Effect of Moisture Content on Terminal Velocity, Compressive Force and Frictional Properties of Melon Seeds

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ABSTRACT

The investigation of the moisture dependence of engineering properties of melon seeds is essential for the design of its processing equipment. Selected engineering properties of two varieties of melon (*Citrulus lanatus*- Variety A and *Solanum sp.*- Variety B) were determined at a moisture content range of 4.06 to 16.81% (dry basis). An increase in the moisture content resulted in a directly proportional increase in all the properties for the two varieties except for the compressive force which decreased as the moisture content increased.

The minimum and maximum value of emptying angle of repose was 21.37^0 for variety B at 4.06% (d.b.) and 24.26^0 for variety A at 16.81% (d.b.). The minimum value for coefficient of friction was 0.19 for Variety B against glass at moisture content of 16.81% (d.b.) and a maximum corresponding value of 0.36 for Variety A against plywood at 4.06% (d.b.), respectively. Variety A seeds had minimum value of terminal velocity of 4.53 m/s at 4.06% (d.b.), and maximum corresponding value was 5.1 m/s at 16.81% (d.b.) for Variety B. The minimum and maximum value of the compressive force was 5.91N at 4.06% (d.b.), and corresponding value was 2.01N at 16.81% (d.b.) and both were obtained from Variety A.

Analysis of variance (ANOVA) showed that the coefficient of friction and compressive force for both varieties of melon seeds were affected significantly by moisture content and/or variety ($P<0.05$). Relationship between the properties and moisture content were expressed by linear equations.

Keywords: Melon seeds, angle of repose, coefficient of friction, terminal velocity, compressive force, Nigeria

1. INTRODUCTION

Melon (*Citrullus Vulgaris*) is one of the valuable plant sources of oil and protein in some parts of the Northern, Eastern and Western States of Nigeria. Melon oil can be used as a source of oil for home consumption and export purposes. The oil residue is used for compounding livestock feed and for fortification of food for adults and babies. Melon also has high protein content, especially after the oil has been extracted and thus can be one of the crops used to solve the nation's protein deficiency. The traditional method of extracting oil from melon is to condition the seeds by drying, roasting and then grinding, after which the oil is then squeezed out from the paste. However the energy involved in this process makes it unsuitable to use for large/commercial scale processing. The processing of melon seed on a commercial scale has great potentials in the country and thus the benefit of melon seed processing for cooking oil needs to be fully exploited. However before extensive production of melon oil can be achieved, the engineering properties of the common commercial varieties of the seed need to be determined. Some researchers have worked on some physical properties of melon seeds which they have reported to be moisture dependent, but limited work has been done on other engineering properties. The knowledge of the moisture dependence of the engineering properties will be useful during equipment design in order to construct equipment that can be used to process the seed whether it is dried or freshly harvested or at any moisture content in between these extremes.

Reports obtained from researches carried out on biological materials indicate that there are various reasons (which include variety and moisture content) for variation in the values of their properties and therefore, specific conditions should be considered while determining these values for the agricultural products. Different studies on physical properties of biological materials have been carried out using different methods. A Wykeham Farrace shear box apparatus was used by Zhang et al. (1994) to determine grain friction of wheat. An inclined surface was used by Chandrasekar and Viswanathan (1999); Olajide and Ade-Omowaye (1999); Masoumi et al (2003) and Atiku et al. (2004) to measure the coefficient of friction of different materials while Konak et al. (2002) used a rotary disk to measure the static and dynamic coefficient of frictions of chickpea seeds. Carman (1996) and Konak et al. (2002) used the free fall method to determine the terminal velocity of seeds while Joshi et al. (1993); Singh and Goswami (1996); Masoumi et al (2003) and Khoshtaghaza and Mehdizadeh (2006) determined the terminal velocity values of pumpkin, cumin seed, garlic and wheat kernel, respectively, by using a wind column. Schaper and Yaeger (1992) used an instron machine to measure the frictional force between potatoes and surfaces.

