Physical properties of *Brachystegia Eurycoma* seeds as affected by moisture content

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Abstract: Some physical, frictional and thermal properties of *Brachystegia eurycoma* seed were studied at different moisture contents in order to explore the possibility of mechanizing the handling and processing techniques. Results showed that the seed could be considered an oval disc in shape. In the moisture range of 2.79% to 27.13% (d.b.), the major, intermediate and minor axial dimensions increased with increase in moisture content from 2.29 mm to 2.45 mm, 1.65 mm to 1.91 mm and 0.34 mm to 0.52 mm, respectively. In the above moisture range, one thousand seed weight, particle density, porosity, roundness, sphericity, surface area and angle of repose increased linearly from 0.901 kg to 1.252 kg, 2270 kg/m^3 to 2520 kg/m^3, 11.23% to 15.46%, 35% to 47%, 67% to 82%, 7.67 cm^2 to 8.48 cm^2 and 16.8° to 29.2° respectively, while bulk density decreased from 745.4 kg/m^3 to 613.6 kg/m^3. Static coefficient of friction on different structural surfaces increased linearly with moisture content and had the highest values on galvanized steel sheet (0.445-0.639), and the lowest values on fiber glass (0.287-0.404). Kinetic coefficient of friction increased linearly with moisture content on different structural surfaces except on galvanized steel sheet where it decreased linearly with increase in moisture content in the above moisture range. It had the highest values on hessian bag material (0.266-0.389), and the lowest values on plywood with wood grains perpendicular to the direction of movement (0.204-0.271). Specific heat ranged from 1474 to 5992.7 J/kgK, and increased with increase in moisture content and temperature. Regression equations were used to express the relationships existing between the seed properties and moisture content.

Keywords: *Brachystegia eurycoma*, physical properties, seed processing, frictional properties, specific heat, moisture content

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1 Introduction

Brachystegia eurycoma is an economic tree crop that grows in the tropical rainforest of West Africa. It belongs to the Caesalpiniaceae family, the spermatophyte phylum and of the order of fabaceae. The crop is classified as legume with its pod containing seeds (Figure 1a) that are dicotyledonous (Figure 1b). *Brachystegia eurycoma* seed contains 56% carbohydrate, 15% crude fat, 9% protein, 4.5% ash, and 2.9% crude fiber[1]. In Nigeria, the seed flour is used as soup thickening and stabilizing agent[1] and as emulsifying agent in food systems[2]. Onimawo and Egbekun[3] reported that the seed helps in maintaining the body temperature when consumed. The seed gum from *Brachystegia eurycoma* compared favourably with commercial gums used in the food industry[4] and can be used as a binding agent in medicinal tablet formulation[5].

Figure 1 *Brachystegia eurycoma* seeds (a)[6] and Cotyledons of *Brachystegia eurycoma* obtained by dehulling the seeds (b)[7]

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The processing of *Brachystegia eurycoma* seeds to obtain the cotyledonous kernels and flour normally involves such operations as parboiling, soaking or roasting prior to dehulling and size reduction. The hulls are removed by running a bottle or stone tangentially on the surface of the seeds spread on a flat surface. The kernels are ground or pounded in a mortar using pestle, to obtain the flour. These processes as presently carried out, are not only labour intensive with low output but also time consuming. In order to appropriate the full economic potentials of *Brachystegia eurycoma* seed, there is the need to develop machine and equipment for carrying out the dehulling and other handling operations that will be efficient in terms of energy consumption and time. The development of such machine and equipment requires knowledge of the physical and mechanical properties of the seeds. Uhegbu et al.[1] investigated the effects of processing methods on the nutritional and antinutritional properties of the seed and Ikegwu et al.[2] noted that the viscosity of the seed flour increased with increase in roasting time and palm oil concentration but decreased with increase in sodium chloride concentration. Ndukwu[7] determined some physical properties of *Brachystegia eurycoma* seed at the moisture content of 12.9% (d.b.) but did not address the variation of the properties with moisture content and processing methods. The moisture-dependent characteristics of physical properties of agricultural products have been noted to have effects on the adjustment, performance efficiency and energy consumption of processing machines[8,9]. Therefore, the effect of moisture content on physical properties of *Brachystegia eurycoma* seed is an important consideration in the design of the handling and processing equipment.

Several researchers[10-16] investigated the moisture dependence of physical properties of oil seeds and nuts (almond nut, high oleic sunflower seed, vetch seed, balanites aegyptiaca nuts, fibered flax seed, roselle seed and dragon head seed) and reported increase of these properties with moisture content with the exception of bulk density that decreased with increase in moisture content. Aviara et al.[17] reported that the physical properties of shea nut all increased with moisture content except the porosity that increased with moisture content up to a point and decreased with further increase in moisture content. The physical properties of beniseed other than bulk density[18] increased with moisture content. Other investigations[9,19-26] revealed that the properties of guna seed, guna seed kernel, hazel nut, arecanut kernel, chicken pea seed and rape seed increased with moisture content except that their true and bulk densities decreased with increase in moisture content. For pumpkin seed[27], karingda seed[28] and sheanut kernel[29], physical properties other than true density and porosity, increased with moisture content. In soya bean[30] and neem nut[31], the true density, bulk density and porosity decreased with increase in moisture content, while other physical properties increased. Physical properties of gram[32], lentil seeds[33], okra seed[34] and hemp seed[35] were found to increase with moisture content with the exception of true and bulk densities for gram, bulk density, true density and porosity for hemp and okra seeds and bulk density for lentil seed that respectively decreased with increase in moisture content. Aviara et al.[36] reported that all the physical properties of moringa oleifera seed and kernel studied including true and bulk densities, increased with increase in moisture content. Some previous study used the method of mixtures to determine the specific heat of fababeans[37], gram[38], African oil bean[39], thevetia nut[40], cumin seed[41], sheanut kernel[42], locust bean seed[43], soybean[44], guna seed[45], moringa oleifera seed and mucuna flagellipes nut[46], and African date fruit cultivars[47] and reported that the specific heat of these agricultural products increased with the increase in moisture content. The objective of this study was to determine the physical properties of *Brachystegia eurycoma* seeds and investigate their interrelationship with moisture content. The properties include size, one thousand seed weight, roundness and sphericity, surface area, particle (true) density, bulk density, porosity, static coefficient of friction, kinetic coefficient of friction, angle of repose and specific heat.

