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Physical Properties of Ginger (Zingiber Officinale)

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I. Introduction

Ginger (*Zingiber Officinale* Roscoe) is a tropical monocotyledon and herbaceous perennial specie belonging to the order *Scitamineae* and family *Zingiberaceae*. It is the oldest rhizome widely domesticated as a spice. The cultivation of ginger commenced in Nigeria in 1927 and the locations include Southern Zaria, Jemma Federated districts and neighboring parts of Plateau but today, ginger is cultivated nationwide (Okwuowulu, 1997). NRCRI (2005) confirmed that ginger grows well in the rainforest region of the country where rainfall is above 2000 *mm* and altitudes ranging from 0 - 800 meters above sea level within a temperature range of 25 ^{0}C – 35 ^{0}C (Njoku *et al.,* 1995). Nigeria's production in 2004 was 117,000 tonnes (FAOSTAT, 2012), 10 % of which is locally consumed as fresh ginger and 90 % dried primarily for the export markets (Ayemibo, 2009) Ginger is a plant with leafy shoots, finger-like perennial underground part or rhizomes called hands and grows to a height of about 1.5 *m* with an aerial part as high as 0.8 *m* depending on cultivars and growing environment (Entrepinoys, 2010). It can be grown on sandy loam and clay loam soil with good drainages and a lot of organic matter. Ginger is popular for its distinct sharp and hot flavor due to an oily substance called *gingerol*. The knobby rhizome is ready for harvesting and dug up when all the leaves and stems of the plant wither, which occurs between 6 and 12 months after planting, harvesting of ginger starts from October and normally continues until April/May, depending on market situation as ginger can be left on the ground (not harvested) for two years. Yields of up to 20-30 tonnes per hectare are possible under improved cultural management. Ginger is in three (3) forms namely: fresh or green ginger, whole dry ginger and split dry ginger. The fresh or green ginger refers to the newly harvested ginger with little or no loss in moisture content; this type of ginger is not in hot demand in the international market because of the length of time it takes for the product to dry up. Dry whole and dry split ginger are the most sort-after ginger in the international market though the whole dry ginger commands higher price because of the longer time it takes for the product to get dried-up and ready for sales.

Ginger is a spice and medicinal plant gaining attention in the pharmaceutical, food and chemical industries. A remarkable increase in the use of medicinal plant products has been observed in the past decade. Due to their properties, medicinal plants are used as primary health care aid among 80 % of the world's population in the form of plant extracts or their active components (WHO, 2008). Today, herbs are still found in 40 % of prescriptions, and the interest for use of herbal remedies instead of chemical drugs is increasing because of lesser side effects (Craig, 1999). Eze and Agbo (2011) reported that processing of ginger in Nigeria has not been standardized consequent upon which low quality ginger which falls short of importer's specifications are produced. In West Africa and Nigeria in particular, this important rhizome is subjected to local processing method which includes cleaning, sorting, peeling, grading, drying, splitting (slicing), size reduction and storage which is labour intensive and generally has a low output. The aspect which is of interest to the engineer (food processor) is the physical properties, mechanical properties, electrical properties, and thermal properties. This gives the engineer guidelines for

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designing machines that will be suitable for the processing of the biomaterial. Most important among these properties is the physical property which is the first consideration in the design of the post-harvest handling and sorting equipment. Jayan and Kumar (2004) designed a planter in relation to the physical properties of certain seeds.

II. Materials And Method

Sampling: Whole fresh ginger rhizomes were procured from Bodija market, Ibadan, Oyo state. The rhizomes were cleaned manually by hand to remove all foreign matter such as dirt, pieces of stone and broken rhizomes. Measurement of physical properties was thereafter followed at the central laboratory of Federal College of Agriculture, Moor plantation, Ibadan. The rhizomes were labeled and numbered as shown in Figure 1, for the purpose of identification of samples and the total number of rhizome used for the research is forty-one (41).

