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ORIGINAL ARTICLE

Effect of Moisture Content on Physical Properties of Fluted Pumpkin Seeds

Augustine O. Igbozulike[1] · **Nnamdi Amamgbo**[1]

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Abstract

Purpose A number of physical properties of fluted pumpkin seeds were evaluated to obtain data for the mechanization of the crop's production and the design of its postharvest equipment.

Methods The properties were investigated at five different moisture content levels, namely 51.50, 53.60, 58.03, 64.02, and 67.30% (wet basis). Standard methods, as reported in the literature for other agricultural products, were used to investigate the relationship between these physical properties and moisture content. Linear regression equations were used to express the relationships between moisture content and the physical properties of the seeds.

Results The seed dimensions increased with an increase in moisture content. The geometric and arithmetic mean diameters increased from 2.43 to 2.65 cm and 2.65 to 2.82 cm, respectively, as moisture content increased. The true and bulk densities decreased from 1.08 to 0.97 g/cm^3 and 0.98 to 0.69 g/cm^3, respectively, with an increase in moisture content. The angle of repose of the seeds reduced from 40.79° to 36.05° as moisture content increased from 51.50 to 67.30%. The coefficient of friction increased with an increase in moisture content from 0.67 to 0.87, 0.59 to 0.75, and 0.58 to 0.63 for wood, steel, and glass surfaces, respectively.

Conclusion The results are of value for the development of equipment for operations, such as planting, harvesting, conveying, cleaning, separation, shelling, de-hulling, milling, packaging, storing, drying, and oil extraction.

Keywords Angle of repose · Bulk density · Coefficient of friction · Seed dimensions · True density

Introduction

Fluted pumpkin (*Telferia occidentalis*) is a vegetable crop that is widely grown and consumed in Nigeria because of its nutritious leaves and seeds. The crop, which was once prevalent in Eastern Nigeria, where it forms part of most households' daily diet, has gained tremendous acceptance in other parts of Nigeria. A pod weighs up to 20 kg and contains approximately 80 seeds on average (Schippers 2000). The leaves, stems, seeds, and roots of the fluted pumpkin are rich sources of food nutrients and can be used as raw material for a variety of products (Akubue et al. 1980; Egbekun et al. 1998; Giami and Isichei 1999; Akwaowo et al. 2000; Giami et al. 2003). The seeds have an oil yield of 48.6% (Esuoso et al. 1998), and the seed oil is a potential raw material for the production of candles, soap, and lubricants because of its low saponification value (Agatemor 2006). The fluted pumpkin is propagated by its dicotyledonous seed. Currently, the crop is grown and processed manually in Nigeria. It has been reported that unavailability of data on the seed properties is hampering the design of systems and machines for the mechanization of its production and postharvest operations (Igbozulike 2015).

Knowledge of the engineering properties of agricultural products is fundamental in the design and development of equipment for operations, such as planting, harvesting, conveying, cleaning, separation, shelling, de-hulling, milling, packaging, storing, drying, and oil extraction. The major physical properties of agricultural products include size, shape, mass, true density, bulk density, volume, angle of repose, and coefficient of friction on various surfaces. Many

✉ Augustine O. Igbozulike
austin.igbozulike@gmail.com

[1] Agricultural & Bioresources Engineering Department, Michael Okpara University of Agriculture, Umudike, P. M. B. 7267, Umuahia, Nigeria

Table 1 Average axial dimensions of fluted pumpkin seeds

Moisture (% w.b)	Length (cm)	Width (cm)	Thickness (cm)	D_g (cm)	D_a (cm)	Sphericity
51.50	3.39	3.24	1.32	2.43	2.65	0.72
53.60	3.42	3.26	1.37	2.46	2.68	0.72
58.03	3.45	3.29	1.44	2.53	2.73	0.73
64.02	3.51	3.30	1.55	2.60	2.79	0.74
67.30	3.54	3.31	1.60	2.65	2.82	0.75

researchers have studied these properties for various agricultural products, such as locust bean seeds (Ogunjimi et al. 2002), wheat (Tabatabaeefar 2003), soybeans (Manuwa and Afuye 2004), onions (Bahnasawy et al. 2004), pistachios (Kashaninejad et al. 2006), rough rice (Varnamkhasti et al. 2008), *Lablab purpureus* (Simonyan et al. 2009), *Garcinia kola* (Igbozulike and Aremu 2009), mahogany (Aviara et al. 2014), kokum (Sonawane et al. 2014), and *Canarium schweinfurthii* (Ehiem et al. 2016).