2 Materials and methods

The *Brachystegia eurycoma* seeds used for this study were obtained from Baga Road Market in Maiduguri, Borno State, Nigeria. The seeds were carefully cleaned to remove dust, foreign materials and broken or immature seeds. Seeds were preserved by storing in air tight polyethylene bags. The moisture content of *Brachystegia eurycoma* seeds was determined by using the method described by Aviara et al[9]. Five samples of the seed in the moisture range of 2.79%-27.13% (d.b.) were prepared for use in carrying out tests. Varying moisture contents were achieved using the addition of calculated amount of water method.

To determine the seed size, 100 seeds were randomly selected from seed samples at different moisture levels. Vernier calliper with a reading of 0.05 mm was used to measure the axial dimensions. One thousand seed weight was obtained using an electronic weighing balance reading to 0.001 g. Roundness and sphericity were determined by tracing the seed shadowgraphs on a graph paper and using the method of counting the squares. Paper foil and method of counting the squares was used to determine the surface area of the seed. Bulk density was determined using the AOAC[48] recommended method. The particle density of seed was determined using the water displacement method. The relationship between true density and bulk density was used to determine the porosity of seed according to Mohsenin[49]. The cylindrical pipe method was used to determine the angle of repose. Static and kinetic coefficients of friction of the seed were determined on different structural surfaces namely, hessian bag material, fiber glass, galvanized steel sheet, plywood with wood grains parallel to direction of movement and plywood with wood grains perpendicular to direction of movement. Specific heat was determined using a copper calorimeters placed inside a flask and the method of mixtures. Measurements were replicated four times at each moisture level, the mean values were reported and regression analysis was used to establish the equations that expressed the relationships between the properties and seed moisture content. The variation of the properties with moisture content was then graphically represented.

3 Results and discussion

3.1 Axial dimensions

The results of *Brachystegia eurycoma* seeds size measured at different moisture contents are presented in Table 1. The table shows that the three axial dimensions increased with increase in moisture content in the moisture range of 2.79%-27.13% (d.b.). The major axis increased from 2.29 mm to 2.45 mm, the intermediate axis from 1.65 mm to 1.91 mm and the minor axis from 0.34 mm to 0.52 mm. The arithmetic mean, geometric mean and equivalent sphere effective diameters of the seed were also presented in Table 1, increased with increase in moisture content. The arithmetic mean diameter had higher values than the geometric and equivalent sphere effective diameters of the seed. These could be of important consideration in the theoretical determination of the seed volume at different moisture contents.

Similar results were reported by Aviara et al.[9] for guna seed, Tavakkoli et al.[50] for soybean and Aviara et al.[51] for mucuna flagellipes nut. The results of the axial dimensions can be used in sizing, grading and mechanical separation of *Brachystegia eurycoma* seeds from stones and other unwanted materials.

Table 1 Axial dimensions of *Brachystegia eurycoma* seed at different moisture contents

Moisture content (%, d.b.)	Major diameter (mm) (a)	Intermediate diameter (mm) (b)	Minor diameter (mm) (c)	Arithmetic diameter (mm) (a+b+c)/3	Geometric mean diameter (mm) $(abc)^{1/3}$	Equivalent sphere effective diameter (mm) $(6W_{1000}/1000\rho_t\pi)^{1/3}$
2.79	2.29	1.65	0.34	1.43	1.09	0.91
9.14	2.31	1.69	0.35	1.45	1.11	0.93
12.34	2.36	1.73	0.39	1.49	1.17	0.95
21.16	2.40	1.80	0.43	1.54	1.23	0.97
27.13	2.45	1.91	0.52	1.63	1.34	0.98

3.2 One thousand seed weight

The variation of one thousand seed weight of *Brachystegia eurycoma* seeds with moisture content is presented in Figure 2. This shows that the one thousand seed weight increased from 0.901 kg to 1.251 kg as the seed moisture content increased from 2.79% to 27.13% (d.b.). This positive trend with moisture content might be due to increase in weight gained with increase in the amount of water contained in the seed as the moisture content increased. The relationship between the mass of one thousand seeds and moisture content was found to be linear and can be expressed with an equation as follows:

$$W_{1000} = 0.014M + 0.847 \quad (1)$$

with value of coefficient of determination, R^2 = 0.995, where W_{1000} is the one thousand seed weight in kg and M is the moisture content in % (d.b.).