Figure 1 : Numbered Ginger Rhizomes

Moisture Content Determination: The moisture content of the ginger rhizomes was obtained according to ASAE Standard S358.2 (1983). The sample was dried in an electric oven at a temperature of 105 °C for 24 hours and weighed using a weighing balance at every 6 hours interval to obtain four different levels of moisture content. The moisture content of the sample in percent dry basis was calculated using Equation 1.

$$Ms = \frac{100\,(W_i - W_f)}{W_f} \qquad (1)$$

Where: Ms is the Moisture Content of Ginger rhizomes (in % dry basis), *Wi* is the Initial Mass of ginger rhizomes before oven drying (in grams) and *Wf* is the Final Mass of the rhizomes after oven drying (in grams).

a) Physical Properties

i. *Determination of Axial Dimensions*

Alphabets x, y, z are used to represent axial dimensions; major, intermediate and minor diameters respectively however, this can also be referred to as *the* length, width and thickness respectively. Vernier calliper (0.001 mm accuracy) was used in taking the measurement of length, width and thickness. Figure 2 shows the measurement of major (x), intermediate (y) and minor (z) diameters.

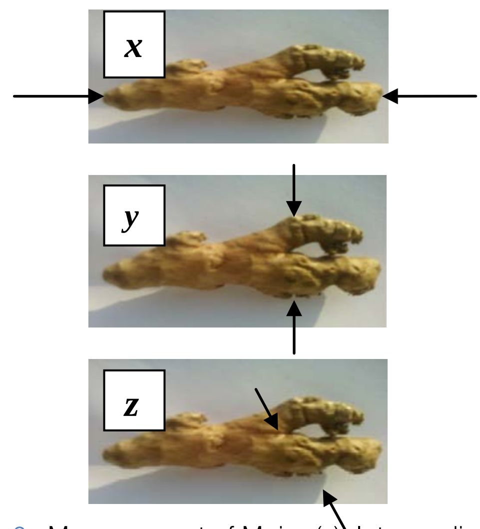

Figure 2 : Measurement of Major (x), Intermediate (y) and Minor Diameter (z) of a Ginger Rhizome

ii. *Determination of Geometric Mean*

The geometric mean was calculated using Equation 2 described by Mohsenin (1986).

$$Gm = (xyz)^{\frac{1}{3}} \qquad (2)$$

Where: Gm is the Geometric Mean, *x* is the Major Diameter of the rhizome, *y* is the Intermediate Diameter of the rhizomes, *z* is the Minor Diameter of the rhizomes (all in *mm*).

iii. *Determination of Sphericity*

The higher the sphericity value of a material, the closer its shape to a sphere, this property is useful in the design of hopper and dehulling equipment for agricultural products, it determines the tendency of a material to roll when placed on a particular orientation. The degree of sphericity of the ginger rhizomes was calculated using Equation 3 described by Mohsenin (1986).

$$\Phi = \frac{(xyz)^{1/3}}{x} = \frac{Gm}{x} \qquad (3)$$

Where: Φ is the Sphericity in decimal and other parameters remain as defined above.

iv. *Determination of Bulk Volume*

The bulk volume of the ginger rhizomes was determined using Archimedes's principle as described by Nelkon (2005). The sample was weighed and immersed in a measuring cylinder containing a known volume of water thus leading to an increase (rise) in the water volume, the difference between the new level of water in the measuring cylinder and the initial level of water is the bulk volume of the seed.

v. *Determination of Bulk Density*

The bulk density of the ginger rhizomes was determined as the ratio of bulk weight of ginger to the bulk volume.

vi. *Determination of Surface Area*

The surface area S in mm^2 was estimated by the relationship given by Asoiro and Anthony (2011) as:

$$S = \pi G m^2 \quad (4)$$

Where: *Gm* is the geometric mean diameter (*mm*) and S is the surface area of the ginger rhizomes (mm^2).

