Determines of Selected Moisture -Dependent Physical and Frictional Properties of Shelled Egusi Melon (Citrullus lanatus Thunb.)

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Abstract— Physical and frictional properties were determined for shelled (i.e. hulled) seeds of egusi melon (Citrullus lanatus Thunb) at moisture content levels of 11.04, 15.7, 21.03 and 24.78 % dry basis. The physical properties investigated were true density, bulk density and the angle of repose; while the frictional properties were the coefficient of static friction and the coefficient of internal friction. Densities were determined using the volume displacement method, while the bulk porosity was calculated as a function of the true and bulk densities. The angle of repose was measured using the cylinder method. The coefficient of static friction of melon seeds on the surfaces of plywood, galvanized iron and glass was determined by sliding a cell filled with the seeds on a tilting table overlaid with the test material surfaces. The coefficient and internal angle of friction were determined by means of a shear test apparatus. Within the range of moisture investigated, the true density of shelled melon seeds decreased from 1.264 to 1.239 kg/m³ while its bulk density increased from 668 to 681 kg/m³. The porosity decreased from 47.19 to 45.36 % while the angle of repose increased from 31.0 to 34.9°. The coefficient of friction of shelled melon seeds on the surfaces of glass, galvanised iron and plywood increased from 0.329 to 0.475, 0.364 to 0.476 and 0.408 to 0.559 respectively. The coefficient and angle of internal friction increased from 0.638 to 0.668 and 32.52 to 33.74°, respectively. These findings are valuable data for efficient design of machines for processing, handling and storage of hulled seeds of egusi melon.

Keywords— Moisture content, shelled egusi melon seeds, friction, flow characteristics.

1 INTRODUCTION

Melon (Citrullus lanatus Thunb.), popularly called ‘egusi’ in many parts of West Africa, is a tendril herbaceous plant, belonging to the family Cucurbitaceae. The seeds of Citrullus lanatus are generally small. When dry (< 14.65 % dry basis) they measure about 12 - 13.63 mm long, 8.0 - 8.03 mm wide and 2.02 - 2.30 mm thick (Oloko and Agbetoye, 2006; Bande et al., 2012). The seeds of C. lanatus are flat comprising a thin golden yellow shell (Fig. 1a) and a white cotyledon (Fig. 1b). The cotyledon contains about 30% protein and over 50% oil (Oloko, 1997). Out of the oil content, 50% is made of unsaturated fatty acids (35% linoleic and 15% oleic) while the remaining 50% oil content is made of saturated fatty acids, which are stearic and palmitic acids. The presence of unsaturated fatty acid makes melon nutritionally desirable. It is also a good source of vitamin B₁, vitamin B₃ and many minerals including zinc, iron potassium, phosphorus, sulphur, manganese, calcium, lead and magnesium (Eugene and Gloria, 2002; Bande et al., 2012). The oil of Citrullus lanatus seed can be used in the manufacture of margarine, shortening, cosmetics and cooking oils, while the residual cake is a useful source of protein for livestock feed.

The seed of C. lanatus may be fermented to yield a highly proteinaceous condiment called ‘ogiri’. Soups and gravies prepared using ‘ogiri’ are generally relished much the same way as those that contain condiments made from the locust bean seed (i.e. iru or dawadawa). According to Giwa, Abdullah and Adam (2010) egusi melon seed oil is a potential feedstock for biodiesel production.

However, freshly harvested fruits of egusi melons do not store well. Soon after harvest, the seeds begin to germinate and thereby become unfit for human consumption. Besides, and quite unlike watermelon (Citrullus colocynthis Schrad.) the fruits of C. lanatus are not edible in their fresh state because of their bitter, hard, white flesh. Accordingly, they must be processed into more utilisable products such as margarine and the other products earlier mentioned. The postharvest processing and handling of egusi melon involve certain unit operations such as depodding, washing, drying, hulling (also called shelling), seed milling, and oil expression. Most of these operations when performed manually are often boring, strenuous, time-consuming, and tedious. In order to reduce or eliminate the tedium and drudgery associated with manual processing, it is imperative to mechanize the operations, especially as they apply to the processing of the cotyledon (or kernel) of melon seeds.

