Engineering properties of luffa (*L. cylindrica*) seed relevant to the processing machineries

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Abstract: Some physical and mechanical properties of Luffa (*L. cylindrica*) seeds were investigated at five different moisture content levels of 6%, 12%, 18%, 24% and 30%. The physical properties which included geometric mean diameters (minor, major, intermediate), sphericity, weight, bulk density and coefficient of static friction were determined. The mean values of the physical properties of the seeds were determined as major diameter 1.1423-1.2427 cm, width 0.54-0.6743 cm, thickness 0.8633-1.079 cm, geometric mean diameter 0.8102-0.9663 cm, sphericity 0.7104-0.7703, surface area 2.0620-2.9512 cm^2, specific gravity 0.7600-1.0267, bulk density 0.3730-0.6053 g m^{-3}, and porosity 0.5823-0.0430, respectively. The physical properties of the seed showed that the moisture content increased but the porosity decreased. The friction coefficient was measured and was between 0.3263-0.4160 on glass, 0.4265-0.5357 on aluminium and 0.4257-0.6197 on wood. The mechanical properties, which include fracture force, compressive strength, deformation, tensile strength and strain, all decreased as follows: moisture contents: 6%-30%, fracture force: 1479 N-1208 N, compressive strength: 288-220 N mm^{-2}, deformation: 5.23-3.86 mm, strength: 3.82-3.09 MPa, and strain: 3.25-2.7. The results will provide the relevant data of efficient process handling and equipment design of the seeds to the engineers and designers.

Keywords: luffa seeds, moisture content, physical properties, mechanical properties

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1 Introduction

Luffa is derived from the cucumber and marrow family and originates from America (Mazali and Alves, 2005). Luffa (*Luffa cylindrica*), commonly called sponge gourd, loofa vegetable sponge, bath sponge or dish cloth gourd, is a member of cucurbitaceous family. The number of species in the genus *Luffa* varies from five to seven. Only two species *L. cylindrica* and ribbed or ridge gourd [*L. acutangula* (L.) Roxb] are domesticated. There is a long history of cultivation in the tropical countries of Asia and Africa. Seeds need to be germinated at 25ºC, grown on and transplanted when the soil temperature is about 18ºC. Although *L. cylindrica* can be left to grow along the ground, best yields and fruit quality are obtained using a support structure (Bal et al., 2004). The Figure 1, Figure 2 and Figure 3 below showed *Luffa cylindrica* seeds, plant and sponge, respectively.

Figure 1 Luffa (*L. cylindrica*) seeds

Figure 2 *Luffa cylindrica* plant

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Figure 3 Dried luffa sponges

Effort is being made towards the possibility of harnessing, converting and recycling waste seeds from edible fruits and those are regarded as weeds (non-edible ones), like *L. cylindrica* from industrial, domestic or technological resources (Oboh and Aluyo, 2009). This emerging cash crop will improve the economies of many countries in the future because of its numerous potentials (Oboh and Aluyo, 2009).

With regard to the industrial and technological development, the cost of fuel is increasing. Oil is extracted from the seeds for industrial use (Bal et al., 2004). The oil extracted from luffa seeds is found to increasing use in the production of biodiesel and bio-lubricant, which is now gaining wide acceptance because of low CO_2 emission and other considerations (Ajiwe et al., 2005). It has been reported that luffa cylindrica has natural fiber which can be used for composite reinforcement (Dittenber and GangaRao, 2012). Attempts have been made by other researchers for the preparation of hybrid composites of natural fiber and synthetic fiber to improve the mechanical properties of the composites (Dittenber and GangaRao, 2012). In oriental medicine, *Luffa cylindrica* has the effect on the treatments of fever, enteritis and swell *etc*. The extracts from vines alive are used as an ingredient in cosmetics and medicine (Lee and Yoo, 2006). They are used for bathing, removing toxins and regenerating the skin. They help varicose veins and cellulite by stimulating circulation. Immature fruits are used as vegetables, which are good for diabetes (Bal et al., 2004). Luffa sponge is a suitable natural matrix for immobilization of microorganisms and has been successfully in the process of bio-sorption of heavy metals from wastewater (Iqbal and Edyvean, 2004).