vii. *Determination of Coefficient of Friction*

The static coefficient of friction was determined with respect to each of the following three structural materials on the tilting table: stainless steel, plywood and glass. The ginger rhizomes were placed parallel to the direction of motion and the table is raised gently by a screw device, the angle at which the rhizomes begin to slide (the angle of inclination) was read from a graduated scale on the tilting table, this was repeated three times for each structural material. The coefficient of friction was calculated as the tangent of this angle as shown in Equation 5 (Olaoye, 2000; Adejumo, 2003; and Pliestic *et al.,* 2006).

$$\mu = \tan\theta \quad (5)$$

Where: μ is the Static Coefficient of Friction (decimal), θ is the Angle of Inclination (degrees).

viii. *Determination of Angle of Repose*

The angle of repose was evaluated by using a specially constructed topless and bottomless box made of plywood, with a removable front panel (Dutta *et al.,* 1988; Olaoye, 2000). The box was filled with rhizomes of ginger and placed on the floor, the front panel was quickly removed allowing the rhizomes to slide down and assume natural slope. This value is used in the design of agricultural machine hopper and other conveying equipment. The angle of repose was calculated from the measurements of the height (*h*) of the free surface of the seeds and the lenght (*l*) of the heap formed outside the box using the relationship described by Bamgboye and Adejumo, (2009):

$$\theta = tan^{-1}\left(\frac{h}{l}\right) \quad (6)$$

Where: θ is the Angle of Repose (degrees), *h* is the Height of the free surface of the rhizomes and *l* is the Length of the heap formed outside the box.

III. Results And Discussion

The number of samples used for the research, the range, the mean value and the standard deviations of some physical properties of ginger are presented in Table 1; these properties include the major diameter, minor diameter, intermediate diameter, geometric mean, sphericity, bulk volume, surface area and the bulk density of ginger rhizomes.

Table 1 : Summary of Physical Properties of Ginger (*Zingiber officinale*)

Property	Number of Samples	Range	Mean value	Standard Deviation
Major Diameter *(mm)*	41	76.1 – 133	112	25.5
Intermediate Diameter *(mm)*	41	60 – 82.0	72.3	9.8
Minor Diameter *(mm)*	41	28 – 44.0	38.3	7.1
Geometric Mean *(mm)*	41	50.4 – 78.3	67.6	12.4
Sphericity *(dec)*	41	0.66 – 0.59	0.61	0.03
Surface Area *(cm^2)*	41	79.8 – 192.6	147	49.8
Bulk Volume *(cm^3)*	41	660 – 1120	832.5	201.2
Bulk Density *(g/cm^3)*	41	0.96 – 0.87	0.92	0.048

a) *Bulk Weight and Moisture Content*

The bulk weight of ginger rhizomes at 6 hours interval of drying ranges from 0.64 kg to 0.97 kg, the percent moisture content dry basis varied from 10.9 - 51.6 % with a mean value of 24.5 % (+ 18.4). For wet basis, the moisture content mean value was lower than the value obtained for the dry basis; the percent moisture content wet basis ranges from 8.6 - 34% with a mean value of 18.2% (+11.04), this implies that ginger has a high moisture content and it is liable to deteriorate

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quickly after harvesting therefore, processing or post-harvest handling should not be delayed because dried foods in general keep longer if held at low moisture contents. This can be attributed to their reduced oxidation and lowered chemical reaction (Bolin, 1980). This value is in the same range with the moisture content of green gram plant ranging from 8.39 to 33.40 % wet basis (Nimkar and Chattopadhyay, 2001). A similar trend was reported by Bande *et al.* (2012) for *Egusi* melon (*Citrullus colocynthis* lanatus) seeds having a moisture content range between 7.11 - 38.7 % wet basis; Zareiforoush *et al.* (2009) for paddy grains having a moisture content range of 8 - 21 % dry basis, Li Ma *et al.* (1998) for foods and other biological materials. However, Alakali and Santimehin (2009) reported that the equilibrium moisture content (EMC) of the ginger powder increases as the water activity increases at constant temperature and an increase in temperature causes more activation of water molecules due to increase in energy level.