In the design of machines for handling and processing of food and agricultural products, certain engineering properties of the material constitute important and essential engineering data (Karimi et al., 2009). Obi and Offorha (2015) stated that various physical and mechanical properties of seeds depend on moisture content and are important in the design of handling, transportation, storing, drying and processing equipment. Therefore, knowledge of engineering properties of melon seeds, is fundamental because it facilitates the efficient design of
equipment for handling, cleaning, separation, packing, storing, drying and mechanical oil extraction.

A lot of data on engineering properties have been reported for various agricultural products such as acha (Satimehin and Philip, 2012), white sesame seed (Darvishi, 2012), cashew nut and kernel (Bart-Plange et al., 2012), soybean (Tavakoli, Rajabipour and Mohtasebi, 2009), pistachio nut and kernel (Razari et al., 2007), locust bean seed (Ogunjinmi, Aviara and Aregbesola, 2002) and Dika-nut seeds (Unuigbe, Adebayo and Onuoha, 2013). Bande et al. (2012) reported certain findings on some physical properties of unshelled egusi melon seeds. The results presented are valuable in the design of equipment for processing unshelled melon seeds such as a huller. However accurate knowledge of the physical, frictional and flow properties of hulled melon seeds is crucial to efficient design of processing equipment for its transportation, storage and handling (Ghasemi et al., 2008). Obi and Offorha (2015) investigated the effect of moisture on the geometric, gravimetric, and frictional properties of unshelled melon seed and kernel (i.e. the cotyledon) in the moisture content range of 2.8–25% (d.b.) and 1.1–23% (d.b.) respectively. They found that the bulk and true densities of the unshelled seed also increased from 408.04 to 500.00 kg/m³ and 820.00 to 1189.00 kg/m³, respectively, while the bulk and true densities of the kernel ranged from 474.80 to 539.00 kg/m³ and 1039.40 to 1229.50 kg/m³, respectively. The static coefficient of friction of the melon kernel was highest for plywood compared with rubber and galvanized sheet.

In spite of the economic and dietary importance of the melon seed, little is known about its physical and frictional characteristics especially when hulled. According to Obi and Offorha (2015), despite extensive literature search, information on the physical and mechanical properties of melon seed and kernel and their dependence on moisture content are scarce. Therefore, this study was conducted to determine some physical, frictional and flow properties relevant to the processing of shelled melon seeds, and the effect of different levels moisture content on the proper ties.

2 MATERIALS AND METHODS

2.1 Sample Preparation

Shelled melon (Citrullus lanatus Thunb.) seeds were bought at North Bank Market in Makurdi, Benue State of Nigeria. The seeds were cleaned remove dirt, broken seeds and foreign materials. The initial moisture content of the seeds was determined according to ASAE (2006) by oven drying at 103 ± 1 °C for 72 hours. The bulk of seeds was divided into four parts. Each part was conditioned to the desired moisture content by adding a predetermined quantity of distilled water calculated using equation (1) (Bart-Plange et al., 2012; Satimehin and Philip, 2012). Distilled water was used in this study because it is pure as most of its impurities had been removed, and would therefore not be a source of experimental error.

\[ Q = G \left( \frac{M_f - M_i}{100 - M_i} \right) \]

where \( Q \) is the mass of water added (kg), \( G \) is the initial mass of the sample (kg), \( M_i \) is the initial moisture content of the sample (% dry basis), and \( M_i \) is the desired moisture content of the sample (% dry basis).

The samples were tightly sealed in separate high-density polythene bags and kept in a refrigerator at 4°C for at least five days to allow for uniform moisture distribution throughout the sample. Prior to the commencement of a test, the required quantity of the sample was withdrawn from the refrigerator and allowed to equilibrate at the room temperature for about two hours. All the engineering properties of the melon seeds were determined at moisture content levels of 11.04, 15.7, 21.03 and 24.78 % dry basis and replicated five times.