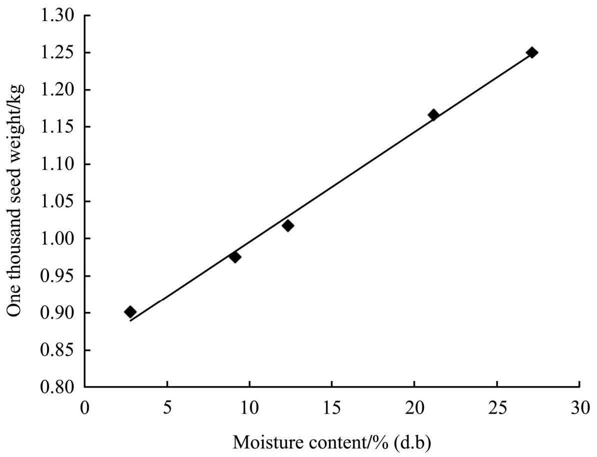

Figure 2 Effect of moisture content on one thousand seed weight of *Brachystegia eurycoma* seed

Similar trend was reported for African yam bean[52], arecanut[21], sheanut[17], round red lentil grain[53] and Samaru sorghum[54]. It was reported that practical application of seed mass is in the design of equipment for cleaning, separation, conveying and elevating unit operations. This weights can also be used to estimate the overall bulk weight of *Brachystegia eurycoma* seeds during bulk handling.

3.3 Bulk density

The effect of moisture content on the bulk density of *Brachystegia eurycoma* seed is shown in Figure 3. The bulk density of the seed was found to decrease from 745.4 to 613.6 kg/m^3 in the moisture range of 2.79 % - 27.13% (d.b.). The decrease in bulk density of the seeds may be resulted from the increase in size with moisture content which must have given rise to decrease in the quantity of the seeds occupying the same bulk volume. 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 a linear and can be represented by the equation:

$$\rho_b = -6.023M + 763.4 \quad (2)$$

with coefficient of determination, R^2 = 0.931, where ρ_b is the bulk density in kg/m^3 and M is moisture content in % (d.b.). Carman[33], Gupta and Das[55], and Visvanathan et al.[31] found the bulk density of lentil seeds, sunflower seeds, neem nuts to decrease as the seed moisture content increased. Bulk density has been reported to have practical applications in the calculation of thermal properties in heat transfer problems, in determining Reynolds number of materials and in predicting physical structure and chemical composition.

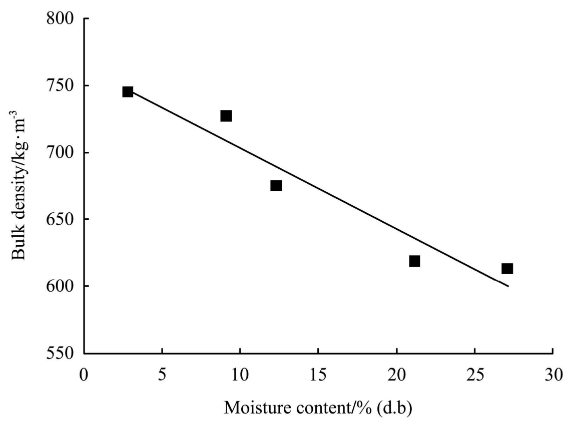

Figure 3 Effect of moisture content on bulk density of *Brachystegia eurycoma* seed

3.4 Particle density

The variation of seed particle density with moisture content is presented in Figure 4. This shows that particle density increased from 2 270 to 2 520 kg/m^3 as the moisture content increased from 2.79% to 27.13% (d.b.). The relationship existing between particle density and moisture content was found to be linear and can be represented by the regression equation:

$$\rho_t = 10.38M + 2249 \quad (3)$$

with a coefficient of determination, R^2 = 0.939, where ρ_t is particle density in kg/m^3 and M is moisture content in % (d.b.). Increase of particle density as seed moisture content increased has been reported for sunflower seeds[55], guna seeds[9], coffee[56], cotton seed[23], balanites aegyptiaca nuts[13], sheanut[17] and round red lentil grain[53]. The particle density of agricultural products have been reported to play significant role in the design of grain cleaning and grading equipment, silos and storage bins, and in maturity and quality evaluation of products which are essential in grain marketing[52].

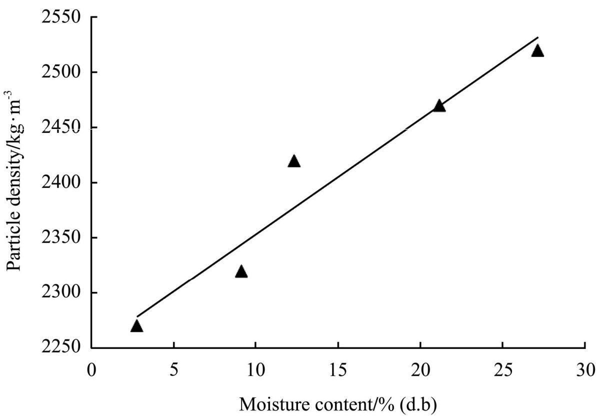

Figure 4 Effect of moisture content on particle density of *Brachystegia eurycoma* seed

3.5 Porosity

The porosity calculated from relevant experimental data increased from 11.23% to 15.46% in the moisture range of 2.79% - 27.13% (d.b.). The effect of moisture content on porosity is presented in Figure 5. The relationship existing between porosity and moisture content appeared linear and can be expressed by the regression equation:

$$P = 0.196M + 10.60 \tag{4}$$

with a coefficient of determination, R^2 = 0.922, where P is porosity in % and M is moisture content in % (d.b.). The increase in porosity with moisture content is at variant with that of karingda seed[28] and African yam bean[52], that decreased with increase in moisture content.