b) Axial Dimensions

The major diameter (length), intermediate diameter (width), minor diameter (thickness), and geometric mean of ginger are significantly different and increases with increasing moisture content. It was observed that Within the moisture content range of 10.9 % dry basis to 51.6 % dry basis, the length of ginger rhizomes increased from 76.1 *mm* to 133 *mm* (75 % increase in length), the width increased from 60 *mm* to 82 *mm* (37 % increase in width) and the thickness increased from 28 *mm* to 44 *mm* (84% increase in thickness) while the geometric mean increased from 50.4 *mm* to 78.3 *mm* (55 % increase). However, the relationship observed between values of length (*x*), width (*y*), thickness (*z*) and geometric mean diameter (*Gm*) and the percent moisture content (*Mc*) of ginger in dry basis are given in equations 7, 8, 9 and 10 respectively.

$$x = 0.977Mc + 87.83\ (R^2 = 0.497) \quad (7)$$

$$y = 0.424Mc + 61.85\ (R^2 = 0.635) \quad (8)$$

$$z = 0.266\ Mc + 31.73\ (R^2 = 0.471) \quad (9)$$

$$Gm = 1.08Mc - 48.34(R^2 = 0.526) \quad (10)$$

A similar trend was reported by Asoiro *et al.* (2011) having a major diameter range of 6.7 cm to 10.32 cm with mean value of 8.1778 cm, the intermediate diameter range of 5 cm to 7.7 cm with mean value of 6.712 cm, minor diameter range of 5.17 to 7.44 cm with mean value of 6.3025 cm and geometric mean diameter of 5.910 cm to 8.057 cm with mean value of 7.013cm.

c) Sphericity

The sphericty of ginger rhizomes decreases with an increase in moisture content, as moisture content of ginger increased from 8.6 to 34% wet basis, the average sphericity of ginger rhizomes decreased from 0.66 to 0.59 (10% decrease), this is similar to findings of Bande *et al.* (2012) on *egusi* melon seed (having a 9 % decrease), Simonyan *et al.* (2009) for *Ronghai lablab* seeds having a sphericity value decreasing from 0.78 to 0.76 between 9.7 and 29 % moisture content wet basis and *Highworth Ronghai* seeds decreasing from 0.659 to 0.653 between 10.2 and 22.6 % wet basis. The relationship between moisture content and the sphericity of ginger rhizomes is given in equation 11.

$$\Phi = -0.001Mc + 0.635(R^2 = 0.312) \quad (11)$$

Sphericity value of most agricultural produce has been reported to range between 0.32 and 1.00 (Mohsenin, 1970; Irtwange and Igbeka, 2002).

d) Bulk volume

The bulk volume of ginger rhizomes increases as the moisture content increases. It was observed that as moisture rises from 10.9 to 51.6 % moisture content dry basis and the bulk volume rises from 0.66 cm^3 to 1.12 cm^3 respectively as shown in Figure 3.