Reports from various authors have also shown that most of the physical properties of biological materials are moisture dependent. An increase in moisture content was observed to result in an increase in the terminal velocity of karingda seeds, pumpkin seed, kernel and hull (Suthar and Das, 1996; Joshi et al., 1993). An increase in moisture content from 7 to 20% (w.b.) of wheat kernel also increased its terminal velocity linearly from 6.81 to 8.63 m/s, respectively (Khoshtaghaza and Mehdizadeh, 2006). The coefficient of friction of gram, sunflower seeds and *Balanites Aegyptiaca* nuts, also increased as the seed moisture content increased (Dutta et al., 1988; Gupta and Prakash, 1992; Aviara et al., 2005).

This study was carried out to determine some of the engineering properties of melon seed and develop equations to model the relationship between moisture content and dependent properties of the seeds.

2. MATERIALS AND METHODS

Melon seeds of two varieties (*Citrulus lanatus*- Variety A and *Solanum sp.* - Variety B) were obtained from the Bodija market in Ibadan. The grains were cleaned with all foreign materials such as dirt, stones, and broken seeds removed. The seeds initial moisture content was determined by oven drying at 105 ± 1^0C for 24 hours. The samples were cooled in desiccators, weighed and the moisture content calculated.

The desired moisture levels were obtained by adding calculated amounts of distilled water to the grain samples and sealed in polyethylene bags. The samples were placed in a refrigerator for one week to enable uniform moisture distribution throughout sample. The required grain quantity is taken out of the refrigerator and allowed to equilibrate to room temperature before each test is carried out (Visvanathan et al. 1996). After equilibration the moisture content of the seeds were determined using a MB 53 Halogen Ohaus moisture analyser

The coefficient of friction was determined against selected surfaces (plywood, galvanised iron and glass) using the inclined plane apparatus (Dutta et al., 1988). An open cylinder filled with seeds was placed on an adjustable tilting surface and the surface was raised gradually until the cylinder began to slide down. The angle of inclination was read from a graduated scale. The method of Maduako & Faborode (1990) was used to determine the dynamic angle of repose. A plywood box of dimensions 450 x 450 x 450 mm^3 with a removable front panel was filled with grains and the front panel was quickly removed allowing the seeds to flow and assume its natural slope. The emptying or dynamic angle of repose was calculated from the measurements of the vertical depth and radius of spread of the samples. Measurements of these properties are means of 10 replications.

The terminal velocities were measured using a wind tunnel similar to the one reported by Omobuwajo et al (2000). For each test, a small sample was dropped into the airstream from the top of the air column, air was blown through the air column and its velocity was varied until the seeds were suspended in the airstream. The air velocity near the location of the grain suspension was measured to give the terminal velocity. The compressive strength of soybean was measured using the Avery Tensiometer machine and the line of action of the force was along the flat axis of the seed.

2.1 Data Processing and Analysis

All tests were conducted on two varieties of melon seeds (*Citrulus lanatus*- Variety A and *Solanum sp.* - Variety B) at three levels of moisture content and repeated three times. The analysis of variance (ANOVA) and comparison of means were performed using EXCEL program (SAS, 2001). Relationship between the properties of melon seed varieties and levels of moisture content was determined. Model coefficients were determined by using the EXCEL routines. The coefficient of multiple determination (R^2) and the mean square error

(MSE) of models and the variation of predicted values with respect to measured values as well as the distribution of the residuals with respect to the estimated coefficients were used to evaluate the models for fitness to the experimental data.

3. RESULTS AND DISCUSSION

The angle of repose (θ) of melon seeds increased with increase in moisture content. This is similar to the observations of other authors (White and Jayas, 2001; Masoumi et al., 2003; Aviara et al., 2005). It varied from 22.51 to 23.30° for variety A and 21.37 to 24.26^0 for variety B (Table 1), this is lower than the range of 34° reported for shea kernels, 22.36° to 33.66° for oblong Balanites Aegyptiaca nuts, and 22.84° to 32.97° for spheroidal Balanites Aegyptiaca nuts, 24.80 to 27.78° for lentil seeds, 27.3 to 37.5° for cocoa beans, 28.07 to 43.58° for guna seeds and 30 to 52° for pumpkin seed and 34 to 42° for pumpkin kernel (Olajide et al, 2000; Aviara et al., 2005; Amin et al., 2004; Bart- Plange and Baryeh, 2003; Aviara et al., 1999; Joshi et al., 1993) but higher than 17° reported for oilbean seed (Oje and Ugbor, 1991) while it is in the same range of 23 to 25° as that for pearl millet (Jain and Bal, 1997).