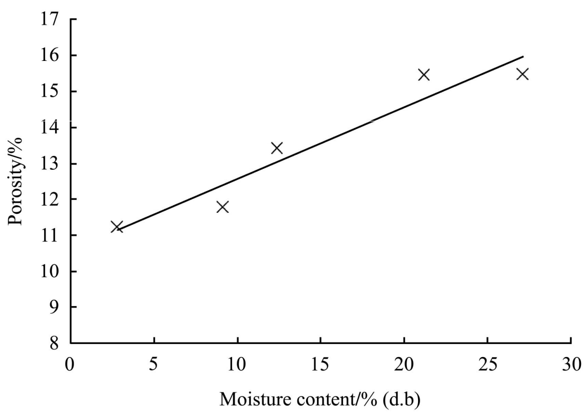

Figure 5 Effect of moisture content on porosity of *Brachystegia eurycoma* seed

Increase in moisture content may have caused a decrease in the cohesion of the bulk seed as a result of resistance to consolidation. It was also observed that as the seed gained moisture, its volume increased thereby increasing the size and shape which must have resulted in the creation of larger pore spaces. Increase in porosity with moisture content was reported for chickpea seeds[22] and green gram[57].

3.6 Roundness and sphericity

The effect of moisture content on roundness and sphericity of *brachystegia eurycoma* seed is presented in Figures 6 and 7, respectively. Roundness and sphericity increased linearly from 35% to 47% and from 67% to 82%, respectively, as the seed moisture content increased from 2.79% to 27.13% (d.b.). The high value of sphericity of the seed indicates that it could be described as oval disc in shape. The relationship between moisture content and roundness and sphericity can be expressed by the following equations:

$$R = 0.492M + 33.65 \tag{5}$$

$$S = 0.640M + 64.90 \tag{6}$$

with values of coefficient of determination, R^2 = 0.998 for roundness and R^2 = 0.993 for sphericity and M is moisture content in % (d.b.). A decrease in sphericity with increase in moisture content after certain moisture level was exceeded has been reported an increase in sphericity with moisture content for African yam bean[52], pigeon pea[58], round red lentil[53], Turkish Mahaleb[59], hemp grains[35] and sunflower seeds[60]. The sphericity has practical application in the design of processing and storage equipment, especially in handling operations such as conveying and discharge from chutes.

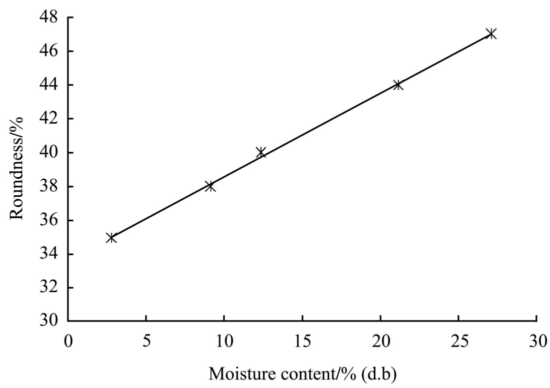

Figure 6 Effect of moisture content on roundness of *Brachystegia eurycoma* seed

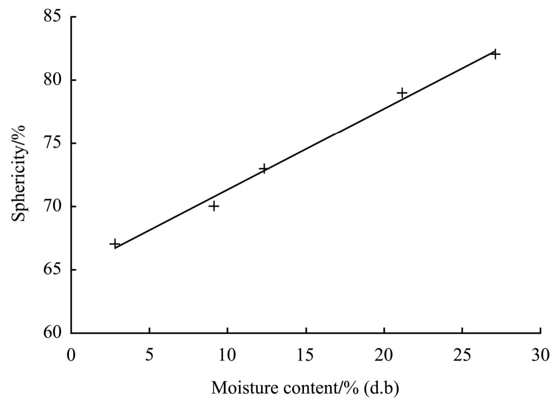

Figure 7 Effect of moisture content on sphericity of *Brachystegia eurycoma* seed

3.7 Surface area

The variation of *brachystegia eurycoma* seed surface area with moisture content is presented in Figure 8. This shows that the surface area increased from 7.67 to 8.48 cm^2 in the moisture range of 2.79% - 27.13% (d.b.). The relationship between moisture content and surface area was found to be linear and can be expressed with the following equation:

$$S_a = 0.033M + 7.573 \tag{7}$$

with values of coefficient of determination, R^2 = 0.869, where S_a is surface area in cm^2 and M is moisture content in % (d.b.).

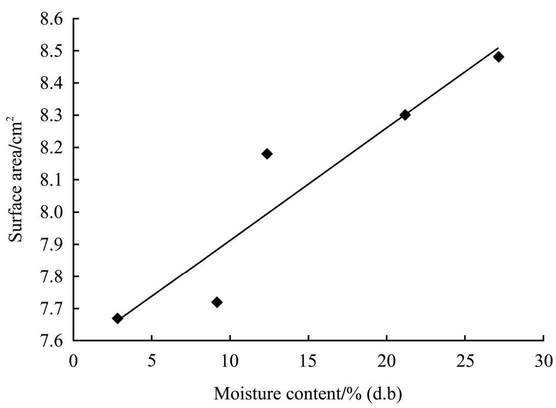

Figure 8 Effect of moisture content on surface area of *Brachystegia eurycoma* seed

3.8 Angle of repose

Values of experimentally determined angle of repose as affected by moisture content are shown in Figure 9. From this, it was observed that the angle of repose increased from 16.8° to 29.2° as the moisture content increased from 2.79% to 27.13 % (d.b.). At higher moisture levels within the investigated range, the seeds must have tended to be more cohesive and less flowable, thereby increasing the values of θ. Angle of repose increased linearly with moisture content and their relationship can be expressed with the equation below:

$$\theta = 0.519M + 15.61 \tag{8}$$

with a coefficient of determination, R^2 = 0.939, where θ is the angle of repose in degrees and M is the moisture content in % (d.b.). Linear relationship between angle of repose and moisture content was also reported for cumin seed[41] and coriander seed[61]. However, a logarithmic relationship was observed for okra seed[34] and sheanut[17]. This property is used in the design of equipment for the processing of particulate solids. For example, it may be used to design an appropriate hopper or silo to store the material. It can be used to size a conveyor belt for transporting the material.