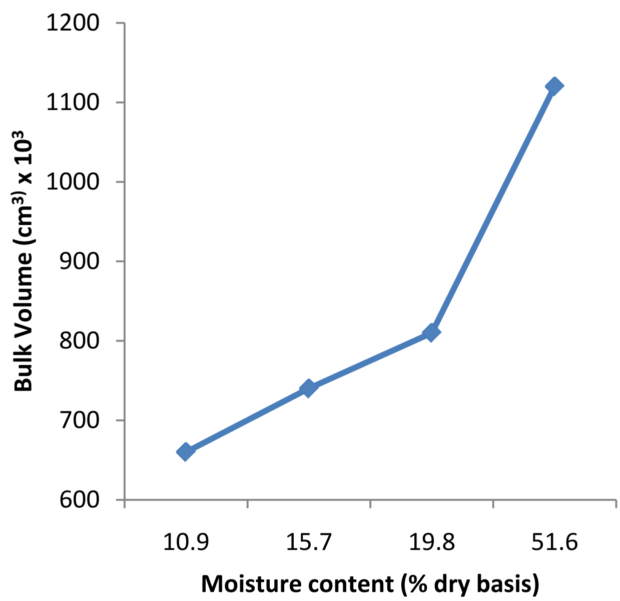

Figure 3 : Effects of Moisture Content on Bulk Volume of Ginger

However, a linear relationship between the bulk volume and moisture content of ginger rhizome was observed to be:

$$Y = 10.85X + 566.6(R^2 = 0.987) \quad (12)$$

Where: Y is the bulk volume (cm^3) and X is the moisture content (% dry basis) and R is the regression analysis.

The volumetric rise may be attributed to the expansion in the axial dimensions which contributed to weight increase of the rhizomes thereby resulting to displacement of more liquid. The variation of bulk volume with moisture content is similar to the trend reported by Bamgboye and Adejumo (2009) for Roselle (*Hibiscus sabdariffa* L.) seeds with the mean volume of the seeds increasing from 29.7×10^{-6} m^3 to 40×10^{-6} m^3 as the moisture content increased from 8.8 to 17 % dry basis; Desphande *et al,* (1993) for soybean seeds; Ozarslan (2002) for cotton seeds; Altuntas and Demirtola (2010) for some grain legume seeds, Simonya *et al.* (2009) for *Ronghai lablab* Seeds increasing from 0.24cm^3 to 0.54cm^3 within 9.7 to 29% moisture content wet basis and *Highworth Lablab* seeds increasing from 0.108 cm^3 at 10.2 % moisture content wet basis to 0.54 cm^3 at 29 % moisture content wet basis, Zareiforoush *et al.* (2009) for paddy grains with the volume of both varieties of paddy grains observed to increase from 26.91 to 29.94 mm^3 and 23.12 to 25.11 mm^3 for *Alikazemi* and *Hashemi* varieties respectively within a moisture content increase from 8 to 21% (d.b.); Asoiro and Anthony (2011) for African yam Beans and Ndukwu (2009) for *Brachystegia eurycoma* seeds.

e) Bulk Density

The bulk density of ginger decreased with an increase in moisture content as shown in figure 4. It decreased from 0.96 g/cm^3 at 10.9 % d.b. to 0.87 g/cm^3 at 51.6 % d.b. The regression equation for the bulk density (B) of ginger was of the form:

$$B = -0.002x + 0.971(R^2 = 0.701) \qquad (13)$$

Similar trend was reported for chickpea seeds by Konak et al. (2002), African yam bean by Irtwange and Igbeka (2002), *lablab* seeds by Simonyan *et al.* (2009), arecanut kernels by Kaleemullah and Gunasekar (2002) and round red lentil grains by Isik (2007). Bulk density has been reported to have practical applications in the calculation of thermal properties in heat transfer problems, in determining Reynolds number in pneumatic and hydraulic handling of materials and in predicting physical structure and chemical composition (Irtwange and Igbeka, 2002).