Table 1: Some selected properties of melon seeds

Variety	A			B		
Moisture content,% d.b.	4.06	8.29	16.81	4.06	8.29	16.81
Angle of Repose, deg	22.51	23.05	24.26	21.37	22.3	23.2
	(1.25)	(1.27)	(1.21)	(1.26)	(1.35)	(1.31)
Terminal Velocity, ms^{-1}	4.53	4.74	4.97	4.62	4.85	5.1
	(0.86)	(0.83)	(0.90)	(0.72)	(0.79)	(0.81)
Compressive Force, N	5.91	3.35	2.01	2.9	2.44	1.56
	(0.52)	(0.57)	(0.41)	(0.31)	(0.38)	(0.32)

- value in brackets are standard deviations

The angle of repose increased as the moisture content increased as in the case of the previous authors. This is because as the moisture content increases, the size of the seed increases, thus reducing the ability of the seeds to flow over each other. An increase in height of the heap the seeds will make occurs which invariably increases the seeds angle of repose. The relationship between the angle of repose and moisture content for the melon varieties are shown in Table 2.

Comparison of means revealed no significant difference ($P<0.05$) between the mean values of angles of repose at different moisture contents for the melon varieties (Table 3). The emptying angles of repose had no significant difference for both varieties at $P<0.05$ (Table 4).

Table 2: Relationship between selected properties of melon seeds and moisture content

Physical property	Variety A	Variety B

	Equation	R^2	Equation	R^2
Angle of repose, θ	21.93 + 0.14M	1.0	20.95 + 0.14M	0.96
Coef. of friction (plywood), μ	39.51 – 0.86M	1.0	33.51 – 0.61M	1.0
Coef. of friction (glass), μ	14.27 + 0.23M	1.0	16.21 + 0.12M	0.99
Terminal velocity, V_t	4.42 + 0.03M	0.97	4.5 + 0.04M	0.97
Compressive Force, F_c	6.52 – 0.28M	0.87	3.32 – 0.1M	1.0

Table 3. The multiple Duncan's comparison of means for physical properties at various moisture contents.

Moisture content (% d.b.)	Coefficient of friction (%)	Angle of repose (deg)	Terminal velocity (ms^{-1})	Compressive force (N)
4.06	0.270[a]	21.94 [a]	4.55[a]	4.41[a]
8.29	0.251[b]	22.68 [a]	4.60[a]	2.90[b]
16.81	0.212[c]	23.73 [a]	5.04[a]	1.79[c]

Means followed by the same letter are not significantly different at P<0.05

Table 4. The multiple Duncan's comparison of means for physical properties of melon seed varieties.

Moisture content (% d.b.)	Coefficient of friction (%)	Angle of repose (deg)	Terminal velocity (ms^{-1})	Compressive force (N)
Variety A	0.254[a]	23.27[a]	4.75[a]	3.76[a]
Variety B	0.239[a]	22.29[a]	4.86[a]	2.3[b]

Means followed by the same letter are not significantly different at P<0.05

The coefficient of friction (μ) decreased from 0.361 to 0.251 on plywood for variety A and 0.310 to 0.232 for variety B (Fig 1). This is generally higher than the values for glass, which is 0.214 to 0.196 and 0.200 to 0.191 for varieties A and B respectively. The coefficients of friction for the varieties of melon against various surfaces increased with moisture content. The same result was reported by Joshi et al. (1993), Suthar and Das (1996), Aviara et al. (1999, 2005), Konak et al. (2002) and Amin et al., (2004) for pumpkin seeds and kernels, karingda seed and kernel, guna seeds, oblong and spheroidal *Balanites Aegyptiaca* nuts, chick pea seeds and lentil seeds respectively. The highest values of coefficient of friction for plywood over glass are in agreement with the trends observed by previous authors (Visvanathan et al. 1996; Suthar and Das, 1996; Amin et al., 2004). The roughness of the plywood surface gave a higher resistance against the flow of grain than that of glass, which was smoother, and thus the coefficient of friction is higher. The models for the relationship between coefficient of friction and moisture content of the two varieties are shown in Table 2. Comparison of means indicated a significant difference (P<0.05) between the mean values of coefficient of friction at different moisture contents and various surfaces (Table 3). The effect of melon seed varieties on coefficient of friction were not significant (p<0.05) as shown in Table 4.