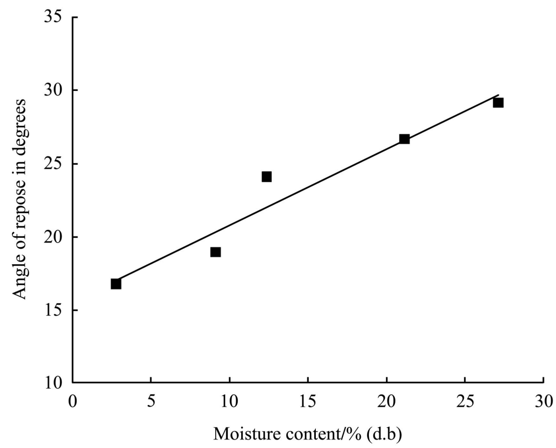

Figure 9 Effect of moisture content on angle of repose of *Brachystegia eurycoma* seed

3.9 Static coefficient of friction

The static coefficient of friction obtained experimentally on five structural surfaces plotted against moisture content in the range of 2.79% to 27.13% (d.b.) is presented in Figure 10. The Figure shows that the static coefficient of friction of *Brachystegia eurycoma* seed increased linearly with moisture content and varied with structural surface. It may be that as the moisture content increased, the seed asperite projection increased causing higher shear stress at the structural surface-seed asperite contacts to be developed[9], thereby giving rise to increase in friction. The static coefficient of friction was maximum on galvanized steel sheet (0.445-0.639), followed by plywood with wood grains perpendicular to the direction of movement (0.375-0.532), hessian bag material (0.354-0.532), and plywood with wood grains parallel to the direction of movement (0.344-0.488) and was minimum on fiber glass (0.287-0.404). The relationship existing between the static coefficient of friction and moisture content can be expressed for different structural surfaces using the following equations:

$$\mu_{pp} = 0.0076M + 0.362 \quad (9)$$

$$\mu_{pl} = 0.0061M + 0.319 \quad (10)$$

$$\mu_{fg} = 0.0052M + 0.266 \quad (11)$$

$$\mu_{hb} = 0.0074M + 0.338 \quad (12)$$

$$\mu_{gs} = 0.0082M + 0.428 \quad (13)$$

with coefficient of determination, R^2 = 0.989, 0.986, 0.981, 0.994 and 0.952, respectively, where μ_{pp}, μ_{pl}, μ_{fg}, μ_{hb} and μ_{gs} are the static coefficient of *brachystegia eurycoma* seed on plywood with wood grains perpendicular to the direction of movement, plywood with wood grains parallel to the direction of movement, fiber glass, hessian bag material and galvanized steel sheet, respectively, and M is moisture content in % (d.b.).

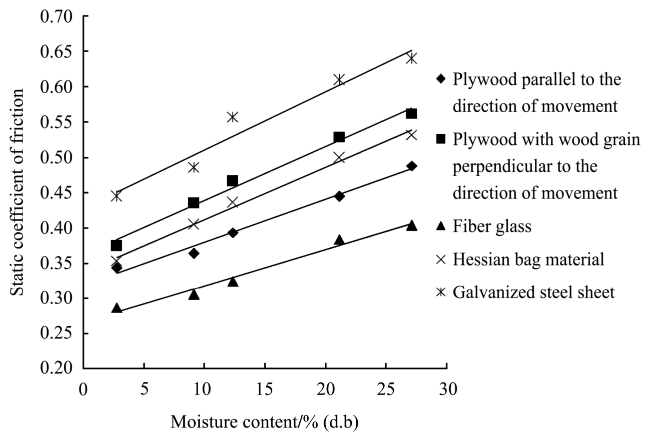

Figure 10 Effect of moisture content on static coefficient of friction of *Brachystegia eurycoma* seed

A linear increase in static coefficient of friction with moisture content was also reported for cumin seed[41], guna seed[9], cucurbit seeds[62] and wheat[63]. This property is useful in product handling equipment design. Also, in the design of silos, bins and other storage structures for the seeds, grains and other agricultural products, the lateral and vertical loads on the walls and floor are determined by the friction coefficient.

3.10 Kinetic coefficient of friction

The kinetic coefficient of friction obtained experimentally on five structural surfaces plotted against moisture content in the range of 2.79% to 27.13% (d.b.) is presented in Figure 11. It was observed that the kinetic coefficient of friction increased linearly with the increase in moisture content on plywood with wood grains perpendicular to the direction of movement, plywood with wood grains parallel to the direction of movement, fiber glass and hessian bag material. However, it decreased linearly with moisture content on galvanized steel sheet (0.405-0.326) where it maintained the highest value until the moisture content of about 18% (d.b.) was exceeded.

The relationship existing between the kinetic coefficient of friction and moisture content can be expressed for different structural surfaces using equations as follows:

$$f_{pp} = 0.0027M + 0.201 \quad (14)$$

$$f_{pl} = 0.0047M + 0.227 \quad (15)$$

$$f_{fg} = 0.0077M + 0.152 \quad (16)$$

$$f_{hb} = 0.005M + 0.252 \quad (17)$$

$$f_{gs} = -0.0033M + 0.412 \quad (18)$$

with coefficients of determination, R^2 = 0.971, 0.993, 0.984, 0.995 and 0.985 respectively, where f_{pp}, f_{pl}, f_{fg}, f_{hb} and f_{gs} are the kinetic coefficient of friction of B*rachystegia eurycoma* seed on plywood with wood grains perpendicular to the direction of movement, plywood with wood grains parallel to the direction of movement, fiber glass, hessian bag material and galvanized steel sheet, respectively.