However, the engineering properties of various agricultural products need to be understood and are very important to the design of machine structure, process and control. The engineering properties are physical, mechanical, thermal, electrical, optical, aerodynamic and hydrodynamic properties. All these properties are very useful in handling, storage, processing, preservation, quality evaluation distribution and marketing of agricultural crops. But in the course of this research, only the physical and mechanical properties were considered. In order to design equipment used in planting, storage, transportation, harvesting, processing, and oil extraction of agricultural oil seeds, it is necessary to know various physical and mechanical properties (Bamgboye and Adebayo, 2012).

The physical and mechanical properties are important in the sizing, separating, grinding, and oil extraction machines. As the true density, bulk density and porosity are used in the design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products. The static friction coefficient of the grinding against the various surfaces is also necessary in designing of conveying, transportation and storage structures. Moreover, moisture content, volume and density plays important roles in numerous technological processes and in evaluating product quality during drying, and also in the design of silo and other storage structures (Olaniyan and Oje, 2002).

Luffa seeds have a wide range of applications and have great potentials. There is little information on the basic physical and mechanical properties of the seeds, which is an identified problem in the development of new method of handling, processing and separating the seed from the kernel. There are no equipment specifically designed and used in handling and processing of luffa seeds. This is probably due to the lack of relevant data and information on the physical and mechanical properties of the seeds at different moisture contents. Therefore, the aim of this study is to determine some engineering properties of luffa seeds locally grown in Minna at five different moisture contents.

2 Materials and methods

2.1 Sample preparation

The luffa seeds were collected from Bosso Campus, Federal University of Technology, Minna, Niger State, Nigeria. The seeds were removed from the sponge gourd. Hundreds of seeds were selected randomly and conditioned to different moisture contents and their physical and mechanical properties were determined. The Figure 4 below showed the five different samples of the luffa seeds used.

Figure 4 Luffa seeds samples

2.2 Moisture content determination

The initial moisture contents of the seeds were determined by using the oven (Genlab Oven Model No. PBS118SF, SNR: 94L234). The seeds were weighed and dried at the temperature of 105°C for 24 hours till there were no more changes in the weight (Aviara et al., 2005). The initial moisture (Dry basis) content was determined by using the expression in Equation (1).

$$m_c = \frac{W_1 - W_2}{W_2} \times 100 \quad (1)$$

where, m_c = moisture content; W_1 = weight of seed before oven dried; W_2 = weight of seed after oven dried.

2.3 Variation of moisture content

The samples were transferred to a separate polythene bags and reconditioned to moisture content levels of 6%, 12%, 18%, 24% and 30%. Calculated amount of distilled water was added to each sample and the bags were sealed tightly. The samples were refrigerated for a week to enable the moisture distribute uniformly throughout the samples. The prepared samples were then taken out of the refrigerator and placed at room temperature for about 2 hours (Koocheki et al., 2007; Işık and Izli, 2007).

The samples of the preferred moisture contents were prepared by adding pre-determined quantity of distilled water by using Equation (2) (Sacilik et al., 2003; Bart-Plange et al., 2012).

$$Q = \frac{W_i(m_f - m_i)}{(100 - m_f)} \quad (2)$$

where, Q = Mass of distilled water to be added, g; W_i = Initial mass of sample, g; m_i = Initial moisture content of the sample in dry basis, %; m_f = Final moisture content of the sample in dry basis, %.

2.4 Size determination

A Mitutoyo absolute digimatic vernier calliper (precision 0.010) was used to measure the major, minor and intermediate diameters of the seeds. The average of each measurement was taken as the reading for each of the samples (Balami et al., 2016; Dauda et al., 2015; Dauda et al., 2014; Joshi et al., 1993).

2.5 Determination of arithmetic mean diameter

The arithmetic mean diameters of luffa seeds were calculated using the relationships given in Equation (3) as reported by Kiani et al. (2008).

$$D_a = \frac{(L + W + T)}{3} \quad (3)$$

where, D_a = arithmetic mean diameter, mm; L = the major diameter or dimension along the longest axis, mm; W = the minor diameter or dimension along the longest axis perpendicular to L, mm; T = the intermediate diameter or thickness dimension along the lowest axis perpendicular to both L and W.