The values for the terminal velocities of the melon varieties are shown in Table 1. The air velocities needed to suspend variety A varied from 4.53 to 4.97 ms^{-1} and 4.62 to 5.10 ms^{-1} for B as the moisture content increased from 4.06 to 16.81% (d.b.). These values are higher than 4.7 to 6.5 ms^{-1} for pumpkin seeds but within the lower range of 4.5 to 6.5 ms^{-1} for karingda seeds (Suthar and Das, 1996), 4.7 to 6.5 ms^{-1} for pumpkin seeds (Joshi et al., 1993) and 4.37 to 6.13 ms^{-1} for squash seeds (Paksoy and Aydin, 2004) but lower than that of 5.8 to 7.6 ms^{-1} for sunflower seeds (Gupta and Das,1997), 6.81 to 8.63 m/s for wheat kernels (Khoshtaghaza and Mehdizadeh, 2006) and 9.83 to 16.66 ms^{-1} for garlic cloves (Masoumi et al, 2003). This increase in terminal velocity as moisture content increases follows the same trend of that of other seeds because the weight of the seeds increases with increase in moisture content, which also increases the air velocity needed to suspend the seeds. This is similar to the observations of Khoshtaghaza and Mehdizadeh (2006). The correlation between terminal velocity and moisture content of the melon seeds is shown in Table 2. Comparison of means indicated no significant difference ($P<0.05$) between the mean values of terminal velocity at different moisture contents and melon varieties (Tables 2 and 3). In Table 3 shows the effect of melon seed varieties on terminal velocity are shown not to be significant ($p<0.05$).

The compressive strength / average force of fracture decreased from 5.91 to 2.01 N for variety A, and 2.90 to 1.56 N for variety B (Table 1) as the moisture content decreased from 16.81 to 4.06% (d.b.). This decrease in compressive strength with decrease in moisture content is similar to the observations of Mamman et al. (2005) obtained from axial and longitudinal compressive loading orientation of Balanites Aegyptiaca nuts. The test results for melon seeds revealed that as the moisture content increased from 4.06 – 16.81% d.b., the toughness or hardness of the seed decreased to almost half its initial value, thus there is a 100 fold increase in the force at rupture at a moisture content of 4.06% d.b. as compared with that of 16.81% d.b. The relationship between the compressive force and moisture content of the seed is shown in Table 2. This property is useful to determine the force required during the size reduction operation when melon seeds are processed. Comparison of means revealed a significant difference ($P<0.05$) between the mean values of compressive force at different moisture contents for the melon varieties (Tables 2 and 3). The compressive force also had a significant difference for both varieties ($P<0.05$), (Table 3).

4. CONCLUSIONS

1. The engineering properties of melon seeds investigated were all moisture dependent. The coefficient of friction, emptying angle of repose and terminal velocity of the melon seeds varieties increased while the compressive force decreased linearly with moisture content.

2. The mean values of coefficient of friction and compressive force for the melon seed varieties were significantly different ($P<0.05$).

3. The mean values of angle of repose, as well the mean values of terminal velocity of the melon seeds had no significant difference ($P<0.05$).

4. The maximum and minimum value of emptying angle of repose were 21.37^0 for variety B at 4.06% (d.b.) and 24.26^0 for variety A at 16.81% (d.b.)

5. The maximum value of coefficient of friction was 0.361 for Variety A against plywood at 4.06% (d.b.) and a minimum corresponding value of 0.191 for Variety B against glass at moisture content of 16.81% (d.b.) respectively.

6. The maximum value for terminal velocity of melon seeds was that of 5.1 m/s at 16.81% (d.b.) for Variety B and a minimum value of 4.53 m/s at 4.06% (d.b.) for Variety A.

7. Melon seed had a minimum compressive force value of 2.01N at 16.81% (d.b.) and a corresponding maximum value of 5.91N at 4.06% (d.b.), and both were obtained from Variety A.

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