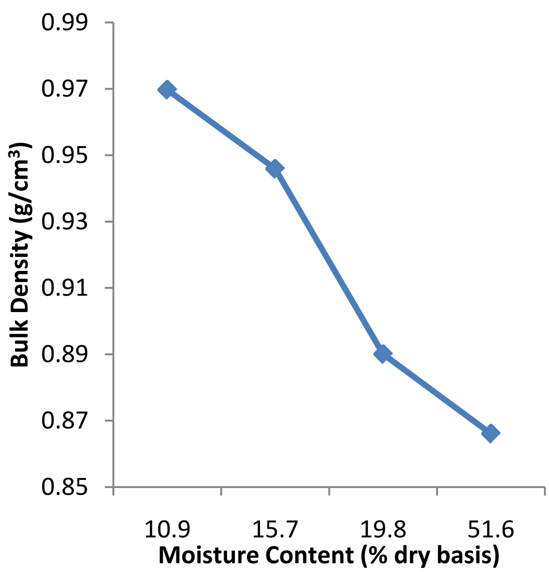

Figure 4 : Effects of Moisture Content on the Bulk Density of Ginger

f) Angle of Repose

The angle of repose is also determined at different moisture levels, it was observed to increase as the moisture content increases as shown in Figure 5. However, the angle of repose of ginger ranges from 41.3^0 at 10.9 % moisture content dry basis to 57.6^0 at 51.6 % moisture content dry basis, a linear relationship observed between the angle of repose and moisture content of ginger is given in equation 13:

$$A = 0.340\,B + 40.68\,(R^2 = 0.873) \qquad (14)$$

Where: A is the angle of repose (degrees) and *B* is the moisture content (percent dry basis) and R is the regression analysis.

This increasing trend of angle of repose with moisture content occurs because surface layer of moisture surrounding the particle hold the aggregate of grain together by the surface tension (Pradhan *et al.*, 2008) and it implies that friction increases on the surface of the rhizomes as water content increases, thereby making the seeds less able to flow on one another. The experimental values were seen to be higher than that of oilbean seed (Oje and Ugbor, 1991). However, similar trend was reported by Zairefoush *et al.* (2009) for different varieties of paddy grains, he observed an increase from 35.67^0 to 41.23^o and 38.27^o to 44.37^0 respectively for *Alikazemi* and *Hashemi* cultivars in the moisture range of 8–21% (d.b.). Bamgboye and Adejumo (2009) reported a similar trend for Roselle

(*Hibiscus sabdariffa* L.) seeds increasing with an increase in moisture content from 20.13° to 24.85°; Fraser et al. (1978) for fababeans, Gamayak *et al.* (2008) for Jatropha seeds increasing from 35^0 to 43^0; Kalamullah and Gunasekar (2002) for *arecanut* kernels, Kerababa (2006); Gursoy and Guzel (2010) for grains; Karaj and Muller (2010) for *Jatropha curcas*.

The effect of moisture content on the angle of repose of ginger rhizomes is shown in figure 5.