2.2 Study Parameters

2.2.1 True Density (\( \rho_t \))

The true density is the ratio of the mass (\( m_0 \)) of a sample of the seed to the solid volume (\( V_s \)) of the seed. The volume of the seed was determined by liquid displacement method. The liquid used was toluene in preference to water because according to Darvishi (2012), toluene is absorbed by the seeds to a lesser extent. In addition, its surface tension is low so that it fills even shallow dips in a seed and its dissolution power is low. Therefore, samples of the melon seeds were weighed on an electronic balance and immediately immersed in toluene held in a graduated measuring cylinder. The volume of toluene displaced gave the volume of the sample immersed. The density of melon seeds at each moisture content was calculated by dividing its mass by the volume of the toluene displaced. The true density was calculated using equation (2).

\[ \rho_t = \frac{m_0}{V_s} \]  

(2)

2.2.2 Bulk Density (\( \rho_b \))

Bulk density of the melon seeds was determined by weighing the sample in a hollow cylindrical container of known volume. The container was filled to the brim by pouring the seeds into it from a height of 150 mm at a constant rate and weighed on an electronic balance (Darvishi, 2012). The bulk density at each moisture content was then calculated using equation (3).

\[ \rho_b = \frac{w_s}{V_b} \]

Where \( \rho_b \) = bulk density, \( w_s \) = mass of seeds, and \( V_b \) = volume of bulk of seeds.

2.2.3 Bulk Porosity (\( \varepsilon \) %)

The porosity of the bulk seed was computed from the values of \( \rho_b \) and \( \rho_t \) using equation (4).

\[ \varepsilon = \left( 1 - \frac{\rho_b}{\rho_t} \right) \times 100 \]

(4)

2.2.4 Angle of Repose (\( \theta \))

A basic property of non-cohesive granular materials is the angle of repose. It is the maximum slope angle with the horizontal at which the material would stand when piled. Above this slope angle, the material starts to flow; below this angle, the material is stable (Kleinhans et al. 2011). In this study, the angle of repose was determined using a hollow cylinder of 150 mm diameter and 250 mm height, opened at both ends. The cylinder was filled with melon seeds and placed at the centre of a circular table having a diameter of 350 mm. The cylinder was raised slowly until the seeds formed a cone on the circular table. The height
(H) and base diameter (D) of the cone were measured and used in calculating the angle of repose using equation (5).

\[ \theta = \tan^{-1} \frac{2H}{D} \]  

(5)

2.2.5 Coefficient of Static Friction (\(\mu_s\))

The coefficient of static friction for melon seed was determined with respect to three contact surfaces namely plywood, galvanized steel, and glass. The determination was carried out by means of a hollow cylinder measuring 75 mm in diameter and 50 mm deep. The cylinder, opened at both ends, was filled with a sample of shelled melon seed and placed on an adjustable tilting table (Fig. 2). The tilting table was overlaid with the test contact surfaces. The contact surface was restrained at one end by means of hinges, while the other end was allowed to move up or down by means of a screw device. The inclination of the contact surface was increased gradually until the cylinder and its content began to slide downward. The angle of tilt (\(\alpha\)) of the contact surface was then measured by means of a graduated scale. The coefficient of static friction (\(\mu_s\)) of the melon seeds against the contact surfaces was calculated using equation (6).

\[ \mu_s = \tan(\alpha) \]  

(6)

At each moisture content level and for each contact surface, the test was replicated five times. For each replication, the cylinder was filled with fresh sample. The tilting table test techniques was similarly employed by Bart-Plange et al. (2007) and Nwakonobi and Ohwualu (2009) for determining friction coefficients of granular food substances on different structural surfaces.