2.6 Geometric mean diameter

The geometric mean diameter of the luffa seed was determined from the major (a), minor (b) and intermediate (c) diameter using the relationship in Equation (4) as reported by Kiani et al. (2008).

$$D_G = (LWT)^{\frac{1}{3}} \quad (4)$$

where, D_G = geometric mean diameter, mm; L = the major diameter or dimension along the longest axis, mm; W = the minor diameter or dimension along the longest axis perpendicular to L, mm; T = the intermediate diameter or thickness dimension along the lowest axis perpendicular to both L and W.

2.7 Hundreds seed mass

Hundreds of seeds weight was measured by counting

100 seeds and then weighed in the digital weighing balance of 0.01 g accuracy (Adventurer Digital Weighing Balance, OHAUS, AR3130, SNR: 8728416524) (Hojat et al., 2009).

2.8 Weight and volume

The weight and volume were determined by using electronic weighing balance and toluene (C_7H_8) (Sigma-Aldrich) displacement method. Toluene was used instead of water displacement method because the seed will be not able to absorb much toluene which can affect both the mass and volume of the seed engineering properties (Balami et al., 2014).

2.9 Sphericity

It is a method to measure how close the material is to a sphere. The sphericity of luffa seeds was determined by obtaining the values of the major, minor and intermediate diameter of the seed. The sphericity was calculated by using the expression in Equation (5) (Balami et al., 2014).

$$\text{Sphericity} = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (5)$$

2.10 Surface area

The surface area was determined by analogy by using Equation (6) as reported by Balami et al. (2014).

$$(S_a) = \frac{\pi d a^2}{2a - d} \quad (6)$$

$$d = (bc)^{0.5}$$

where, S_a = the surface area, mm^2; a = Major diameter, mm; b = Intermediate diameter, mm; c = Minor diameter, mm.

2.11 Bulk density

The bulk density of luffa seed was determined by pouring the seed into a 24 mL container and the excess seeds were removed by a strike-off stick. The content was weighed with a digital balance (MT 2000, Gibertini Electronical, Italy) with sensitivity of 0.001 g and divided by the volume of the container using the expression in Equation (7) (Koocheki et al., 2007).

$$B = \frac{M}{V} \quad (7)$$

where, M = Mass of the seeds, g; V = Volume of the seeds, mL.

2.12 True density

The liquid displacement method as described by Tavakoli et al. (2009) was used to determine the true density of the seed samples. Volume of the seeds was determined by toluene (C_7H_8) (Sigma-Aldrich) displacement method. Toluene was used to evaluate the absorption levels for the reason that its surface tension was very low compared to water and toluene could flow smoothly over the seed surface.

Toluene was poured into a measuring cylinder of 1000 cm^3. The amount of toluene displaced was determined by hanging each of the seeds in the graduated measuring cylinder and the increase in the weight of the seed was calculated. The mass of each seed was obtained by using an electronic balance with sensitivity of 0.001 g. The true density was calculated by using the relationship in Equation (8) (Balami et al., 2014).

$$(\rho_t) = \frac{M}{V_t} \quad (8)$$

where, ρ_t = true density; M = mass of the seeds, g; V_t = Volume of the seeds, m^3.

2.13 Porosity

The porosity (ε) values were calculated from the values of true density and bulk density using the relationship in Equation (9) as reported by Bup et al. (2013).

$$\text{Porosity } (\varepsilon) = (1 - \frac{\rho_b}{\rho_t}) \times 100 \quad (9)$$

where, ρ_b is the bulk density and ρ_t is the true density.

2.14 Determination of static coefficient of friction

The static friction coefficient of luffa seeds was determined on three different surfaces (plywood, glass and mild steel) for all the three samples. It was determined by filling a hollow plastic box with seeds. The box was placed on the surface, which was gradually tilted until the box just began to slide down the surface. The angle of the surface made with the horizontal was taken. The friction coefficient (μ) was obtained using Equation (10) by finding tangent of the angle (Adejumo 2003).

$$\mu = \tan\beta \quad (10)$$

where, μ = Static coefficient of friction; β = angle of inclination.

2.15 Determination of specific gravity

The specific gravity was determined as a function of moisture content by the use of a void meter manufactured

(Jecons Scientific Limited, Bedfordshire, England). The luffa seeds were placed in the sample jar and water was added to determine the percentage void content by reading value from the scale on the tube. The percentage void content of the sample was computed on the basis of the mass of the sample in the sample jar which was subtracted from the mass of the sample in the jar. The value obtained was used to divide the weight of the sample to obtain the specific gravity (Adejumo, 2003).