The objective of this work is to determine the physical properties of the fluted pumpkin seed, such as length, width, thickness, geometric mean diameter, arithmetic mean diameter, sphericity, surface area, bulk and true densities, angle of repose, and coefficient of friction as a function of moisture content.

Materials and Methods

Material Sampling

Twenty large fluted pumpkin pods were bought from Ndoro market in Ikwuano Local Government Area of Abia State. The seeds were manually extracted from the pods, carefully cleaned, and sorted to remove damaged seeds. Samples were kept in sealed jute bags for 24 h under ambient conditions to allow for moisture stabilization throughout the seeds (Aviara et al. 2014). Samples were conditioned to five different moisture content levels, namely 51.50%, 53.60%, 58.03%, 64.02%, and 67.30%, using the method described by Arjun et al. (Arjun et al. 2017) to determine the properties.

Determination of Physical Properties

The length (L), width (W), and thickness (T) of each seed were measured using a vernier caliper (Mitutoyo, Japan) with an accuracy of 0.01 mm. A total of 100 seed samples were randomly picked for axial dimension measurement at each moisture level. The arithmetic and geometric mean diameters were calculated using the following relationships (Galender et al. 2008):

$$D_a = \frac{L + W + T}{3} \quad (1)$$

$$D_g = (\mathrm{LWT})^{\frac{1}{3}} \quad (2)$$

Here, D_a = arithmetic mean diameter (cm), D_g = geometric mean diameter (cm).

The sphericity ($\varnothing$) was calculated using the following relationship (Koocheki et al. 2007):