Fig 2: A tilting table for measuring coefficient of static friction

2.2.6 Angle of Internal Friction (\(\psi\))

The angle of internal friction, \(\psi\), for shelled melon seeds at different moisture levels were determined by means of a shear test apparatus (Fig. 3). The apparatus comprises two hollow boxes namely a shear cell and a retaining box. The shear cell measures 150 mm x 150 mm x 50 mm while the retaining box measures 300 mm x 200 mm x 50 mm. Both boxes were filled with samples of the shelled melon seeds. The retaining box was fastened onto a flat wooden surface and the shear cell was in turn placed on the retaining box. A flange carrying a pulley at its end was also fastened to the flat surface. A hook was attached to one side of the shear cell and a light string was attached to it. The string passes over the pulley, and a weight was hung from the other end of the string. The shear test apparatus was used for measuring the shear stress (\(\tau\)) for different values of normal stress (\(\sigma\)) at normal loads of 200, 300, 400, and 500g. The plot of \(\tau\) versus \(\sigma\) gives a straight line with slope \(\mu_s\) such that \(\tau\) and \(\sigma\) are related by equation (7).

\[ \tau = \tau_0 + \sigma \cdot \mu_s \]  

(7)

where \(\mu_s = \tan \psi\).

The normal stress, \(\sigma\) (g/cm\(^2\)) was calculated using equation (8) (Irtwange and Igbeke 2002)

\[ \sigma = \frac{W_i + W_s}{A} + \rho h \]  

(8)

where \(W_i\) = weight of the shear cell (g)
\(W_s\) = weight of the normal load on the shear cell (g)
\(A\) = cross-sectional area of the shear cell (cm\(^2\))
\(h\) = height of the sample melon seeds in the shear cell (cm)
\(\rho\) = density of the seeds (g/cm\(^3\)).

The shear stress (\(\tau\)) was similarly calculated using equation (9).

\[ \tau = \frac{W_s(1-\eta/2)}{A} \]  

(9)

where \(\eta\) = coefficient of friction of pulley (Sethi, Grover and Thakur, 1992) and \(W_s\) = (weight required to slide the shear cell when loaded) – (weight required to slide the shear cell when empty).

Fig 3: Shear test apparatus for measuring coefficient of internal friction

3 RESULTS AND DISCUSSION

3.1 True and Bulk Density Density

The values of the true density and bulk density of shelled melon seeds are shown in Figure 4. The true density of shelled melon seeds were consistently above that of water, ranging from 1247 kg/m\(^3\) to 1264 kg/m\(^3\) in the moisture content ranged studied. This implies that the seeds can be expected to sink in water, an important property in hydrodynamic separation of the seeds from less dense dirt and impurities. Accurate value of true density is useful for designing separation equipment such a a pneumatic separator. The true density was observed to decrease linearly from 1264 kg/m\(^3\) at 11.04% moisture content to 1247 kg/m\(^3\) at 24.78% moisture (Fig. 4). The reason for this decrease is that swelling occurs as the moisture content of shelled melon seed increases. The decrease in true density with increase in moisture content could also be attributed to the relatively elevated true volume that occurs in comparison with the corresponding mass which the seed attained due to adsorption of water. This phenomenon is an antithesis to Bart-Plange et al. (2012) who reported a positive linear relationship between the true density and moisture content for cashew nut and kernel. The authors explained that an increase in the true densities of cashew nut and kernel indicate that there is a higher grain mass increase in comparison to its volume increase as its
moisture content increases. The moisture (M) dependence of the true density ($\rho_t$) of shelled melon seeds follows a linear model expressed mathematically by equation (10).

$$\rho_t = 1285.0 - 1.763M \quad (R^2 = 0.938) \quad (10)$$

This negative linear correlation is similar to those reported for bambara groundnuts by Baryeh (2001) and unshelled melon seeds by Bande et al. (2012) whose values of true density were consistently lower than those of the shelled melon seeds. The lower values for unshelled melon seeds could be attributed to the presence of a seed coat which offers resistance to moisture adsorption by the cotyledon it encases. Hence the volumetric expansion of a constant mass of exposed cotyledon of melon seeds (i.e. shelled melon seeds) is much higher than that of unshelled melon seeds.