2.16 Angle of repose

The angle of repose with the horizontal at which the material will stand when piled. It was determined using topless and bottomless cylinder of 0.15 m diameter and 0.25 m height. The cylinder was placed at the centre of a raise circular plate with a diameter of 0.35 m and was filled with luffa seeds. The cylinder was raised slowly until it formed a cone on a circular plane. The height of the cone was measured and the filling angle of repose was calculated by using the following relationship in Equation (11) as reported by Karababa (2006).

$$\theta = \tan^{-1}(\frac{2d}{H}) \tag{11}$$

where, d = diameter of the cone formed, m; H = height of the cone, m.

2.17 Determination of mechanical properties

The mechanical properties of the luffa seeds at five different moisture contents were determined at Institute of Agricultural Research, Samaru, Zaria. The compressive test was conducted using Testometric Machine (ZDM50-2313/56/18, VEB, Dresden, Germany). The testometric machine was shown in the Figure 5 below.

Figure 5 Testometric AX Machine (M 500-25 kN)

3 Results and discussion

3.1 Physical properties

The results obtained from the physical and mechanical properties of luffa seeds were further subjected to statistical analysis. The analysis was used to consider the effects of the variation in proportion of the moisture content levels on the physical and mechanical properties of luffa seed. One-way ANOVA (Duncan multiple range test) was used to present or absent the significance in proportion of the level at 5% (α = 0.05). The results for the physical and mechanical properties were shown in Table 1 and Table 2 below.

Table 1 Physical properties of *luffa seeds* at different moisture contents

Properties	6%(db)	12%(db)	18%(db)	24%(db)	30%(db)
Bulk density, g m^{-3}	0.3730 ± 0.0058^{a}	0.4027 ± 0.00^{b}	0.4567 ± 0.00^{c}	0.5257 ± 0.00^{d}	0.6053 ± 0.00^{e}
True density	0.8960 ± 0.001^{d}	0.7427 ± 0.00^{c}	0.6860 ± 0.00^{b}	0.6327 ± 0.00^{a}	0.6333 ± 0.00^{a}
Porosity	0.5823 ± 0.00^{e}	0.4580 ± 0.00^{d}	$0.33^{d}3\pm0.00^{c}$	0.1677 ± 0.00^{b}	0.0430 ± 0.00^{a}
Specific gravity	0.7600 ± 0.01^{b}	1.0667 ± 0.00^{d}	1.0767 ± 0.00^{d}	1.0842 ± 0.00^{a}	1.0892 ± 0.00^{c}
Angle of repose^{0}	82.7 ± 0.61^{c}	83.433 ± 0.06^{d}	$82.60\pm0.2b^{c}$	82.10 ± 0.10^{ab}	81.700 ± 0.10^{ab}
Minor diameter, cm	0.54 ± 0.01^{a}	0.6163 ± 0.00^{b}	0.6513 ± 0.00^{c}	0.6830 ± 0.00^{d}	0.6943 ± 0.00^{d}
Intermediate diameter, cm	0.8633 ± 0.00^{a}	0.9037 ± 0.00^{b}	0.9930 ± 0.00^{c}	1.0760 ± 0.00^{d}	1.0790 ± 0.00^{e}
Major diameter, cm	1.1423 ± 0.00^{a}	1.1483 ± 0.00^{b}	1.1503 ± 0.00^{b}	1.2377 ± 0.00^{c}	1.2427 ± 0.00^{d}
Geometric mean Diameter, cm	0.8102 ± 0.00^{a}	0.8613 ± 0.00^{b}	0.9342 ± 0.04^{c}	0.9688 ± 0.00^{c}	0.9693 ± 0.00^{c}
Sphericity	0.7104 ± 0.02^{a}	0.7489 ± 0.00^{a}	0.7675 ± 0.09^{a}	0.7685 ± 0.00^{a}	0.7703 ± 0.00^{a}
Surface area, cm^2	2.0620 ± 0.02^{a}	2.3303 ± 0.01^{a}	2.7457 ± 0.27^{b}	2.9447 ± 0.00^{b}	2.9512 ± 0.00^{b}
Coefficient of glass	0.3263 ± 0.00^{c}	0.3460 ± 0.01^{b}	0.3527 ± 0.00^{b}	0.3617 ± 0.00^{b}	0.4160 ± 0.00^{b}
Coefficient of aluminium	0.4265 ± 0.00^{e}	0.4520 ± 0.00^{d}	0.4803 ± 0.00^{c}	0.4990 ± 0.00^{b}	0.5357 ± 0.00^{a}
Coefficient of wood	0.4257 ± 0.00^{e}	0.4690 ± 0.00^{d}	0.5097 ± 0.00^{c}	0.5217 ± 0.00^{b}	0.6197 ± 0.00^{a}