$$\varnothing = \frac{(\mathrm{LWT})^{\left(\frac{1}{3}\right)}}{L} \quad (3)$$

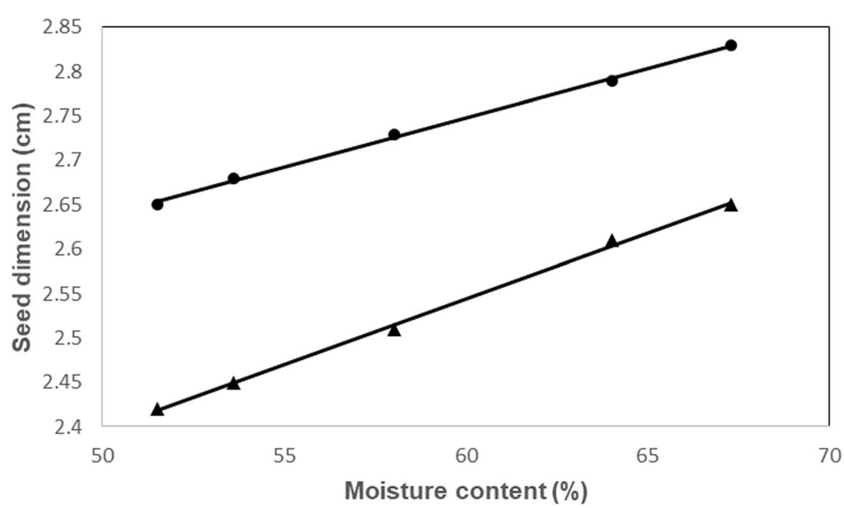

Fig. 1 Effect of moisture content on dimensions of fluted pumpkin seeds

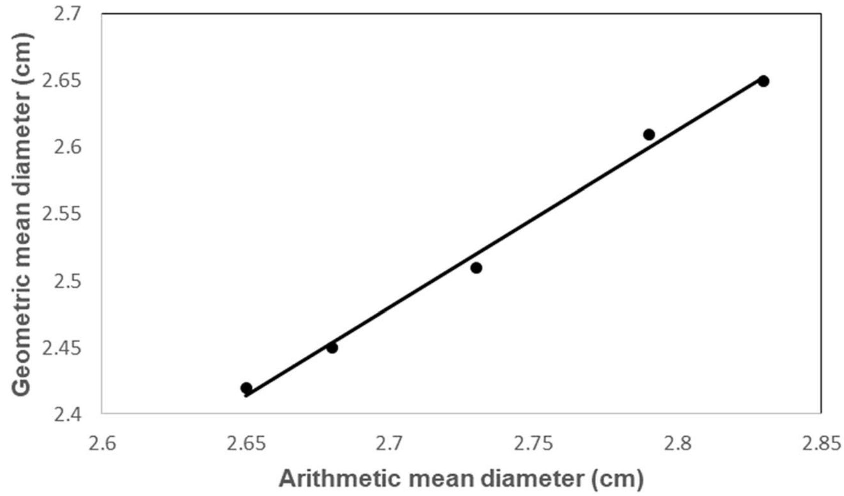

Fig. 2 Relationship between geometric and arithmetic mean diameters

The surface area (S) was calculated using the relationship given by Mccabe et al. (Mccabe et al. 1985):

$$S = \pi D_g^2 \quad (4)$$

Determination of Gravimetric Properties

The true density (ρ_t) was determined using the water displacement method (Igbozulike and Aremu 2009). The weight of the seeds was measured and the number of seeds in the sample carefully counted. The seeds were poured into a graduated cylinder and the volume of water displaced was measured. A total of 10 replications were performed and the true density was computed, thus:

$$\rho_t = \frac{M_t}{V_t} \quad (5)$$

Here, ρ_t = true density (g/cm^3), M_t= true mass (g), V_t = true volume (cm^3).

The bulk density was obtained by pouring the seeds from a constant height into an empty cylinder of known volume and weight, and scraping off the mound that piled above the brim of the cylinder. The cylinder was tapped 10 times for the seeds to consolidate and to achieve uniformity in bulk density. The cylinder was then weighed. Ten replications were performed. Bulk density was calculated from the following relationship (Akaaimo and Raji 2006):

$$\rho_{b=\frac{M_b}{V_b}} \quad (6)$$

Here, $\rho_{b=}$ bulk density (g/cm^3), M_b= bulk mass (g), V_b = bulk volume (cm^3).

The static coefficient of friction of the seeds was determined using the method described by Razavi and Milani (Razavi and Milani 2006). Three material surfaces namely wood, metal, and glass were used for the experiment. The static coefficient of friction (μ) was calculated as follows:

$$\mu = tan\propto \quad (7)$$

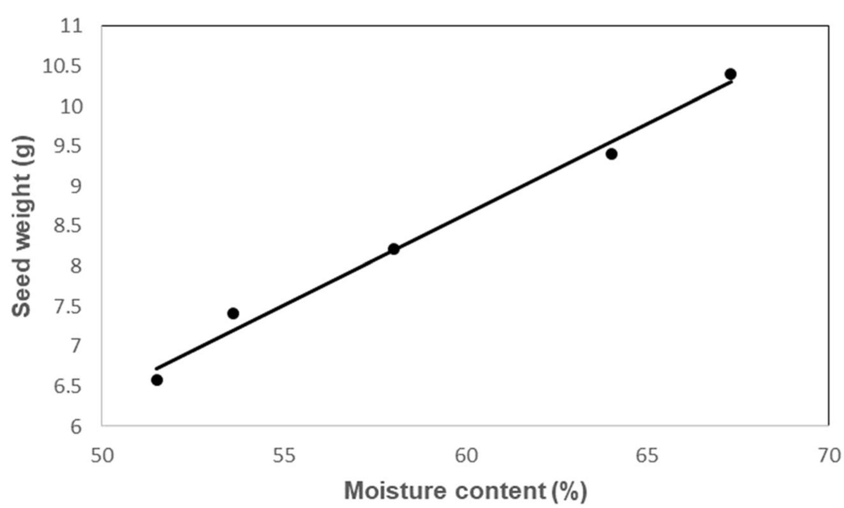

Fig. 3 Effect of moisture on the weight of fluted pumpkin seeds

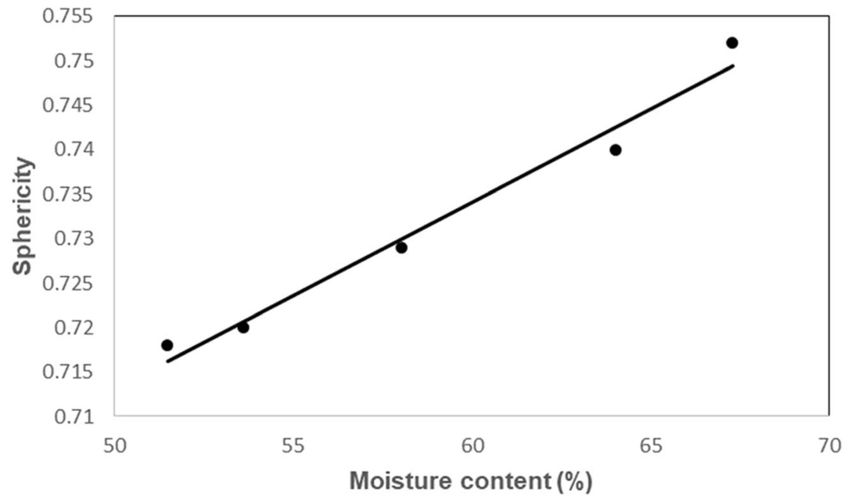

Fig. 4 Effect of moisture content on sphericity of fluted pumpkin seeds

Here, μ = static coefficient of friction and $\propto$ = angle of tilt.

The angle of repose(φ) of the seeds was determined using a topless and bottomless cylinder that was placed on top of a circular base (Razavi and Milani 2006). The cylinder was filled with seeds and then gradually lifted to allow the seeds to flow out into a pile. The base (b) of the pile and its height (h) were recorded. The angle of repose was calculated as follows (Akaaimo and Raji 2006):

$$\varphi = \tan^{-1}\left(\frac{2h}{b}\right) \tag{8}$$

Results and Discussion

Seed Dimensions

The axial dimensions of the seeds at different moisture content levels are presented in Table 1. It can be seen that the three axial dimensions increase with an increase in moisture from 51.50 to 67.30%. This explains why the seed shape remains unchanged with a change in moisture content. An increase in axial dimensions with a moisture increase has been reported for chickpea seeds (Eissa et al. 2010), coriander seeds (Coskuner and Karababa 2007), and millet (Baryeh 2002). The geometric and arithmetic mean diameters increase from 2.43 to 2.65 cm and 2.65 to 2.82 cm, respectively, as moisture content increases. Seed dimension data will assist in the design of standard containers for seed packaging.

It was observed that the arithmetic and geometric mean diameters increased linearly with a moisture increase (Fig. 1). Their relationships can be represented by the following regression equations:

$$D_a = 0.0111M_c + 2.0816 \qquad \left(R^2 = 0.998\right) \tag{9}$$

$$D_g = 0.0148M_c + 1.6554 \qquad \left(R^2 = 0.998\right) \tag{10}$$

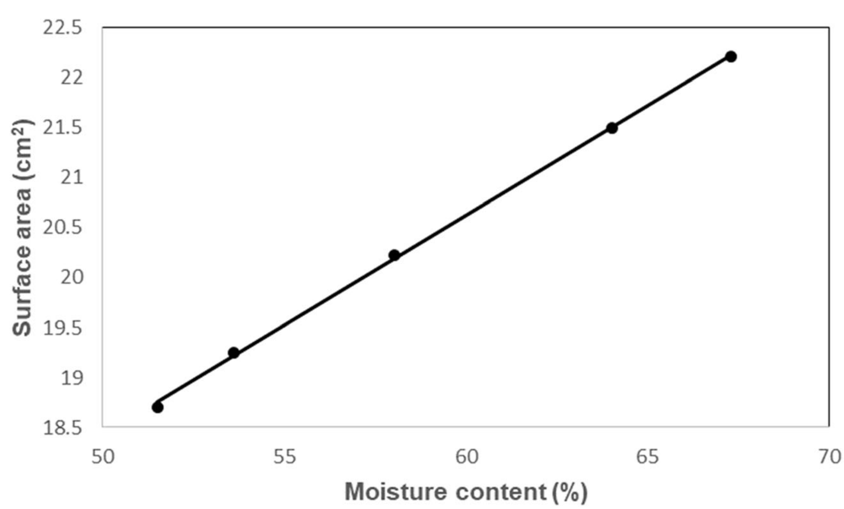

Fig. 5 Effect of moisture content on surface area of fluted pumpkin seeds

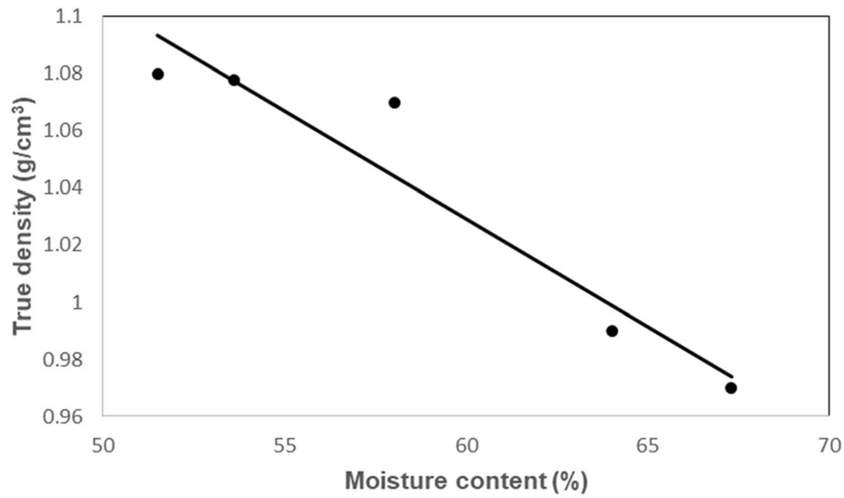

Fig. 6 Effect of moisture content on true density of fluted pumpkin seeds

A linear relationship was found between the geometric and arithmetic mean diameters (Fig. 2). The linear equation for this relationship is given, thus:

$$D_g = 1.3289D_a - 1.1077 \qquad (R^2 = 0.993) \quad (11)$$

The weight of the seeds ranged from 6.7 to 10.5 g and increased as the seeds' moisture content increased. A similar increasing trend of seed weight with moisture content has been reported for chickpea seeds (Eissa et al. 2010). The relationship between seed mass and moisture content is also linear (Fig. 3), and this can be represented with a regression equation, thus:

$$W_s = 0.2262M_c - 4.9203 \qquad (R^2 = 0.989) \quad (12)$$

The sphericity values of the seed increased from 0.72 to 0.75 as the moisture value increased. Similar increases in sphericity values with a moisture content increase has been reported (Sonawane et al. 2014; Arjun et al. 2017; Sacilik et al. 2003; Vilche et al. 2003) for kokum, makhana, quinoa, and hemp seeds, respectively. The sphericity values of fluted pumpkin seeds fall within the 0.32–1.00 sphericity range for most agricultural products (Mohsenin 1986). The sphericity values indicate that the seeds are unlikely to rotate easily during handling. The closer the sphericity is to 1.0, the higher the tendency to roll about any of the three axes. This knowledge is important for designing handling equipment. The effect of moisture content on sphericity is shown in Fig. 4, represented by the following regression equation:

$$\varnothing = 0.0021M_c + 0.6081 \qquad (R^2 = 0.979) \quad (13)$$

The surface area of the seeds ranged between 18.7 and 22.21 cm^2. It showed a significant increase with a moisture content increase. This result is in agreement with reports of Baryeh (Baryeh 2002), Taghi Gharibzahedi et al. (Taghi Gharibzahedi et al. 2011), and Vishwakarma et al.