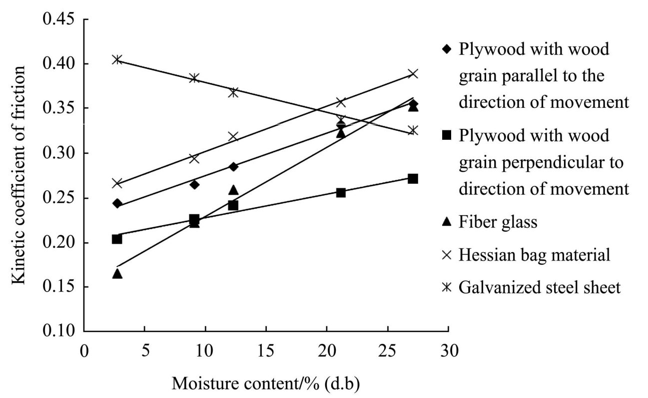

Figure 11 Effect of moisture content on kinetic coefficient friction of *Brachystegia eurycoma* seed

Carman[33], Ebubekir et al.[64], and Sessiza et al.[65] reported an linear increase of friction of lentil seed, fenugreek seeds, and capper seed fruit with moisture content. The kinetic coefficient of friction is needed before the power requirements for continued flow of granular or unconsolidated materials can be estimated.

3.11 Specific heat

The specific heat of *Brachystegia eurycoma* seed at five moisture levels in the range of 2.79%-27.13% (d.b.) and four temperature ranges (303-318 K, 303-326 K, 303-334 K and 303-341.4 K) between the initial temperature of the seed and final temperature of water and seed mixture, was found to lie between 1 474 J/(kgK) and 5 992.7 J/(kg K). The variation of specific heat of the seed with moisture content is shown in Figure 12. It was observed that the specific heat increased linearly with moisture content for each temperature range indicated. The relationship between the specific heat and moisture content can be expressed by the following equations:

303-318 K: $C_s = 128.2M + 1267$ ($R^2 = 0.990$) (19)

303-326 K: $C_s = 142.3M + 1381$ ($R^2 = 0.991$) (20)

303-334 K: $C_s = 139.1M + 2014$ ($R^2 = 0.993$) (21)

303-341.4 K: $C_s = 129.9M + 2508$ ($R^2 = 0.998$) (22)

where, C_s is the specific heat of seed in J/(kg K) and M is the moisture content in % (d.b.). Similar trend was observed for sheanut kernel[42], guna seed and kernel[45], cumin seed[41] and soyabean[66]. Knowledge of the specific heat of the seed and the effect of moisture content and temperature on it is essential for the design of the thermal process systems should be known, as varying moisture content and temperature could form some of the process conditions. The thermal properties of the seed are essential in the development of the processes and equipment needed in its thermal processing, as well as in drying and storage.

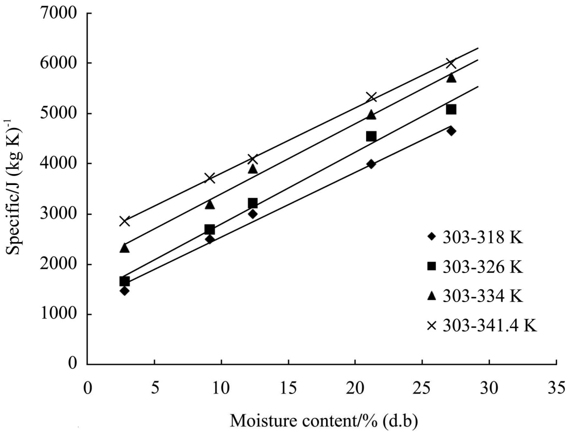

Figure 12 Effect of moisture content on specific heat of *Brachystegia eurycoma* seed

4 Conclusions

The following conclusions could be drawn from the investigation of various physical properties of *brachystegia eurycoma* seeds:

(1) As the moisture content increased, the dimensions of the seed increased in the three axes.

(2) One thousand seed weight increased linearly with the increase of moisture content.

(3) Bulk density decreased linearly, while the true density and porosity increased linearly with the increase of moisture content.

(4) Roundness, sphericity and surface area of the seed increased with increase of moisture content and had values that enabled the seed to be described as an oval disc in shape.

(5) Angle of repose of the seed increased linearly with the increase of moisture content.

(6) Static coefficient of friction increased linearly with the increase of moisture content and varied with structural surface.

(7) Kinetic coefficient of friction increased linearly with the increase of moisture content on plywood with wood grains perpendicular to the direction of movement, plywood with wood grains parallel to the direction of movement, fiber glass and hessian bag material, while decreased linearly with the increase in moisture content on galvanized steel sheet.

(8) Specific heat of the seed increased linearly with the increase in moisture content.

[References]

[1] Uhegbu F O, Onwuchekwa C C, iweala E E J, Kanu I. Effect of processing methods on nutritive and antinutritive properties of seeds of Brachystegia eurycoma and Detarium microcarpum from Nigeria. Pakistan Journal of nutrition, 2009; 8(4): 316-320.

[2] Ikegwu O J, Oledinma N U, Nwobasi V N, Alaka I C. Effect of processing time and some additives on the apparent viscosity of 'achi' Brachystegia eurycoma flour. Journal of Food Technology, 2009; 7(2): 34-37.

[3] Onimawo A, Egbekun M K. Comprehensive food science and nutrition. Revised edition. Ambik Publishers, Benin-city, Nigeria, 1998.