Note: value followed by same superscript alphabet are not significantly different at (p<0.05) along the rows. Values are Mean±Standard deviation.

Table 2 Effect of Moisture Content on Mechanical Properties of Luffa Seed

Moisture content	Fracture force, N	Compressive strength, N mm^{-2}	Deformation, mm	Strength, MPa	Strain
6%	1479±1.0^{e}	288±1.0^{e}	5.23±.01^{e}	3.82±.01^{c}	3.25±.01^{d}
12%	1398±1.0^{d}	283±1.0^{d}	5.01±.01^{d}	3.5556±.01528^{b}	3.09±.01^{c}
18%	1249±1.0^{c}	275±1.0^{c}	4.99±.01^{c}	3.12±.0100^{a}	2.92±01^{b}
24%	1219±10^{b}	250±1.0^{b}	4.26±.01^{b}	3.06±.01^{a}	2.8±.01^{a}
30%	1208±1.0^{a}	220±1.0^{a}	3.86±.01^{a}	3.09±.13973^{a}	2.7±.01^{a}

Note: value followed by same superscript alphabet are not significantly different at (p<0.05) along the rows. Values are Mean±Standard deviation.

Analysis of the result showed that the moisture content has significant difference (p<0.05) on the length, width, thickness, arithmetic and geometric properties of the seeds.

3.2 Effect of moisture content on geometric mean

The geometric mean and arithmetic mean diameters (Figure 6) increased with the increase of the moisture content and the dimension. The arithmetic and geometric mean diameters ranged from 0.8102 to 0.9663 cm. It was an important consideration in the theoretical determination of the seeds volume at different moisture contents. The similar results was also reported that the physical properties increased as the moisture content increased for soybean grains and Roselle seeds (Tavakkoli et al., 2009; Bamgboye and Adejumo, 2009).

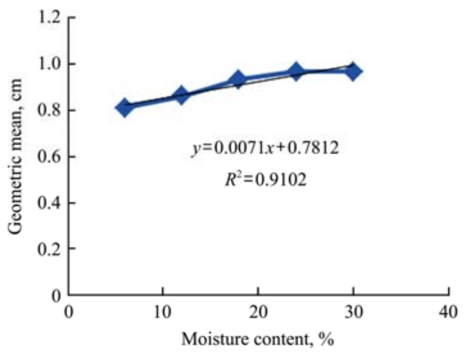

Figure 6 Effect of moisture content on geometric mean diameters

3.3 Bulk density

The bulk density varied from 0.373 to 0.6053 g cm^{-3} and this indicated an increase in bulk density as moisture content increased from 6% to 30%. This may be attributed to the increase in the mass as a result of moisture gained in the sample which was higher than the accompanying volumetric expansion of the bulk as reported by Pradhan et al. (2008). A similar increasing trend in bulk density was reported by Baryeh and Mangope (2002) for QP-38 variety pigeon peas. The relationship between bulk density and moisture content was shown in Figure 7.

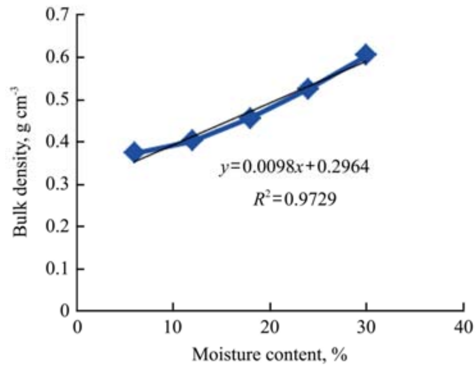

Figure 7 Effect of moisture content on bulk density

3.4 True density

The true density varied from 1.27 to 0.98 g cm^{-3} as the moisture content increased from 6% to 30%. The effect of moisture content on true density showed a decrease in true density with increasing moisture content. Related result had been reported by Silick et al. (2003) for hemp seed, and Altuntaş and Demirtola (2007) for some legumes seeds. The relationship between true density and moisture content was shown in Figure 8.