The bulk density of shelled melon seed increased with moisture content from 668 kg/m$^3$ at 11.04% d.b. to 681 kg/m$^3$ at 24.78% d.b. This decrease could be attributed to the fact that as a fixed volume of the seeds absorb moisture, its mass increases with an increase in moisture content. The relationship between the bulk density and the moisture content is mathematically by equation (11).

$$\rho_b = 0.939M + 658.5 \quad (R^2 = 0.961) \quad (11)$$

This linear trend has also been observed for unshelled melon seeds by Bande et al. (2012). Knowledge of the bulk density of a granular solid is important in determining the capacity of its storage and transport systems (Obi and Offorha, 2015).

The decrease in porosity is due to the volumetric expansion which occurs in the seed as it absorbs more moisture. This leads to reduction in inter-granular void spaces, giving more compact arrangement of the seeds and hence a reduction in its bulk porosity. The lower values of porosity at higher moisture content levels implies that a packed bed of the seeds would encounter decreasing resistance to airflow during a drying or aeration process as the seeds become drier. Hence moist seeds would require decreasing fan and motor power to force a stream of air through the bulk as drying progresses.

$$\epsilon(\%) = -0.159M + 48.96 \quad (R^2 = 0.980) \quad (12)$$

3.3 Angle of Repose ($\theta$)

Fig. 6 shows the angle of repose of shelled melon seeds linearly increases with moisture content from 31.0 to 34.9° as moisture content increases from 11.04 to 24.78 % d.b. The linearity is expressed as equation (13).

$$\theta = 0.286M + 27.81 \quad (R^2 = 0.999) \quad (13)$$

Similar trends were reported for some other oil bearing seeds such as soybean grains (Tavakoli, Rajabipour and Mohtasebi, 2009) and jatropha seeds (Garnayak et al., 2008). This also agrees with observation of Obi and Offorha (2015) who reported that filling angle of repose of melon kernel increased from 30.52 to 38.04° in the moisture content range of 1.1 to 23% dry basis. The reason for the increase in the angle of repose with moisture content is that moisture in granular materials is able to bridge the gaps between particles. As a result, electrostatic attraction of the water to solid surfaces will increase the angle of repose. Other explanations have also been proposed by Irtwange and Igbeke (2002), Gharib-Zahedi et al. (2010), Bande et al. (2012) and Tavakoli, Rajabipour and Mohtasebi (2009).

The angle of repose is essential in modelling numerous phenomena involving granular materials. In particular, it is important in the design of equipment for the processing of particulate solids. For example, it is key in determining hopper openings and side wall slopes of storage bins. It is useful in calculating the width of a conveyor belt for transporting the material, and for bulk transporting of seeds using chutes (Irtwange and Igbeke, 2002; Gharib-Zahedi et al., 2010). The angle of repose is also crucial in correctly calculating stability in vessels. Therefore, moisture content of seeds should be taken into account while designing such equipment and structures.

3.4 Angle of Internal Friction ($\phi$)

Fig. 6 shows that the angle of internal friction has a positively linear relationship with moisture content which can be expressed mathematically as equation (14).

$$\phi = 0.083M + 31.6 \quad (R^2 = 0.976) \quad (14)$$
The friction angle increased from 32.52 to 33.74° as moisture content increased from 11.04 to 24.78% d.b. The increase may be attributed to the increase in cohesion between seeds as its moisture content increases. Secondly, the surface layers of moisture surrounding the particles tend to hold the seeds together by surface tension thereby reducing the mobility from 1.568 to 1.496 as the seed moisture increases from 11.04 to 24.78% d.b.