[4] Uzomah A, Ahiligwo R N. Studies on the rheological

properties and functional potentials of achi (Brachystegia eurycoma) and ogbono (Irvingia gabonensis) seed gums. Food Chemistry, 1999; 67: 217-222.

[5] Olayemi O, Jacob O. Preliminary evaluation of Brachystegia eurycoma seed mucilage as tablet binder. International Journal of Pharmaceutical Research and Innovation, 2011; 3: 1-6.

[6] Uzomah A, Odusanya O S. Mucuna sloanei, detarium microcarpum and brachystegia eurycoma seeds: Preliminary study of their starch-hydrocolloid system. African Journal of Food Science, 2011; 5(13): 733-740.

[7] Ndukwu M C. Determination of selected physical properties of Brachystegia eurycoma seeds. Research in Agricultural Engineering, 2009; 55(4): 165-169.

[8] Mieszkalski L. The role of physical properties of seeds in the design of dehullers. International Agrophysics, 1997; 11: 283-291.

[9] Aviara N A, Gwandzang M I, Haque MA. Physical properties of guna seeds. Journal of Agricultural Engineering Research, 1999; 73: 105-111.

[10] Aydin C. Physical properties of almond nut and kernel. Journal of Food Engineering, 2003; 60: 315-320.

[11] Santalla E M, Mascheroni R H. Physical properties of high oleic sunflower seeds. Food Science and Technology, 2003; 9: 435-442.

[12] Yalcin I, Ozarslan C. Physical properties of vetch seed. Biosystems Engineering, 2004; 88: 507-512.

[13] Aviara N A, Mamman E, Umar B. Some physical properties of Balanites aegyptiaca nuts. Biosystems Engineering, 2005; 92: 325-334.

[14] Wang B, Li D, Wang L J, Huang Z G, Zhang L, Chen X D, et al. Effect of moisture content on the physical properties of fibered flax seed. International Journal of Food Engineering, 2007; 3(5), 1556-3758.

[15] Bamgboye A I, Adejumo O I. Physical properties of roselle (Hibiscus sabdariffa L.) seed. Agricultural Engineering International: The CIGR e-Journal XI, manuscript 1154, 2009; Available at: www.cigrjournal.org.

[16] Shafiee S, Modares M A, Minaee S, Haidarbigi K. Moisture dependent physical properties of dragon head seeds (Lallemantia Iberia). Agricultural Engineering International: The CIGR e-Journal XI, manuscript 1192, 2009; Available at: www.cigrjournal.org.

[17] Aviara NA, Oluwole F A, Haque M A. Effect of moisture content on some physical properties of sheanut (Butyrospernum paradoxum). International Agrophysics, 2005; 19: 193-198.

[18] Tunde-Akintunde T Y, Akintunde B O. Effect of moisture content and variety on selected physical properties of beniseed. Agricultural Engineering International: The CIGR e-Journal IX, manuscript FP 07 021, 2007; Available at: www.cigrjournal.org.

[19] Aviara N A, Haque M A. Moisture dependence of densities, coefficients of friction and angle of repose of guna seed and kernel. Journal of Engineering Applications, 2000; 2: 44-53.

[20] Aydin C. Physical properties of hazel nuts. Biosystems Engineering, 2002; 82: 297-303.

[21] Kaleemullah S, Gunasekar J J. Moisture dependent physical properties of arecanut kernels. Biosystems Engineering, 2002; 82: 331-338.

[22] Konak M, Carman K, Aydin C. Physical properties of chick pea seeds. Biosystems Engineering, 2002; 82: 73-78.

[23] Ozarslan C. Physical properties of cotton seed. Biosystems Engineering, 2002; 83: 169-174.

[24] Abalone R, Cassinera A, Gaston A, Lara M A. Some physical properties of amaranth seeds. Biosystems Engineering, 2004; 89: 109-117.

[25] Zewdu A, Solomon W. Physical properties of grass pea (*Lathyrus sativus* L.) seeds. Agricultural Engineering International: The CIGR e-Journal X, manuscript FP 06 027, 2008; Available at: www.cigrjournal.org.

[26] Izli N, Unal H, Sincik M. Physical and mechanical properties of rapeseed at different moisture contents. International Agrophysics, 2009; 23: 137-145.

[27] Joshi DC, Das S K, Mukherjee R K. Physical properties of pumpkin seed. Journal of Agricultural Engineering Research, 1993; 54: 219-229.

[28] Suthar S H, Das S K. Some physical properties of karingda (Citrullus lanatus [Thumb] mansf.) seeds. Journal of Agricultural Engineering Research, 1996; 65: 15-22.

[29] Aviara N A, Haque M A, Izge I A. Physical and frictional properties of sheanut. AgroScience, 2000; 1: 19-34.

[30] Deshpande S D, Bal S, Ojha T P. Physical properties of soy bean. Journal of Agricultural Engineering Research, 1993; 56: 89-98.

[31] Visvanathan R, Palanisamy P T, Gothandapani L, Sreenarayanan V V. Physical properties of neem nut. Journal of Agricultural Engineering Research, 1996; 63: 19-26.

[32] Dutta S K, Nema V K, Bhardwaj R K. Physical properties of gram. Journal of Agricultural Engineering Research, 1988; 39: 259-268.

[33] Carman K. Some physical properties of lentil seeds. Journal of Agricultural Engineering Research, 1996; 63: 87-92.

[34] Sahoo P K, Srivastava A P. Physical properties of okra seed. Biosystems Engineering, 2002; 83: 441-448.

[35] Sacilik K, Ozturk R, Keskin R. Some physical properties of hemp seed. Biosystems Engineering, 2003; 86: 191-198.