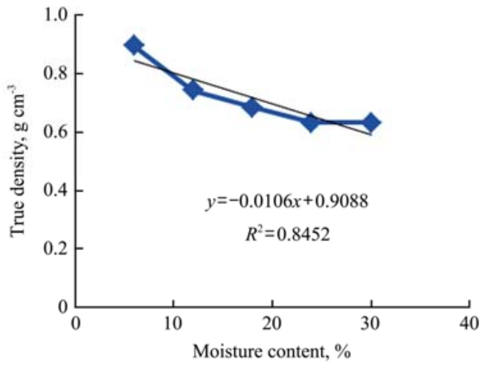

Figure 8 Effect of moisture content on true density

3.5 Effect of moisture content on surface area

The surface area ranged from 2.0620 to 2.9512 mm^{2} when the moisture content increased from 6% to 30%. This moisture content effect on the luffa seeds surface area was statistically significant (p<0.05). The increase of the values might be attributed to its dependence on the three linear dimensions. Similar results have been reported by Saçilik et al. (2003) for hemp seeds. Figure 9 below showed the relationship between moisture content and surface area.

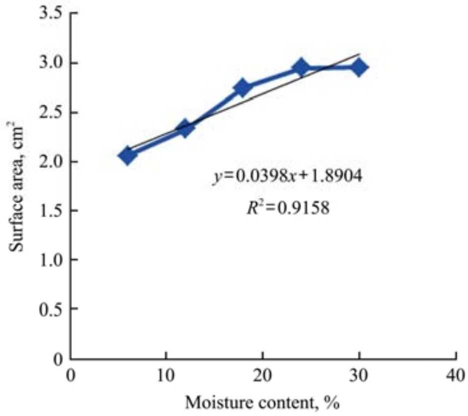

Figure 9 Effect of moisture content on surface area

3.6 Effect of moisture content on porosity

As shown in Table 1, the porosity for luffa seed decreased with the increase in moisture content. It decreased from 0.5823 to 0.0430 as the moisture content increased from 6% to 30%. Higher porosity provided better aeration and water vapour diffusion during deep bed drying. Similar trend was reported for hazel nut (Aydin, 2002) and popcorn (Karababa, 2006). The relationship between the porosity and moisture content was shown in the Figure 10.

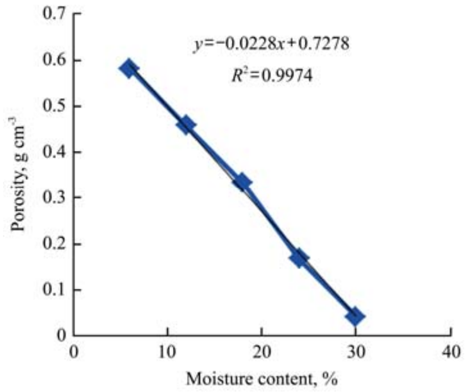

Figure 10 Effect of moisture content on porosity

3.7 Effect of moisture content on coefficient of friction

The friction coefficient for all samples at the various moisture content levels followed a similar pattern. It increased with an increase of moisture content on all the surfaces used. In Figure 11, it was observed that the friction coefficient was highest on wood surface. This is similar to that reported by Çalisir et al. (2005) for rape seeds and karinda seeds (Suthar and Das, 1996). While the minimum friction occurred for samples on the glass surface, this is similar to that reported for lentil seeds (Amin et al., 2004). This difference could be due to the roughness of the various surfaces.

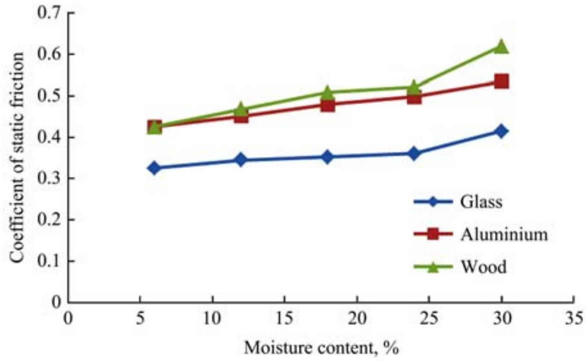

Figure 11 Effect of moisture content on the friction coefficient

Analysis of the result showed that the moisture content was statistically significant ($p<0.05$) on the deformation, strength, and strain while it has no significant effect ($p<0.05$) on the fracture force and compressive strength.