Knowledge of angle of internal friction, $\phi$, is crucial to the accurate determination of the flow rates and patterns of particulate solids through orifices during emptying of storage bins. The angle is an important parameter in the determination of lateral pressures on the walls of shallow and deep silos using Rankine and Janssen equations, respectively (Bart-Plange et al., 2007).

**3.5 Coefficient of Static Friction, $\mu$**

The values of the coefficient on the surfaces of plywood, galvanized iron sheet and glass increased from 0.408 to 0.559, 0.364 to 0.476 and 0.329 to 0.475 respectively, as its moisture content increased from 11.04% to 24.78%. The increase in the coefficient of friction with moisture content generally follows a linear trend (Fig. 7). The increase at higher moisture content may be attributed to an increase in intermolecular force of adhesion between the melon seeds and the contact surfaces as the moisture content of the seeds increases. Plywood generally presented the most resistance to flow of shelled melon seeds as epitomized by the higher coefficients of static friction of the seeds on its surface at all moisture levels studied. This is due to the higher static frictional forces occasioned by the interlocking of the irregularities of surfaces of the plywood and seeds. This is in agreement with Bande et al. (2012) who similarly observed that the friction coefficient of unshelled melon seed was highest with plywood compared with metal, aluminum and plastic surfaces. Obi and Offorha (2015) reported similar observation on melon seed and kernel.

Conversely, glass offered the least resistance to flow of melon seeds due to its smoother surface compared to the surfaces of plywood and galvanised steel. These results are consistent with the observation of Fathollahzadeh et al. (2008) for the friction of apricot kernel on wood, galvanised sheet, glass and fibreglass sheet. This data on the coefficient of friction of shelled melon seeds is important for designing storage bins, hoppers, pneumatic and screw conveyors etc.

The relationships between the coefficient of static friction ($\mu$) of shelled melon and moisture content (M) for the contact surfaces of plywood ($\mu_{\text{ply}}$), galvanized steel ($\mu_{\text{gal}}$) and glass ($\mu_{\text{glas}}$) are, respectively, as follows. 

\[
\mu_{\text{ply}} = 0.009M + 0.297 \quad (R^2 = 0.894) \\
\mu_{\text{gal}} = 0.007M + 0.281 \quad (R^2 = 0.982) \\
\mu_{\text{glas}} = 0.009M + 0.235 \quad (R^2 = 0.913)
\]

4 CONCLUSION

From the results of the investigations in this report, the following conclusions may be drawn.

1) All the physical and frictional properties of shelled (i.e. hulled) seeds of egusi melon are linearly dependent on moisture content within the range of 11.04 to 24.78% dry basis.

2) The true density of shelled melon seeds are consistently above that of water. This implies that the seeds would sink in water, making hydrodynamic separation of the seeds from less dense dirt and impurities possible. The true density ranged from 1247 kg/m$^3$ to 1264 kg/m$^3$ in the moisture content range studied. On the other hand, the bulk density of the seeds increased from 668 to 681 kg/m$^3$.

3) The porosity of shelled melon seeds decreased as its moisture content increases. The value increased from 47.19 to 45.36 % as the moisture content increased from 11.04% to 24.78% dry basis. The porosity is important in drying processes and in the design of pneumatic conveying systems for the seeds.

4) The angle of repose increased with increasing moisture content: increasing from 31.0 to 34.9° as the moisture content increased from 11.04% to 24.78% dry basis. This also is important in designing belt conveyors for the seeds.

5) Amongst the three structural surfaces studied, plywood presents the most resistance to flow of shelled melon seeds, and the resistance increases as the seed moisture content increases. Knowledge of the resistance of various structural surfaces to flow of the melon seeds is important when selecting a material for hopper design and silo strength calculations.

6) The coefficient of internal friction between shelled melon seeds increases as the seed moisture content increases. This would lead to a reduction in the flowability of the seeds over each other. Therefore,
greater mobility would be obtained from a drier bulk of seeds than would be obtained from moist seeds. This important property readily finds application in the design of storage bins and handling systems.

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