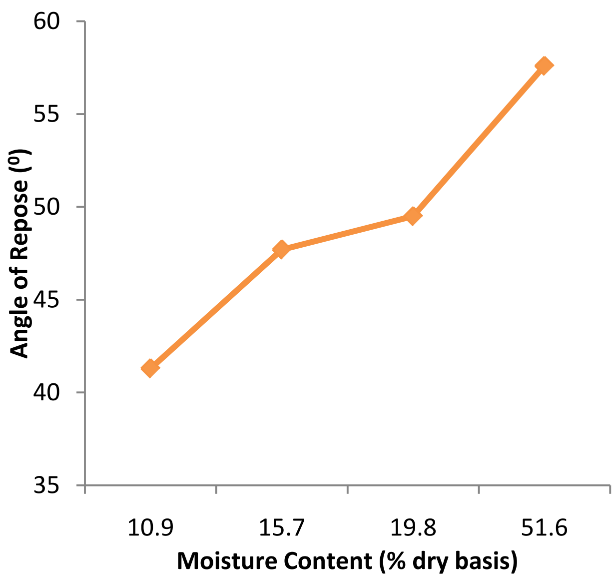

Figure 5 : Effect of Moisture Content on the Angle of Repose of Ginger

Coefficient of Friction: The coefficient of friction of seeds is required in the design of silos and hopper for processing machines thus, it was determined with respect to glass, stainless steel and wood surfaces, it was observed that the coefficient of friction was highest on wood and least on glass and it increases with an increase in the moisture content. A similar trend was reported by Zareiforoush *et al.* (2009) for two cultivars of paddy grains. He reported that the least static coefficient of friction may be owing to smoother and more polished surface of the glass than the other materials used. It was observed that the coefficient of friction for ginger rhizomes increased with increasing moisture content on all surfaces. The reason for the increased friction coefficient at higher moisture content may be owing to the water present in the rhizomes, offering a cohesive force on the surface of contact. As the moisture content of ginger increases, the surface of the samples becomes stickier. Other researchers reported a similar trend that coefficient of friction increases as the moisture content increase (Pradhan *et al.,* 2008; Altuntas and Erkol, (2010), Elfawal *et al.,* 2009).

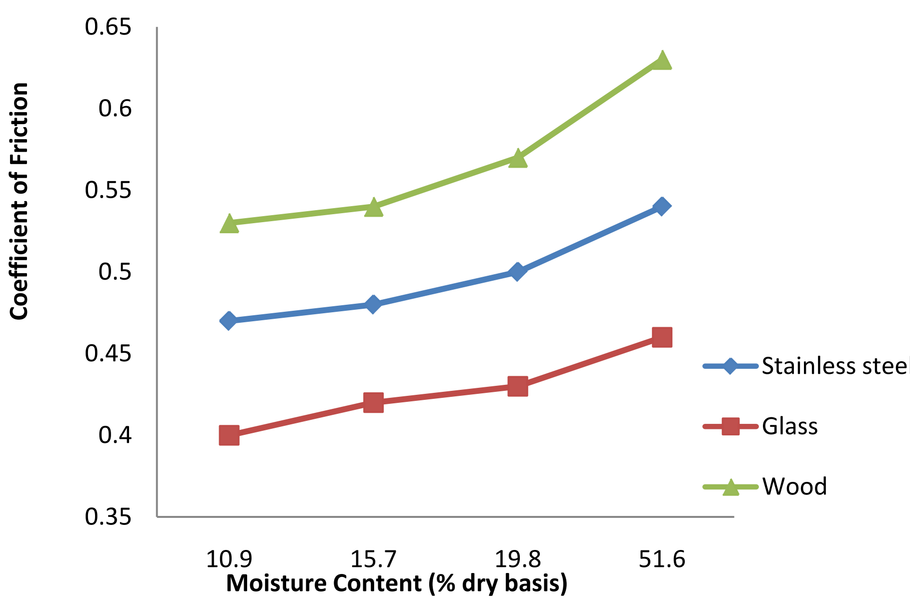

Figure 6 : Coefficient of Friction of Ginger on Glass, Steel and Wood

IV. Conclusions

The research looked at some selected physical properties of *Zingiber officinale,* such as axial dimensions (length, width and thickness), geometric mean, sphericity, bulk density, volume, bulk density, surface area, angle of repose and the coefficient of friction which are essential in the design and construction of the processing and handling equipment of *Zingiber officinale* and plays an important role in selecting the proper sorting, grading and cleaning equipment. The main dimensions are considered in selecting and designing the suitable size of the screen perforations. The physical properties of ginger measured showed some deviations from the mean value which is typical of biomaterials. The following conclusions were drawn from the research:

1. The physical properties of the seed determined as a function of moisture content varied significantly with the moisture content.
2. The axial dimensions, geometric mean diameter, angle of repose, surface area, bulk density, and coefficient of friction showed an ascending relationship with moisture rise while bulk density and sphericty which has a descending relationship on moisture gain. These properties would provide important and essential data for efficient process and equipment design.
3. The coefficient of friction varies from one material to the other (0.4 for glass, 0.49 for stainless steel and 0.55 for wood). However, glass or stainless steel which has the lowest values of coefficient of friction should be used when constructing seed hopper in ginger processing machines with side inclination of about 450 to allow easy sliding of the ginger rhizomes.

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