3.8 Effect of moisture content on fracture force

As shown in Table 2, moisture content increased as the fracture force decreased. The fracture force decreased from 1479 to 1208 N as the moisture content increased from 6% to 30%. This might be due to the fact that at higher moisture content, the seeds became softer and required less force to fracture (Renny et al., 2015). Altuntas and Yildiz (2007) also conducted a research to study the effect of moisture content on mechanical properties of faba bean grains and reported that as the moisture content increased from 9.89% to 25.08%, the rupture force values ranged from 314.17 to 185.10 N. The Figure 12 below showed the relationship between the moisture content and fracture force.

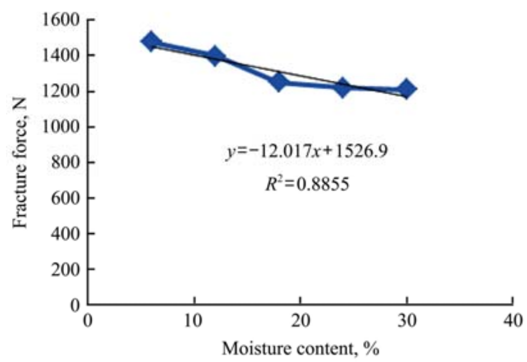

Figure 12 Effect of moisture content on fracture force

3.9 Effect of moisture content on compressive strength

The relationship between compressive strength and moisture content was shown in Figure 13 below. The compressive strength decreased linearly from 288 to 220 N as the moisture content increased from 6% to 30%. It might be due to the fact that they became softer and the forces reduced the strength as the seed absorbed moisture. Similar decreasing trend was observed with the moisture increased in the determination of the strength for barley kernels under uni-axial compression (Bargale et al., 1995).

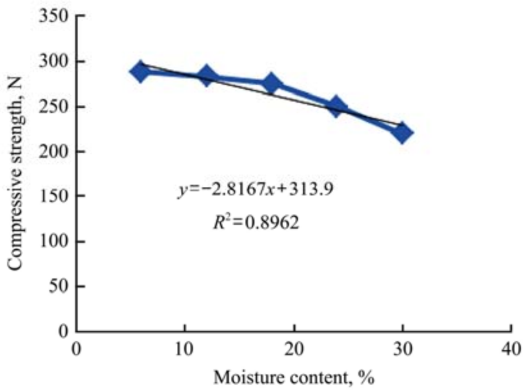

Figure 13 Effect of moisture content on compressive strength

3.10 Effect of moisture content on deformation, strength, and strain

The deformation, strength and strain decreased from 5.23 to 3.86 mm, 3.82 to 3.09 N, 3.25 to 2.7, respectively as the moisture content increased from 6% to 30%. The relationship between the deformation, strength and strain was shown in the Figure 14 below.

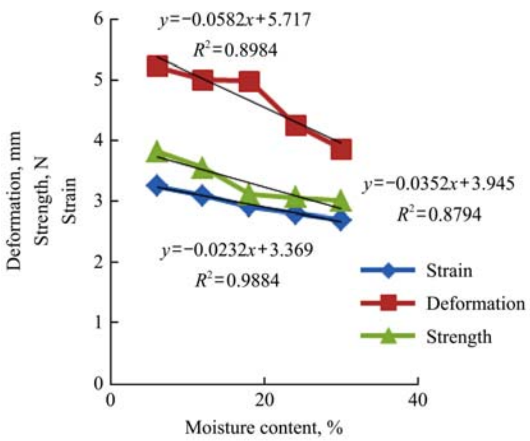

Figure 14 Effect of moisture content on deformation, strength and strain

4 Conclusions

The variation in the moisture content increased the linear dimensions, bulk density, geometric diameter, surface area and the coefficient of friction along the three surfaces, but decreased the true density and porosity. The variation in the moisture content also decreased the mechanical properties. Statistical analyses ($p<0.05$) revealed that the variation in the moisture content had a significant effect on the physical properties and the mechanical properties except for the fracture force and the compressive strength.

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