.9731 \quad (18)$$

$$\mu_{fg} = 0.0872 + 0.1138Ln(M), \quad R^2 = 0.9557 \quad (19)$$

where: μ_h is the static coefficient of friction of red kidney beans on hessian bag material, μ_{pp} is coefficient of static friction on plywood with wood grains perpendicular to the direction of movement, μ_{pl} is coefficient on plywood with wood grains parallel to the direction of movement, and μ_{fg} is coefficient on fiber glass.

This property is very useful in the design of silos, bins, and storage container for seeds.

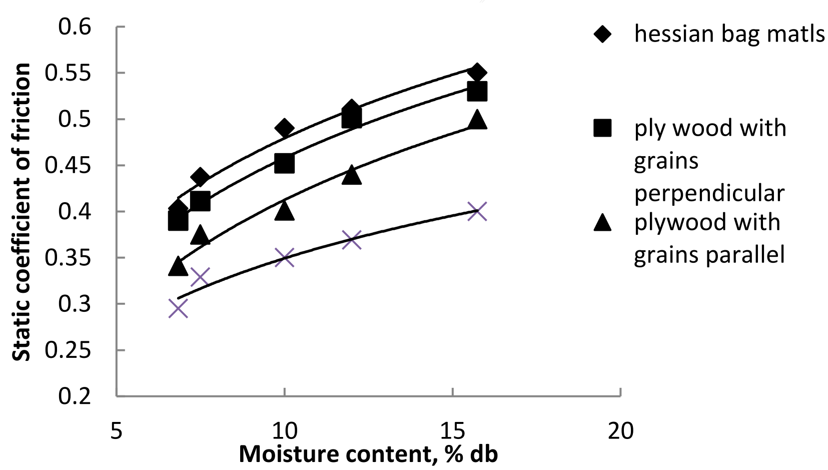

Figure 9: Effect of moisture content on static coefficient of friction of red kidney beans seed on different structural surfaces

3.10 Kinetic coefficient of friction

The variation of kinetic coefficient of friction of red kidney beans with moisture content on four structural surfaces is presented in Figure 10. The kinetic coefficient of friction increased linearly with increase in moisture content in the range of 6.84 – 15.74% (db). It is observed that the kinetic coefficient of friction was highest against hessian bag (0.599-0.651) followed by plywood with wood grains perpendicular to the direction of movement (0.50-0.526) then plywood with wood grains parallel to the direction of movement and lowest on fibre glass (0.201-0.422). The relationships existing between the kinetic coefficient of friction and moisture content of the seed on hessian bag material, plywood with wood grains perpendicular to the direction of movement and plywood with wood grains parallel to the direction of movement were linear, while the relationship on fiber glass was a polynomial of the second order. These relationships were expressed using the regression Equations (20) to (23).

$\lambda_h = 0.5671 + 0.0053M$, $R^2 = 0.9697$ (20)

$\lambda_{pp} = 0.4953 + 0.0017M$, $R^2 = 0.7509$ (21)

$\lambda_{pl} = 0.3671 + 0.0138M$, $R^2 = 0.9918$ (22)

$\lambda_{fg} = -0.4621 + 0.1376M - 0.0052M^2$, $R^2 = 0.99$ (23)

where: λ is kinetic coefficient of friction.

The kinetic coefficient of friction is needed before the power requirement for continued flow of granular or unconsolidated materials can be estimated.

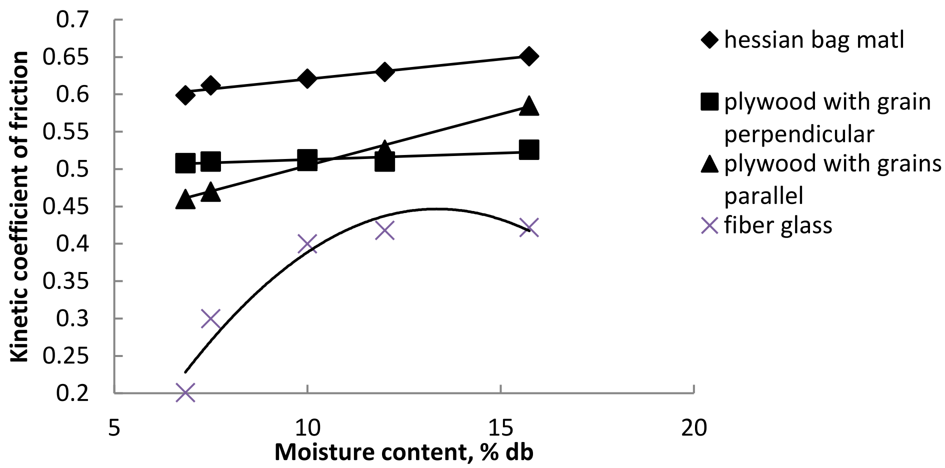

Figure 10: Effect of moisture content of kinetic coefficient of friction of red kidney bean seed on different structural surfaces

4. Conclusions

The physical properties of red kidney bean seed determined at five moisture levels yielded important data that will be useful in machine designs for planting, processing, packaging and storing of the products and showed significant differences at all moisture levels.

In the moisture range of 6.84 - 15.74% (d.b) for red kidney seeds, the investigations on the physical properties revealed the following;

(i) The major (length), intermediate (width) and minor (thickness) dimensions of the seed increased from 11.4 - 16.83, 6.2 - 8.87 and 4.3 - 5.16 mm, respectively. *Arithmetic and Geometric diameters increased from 8.6-10.29 mm and from 8.3-9.14 mm, respectively.*

(ii) Sphericity increased with increase in moisture content from 0.601 to 0.684.

(iii) One thousand seed weight increased from 3.3 - 4.22 kg.

(iv) True density increased from 1129-1290 kg/m^3, while bulk density decreased from 679.14 – 563.04 kg/m^3.

(v) Surface area and porosity increased from 7.4 – 7.7 cm^2, and from 39.8-56.7%, respectively.

(vi) Angle of response increased from 25.1 - 29.44 and both static and kinetic coefficients of friction increased linearly with moisture content and varied with structural surface.

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