[36] Aviara N A, Power P P, Abbas T. Moisture-dependent physical properties of moringa oleifera seed relevant in bulk handling and mechanical processing. Industrial Crops and Products, 2013; 42: 96-104.

[37] Fraser B M, Verma S S, Muir WE. Some physical properties of fababeans. Journal of Agricultural Engineering Research, 1978; 23: 53-57.

[38] Dutta S K, Nema V K, Bhardwaj R K. Thermal properties of gram. Journal of Agricultural Engineering Research, 1988; 39: 269-275.

[39] Oje K, Ugbor E C. Some physical properties of oil bean seed. Journal of Agricultural Engineering Research, 1991; 50: 305-313.

[40] Oje K. Some engineering properties of thevetia nut. Journal of Agricultural Engineering and Technology, 1993; 1: 38-45.

[41] Singh K K, Goswami T K. Physical properties of cumin seed. Journal of Agricultural Engineering Research, 1996; 64: 93-98.

[42] Aviara N A, Haque M A. Moisture dependence of thermal properties of sheanut kernel. Journal of Food Engineering, 2001; 47(2): 109-113.

[43] Ogunjimi L A O, Aviara N A, Aregbesola O A. Some engineering properties of locust bean seed. Journal of Food Engineering, 2002; 55: 95-99.

[44] Aviara N A, Ajibola O O, Oni S A. Effect of moisture content and temperature on the specific heat of soybean TGX 1440 – 1E. Proceedings of the Nigerian Institution of Agricultural Engineers, 2003; 25: 183-193.

[45] Aviara N A, Haque M A, Ogunjimi L A O. Thermal properties of guna seed. International Agrophysics, 2008; 22: 291-297.

[46] Aviara N A, Ehiabhi S E, Ajibola O O, Oni S A, Power P P, Abbas T, et al. Effect moisture content and temperature on the specific heat of soya bean, moringa oleifera seed and mucuna flagellipes nut. International Journal of Agricultural and Biological Engineering, 2011; 4(1):87-92.

[47] Aviara N A, Lawal A A, Ogunjimi L A O, Dauda A. Some engineering properties of four African Date Palm fruit cultivars. Research Journal of Applied Science, Engineering and Technology, 2014; 7(2): 379-387.

[48] AOAC Official Methods of Analysis, 13th ed. Association of Official Analytical Chemists, Washington, DC, 1980.

[49] Mohsenin N N. Physical Properties of Plant and Animal Materials, 2nd ed. Gordon and Breach Science Publishers, New York, pp 889; 1986.

[50] Tavakoli H, Rajabipour A, Mohtasebi S S. Moisture-dependent of some engineering properties of soybean grains. Agricultural Engineering International: The CIGR e-journal. Manuscript 1110. Vol. XI., 2009; Available at: www.cigrjournal.org.

[51] Aviara N A, Onuh O A, Ehiabhi S A. Physical properties of Mucuna flagellipes nuts. GSB Seed Science and Biotechnology, 2010; 4(1): 59-68.

[52] Irtwange S V, Igbeka J C. Some physical properties of two African yam bean (Sphenostylis stenocarpa) accessions and their interrelation with moisture content. Applied Engineering in Agriculture, 2002; 18(5): 567-576.

[53] Isik E. Some physical and mechanical properties of round red lentil grains. Applied Engineering in Agriculture, 2007; 23(4): 503-509.

[54] Simonyan K J, El-Okene A M, Yiljep Y D. Some physical properties of Samaru sorghum 17. Agricultural Engineering International: the CIGR e-journal Manuscript FP 07008. Vol. IX., 2007; Available at: www.cigrjournal.org.

[55] Gupta R K, Das S K. Physical properties of sunflower seeds. Journal of Agricultural Engineering Research, 1997; 66: 1-8.

[56] Chandrasekar V, Visvanathan R. Physical and thermal properties of coffee. Journal of Agricultural Engineering Research, 1999; 73: 227-234.

[57] Nimkar P M, Chattopadhyay P K. Some physical properties of green gram. Journal of Agricultural Engineering Research, 2001; 80: 183-189.

[58] Baryeh E A, Mangope B K. Some physical properties of QP-38 variety pigeon pea. Journal of Food Engineering, 2002; 56: 341-347.

[59] Aydin C, Ogut H, Konak M. Physical properties of Turkish Mahaleb. Biosystems Engineering, 2002; 83: 231-234.

[60] Isik E, Izli N. Physical properties of sunflower seeds (*Helianthus anuus* L.). International Journal of Agricultural Research, 2007; 2: 677-686.

[61] Yalcin C, Ersan K. Physical properties of coriander seeds. Journal of Food Engineering, 2007; 80(2): 408-416.

[62] Milani E, Seyed M, Razavi A, Koocheki A, Nikzadeh V, Vahedi N, et al. Moisture dependent physical properties of cucurbit seeds. International Agrophysics, 2007; 21: 157-168.

[63] Kheiralipour K, Karimi M, Tabatabaeefar A, Nadari M, Khoubaht G, Heidarbeigi K. Moisture-dependent physical properties of wheat (*Triticum aestivum L*). Journal of Agricultural Technology, 2008; 4(1): 53-64.

[64] Ebubekir N, Eugin O, Faruk O T. Some physical properties of Fenugreek *(trigenella Foenum–graceum L.)* seeds. Journal of Food Engineering, 2004; 71:37-43.

[65] Sessiz A, Esgici R, Kizil S. Moisture dependent physical properties of caper (Capparis spp.) fruit. Journal of Food Engineering, 2007; 79(4): 1426-1431.

[66] Deshpande S D, Bal S. Specific heat of soyabean. Journal of Food Process Engineering, 1999; 22:469-477.