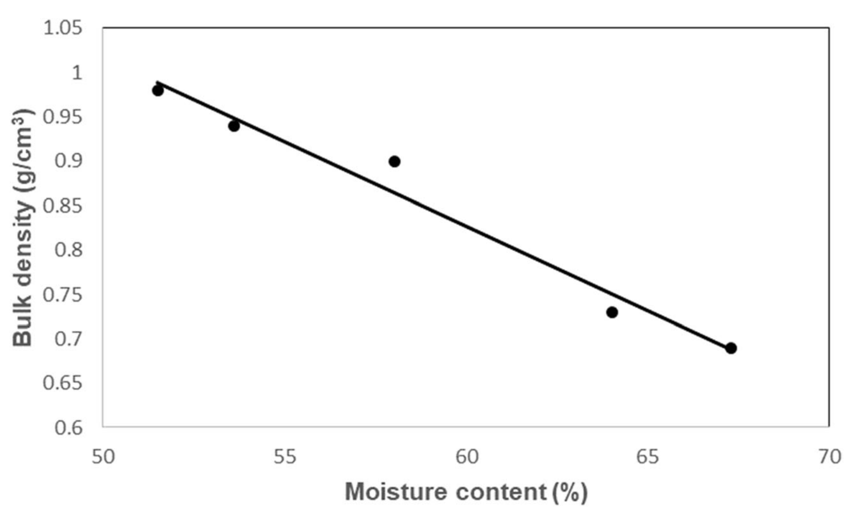

Fig. 7 Effect of moisture content on bulk density of fluted pumpkin seeds

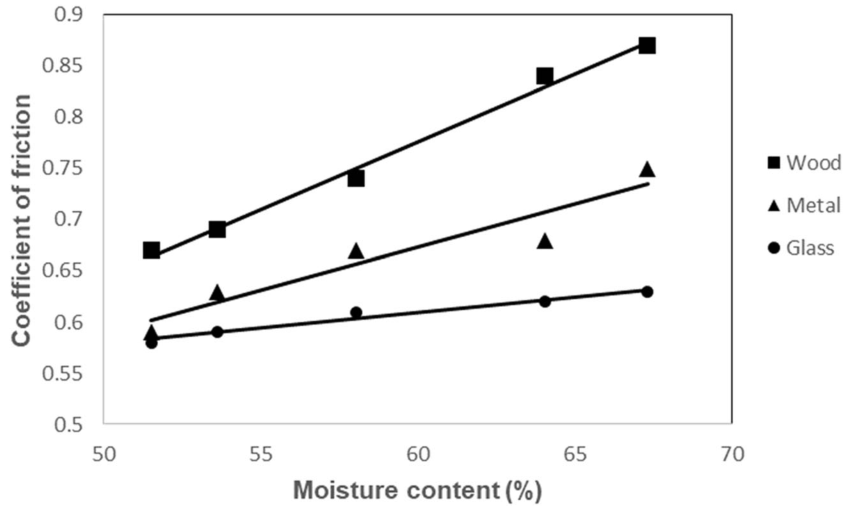

Fig. 8 Effect of moisture content on coefficient of friction of fluted pumpkin seeds against different material surfaces

(Vishwakarma et al. 2012) on surface areas of millet, castor seeds, and guar seeds, respectively. The seeds have a linear relationship with moisture content (Fig. 5), represented by the following regression equation:

$$A_s = 0.2199M_c + 7.4307 \qquad (R^2 = 0.999) \qquad (14)$$

Gravimetric Properties

The true density of the seeds decreased from 1.08 to 0.97 g/cm^3 as the moisture content increased from 51.5 to 67.30%. The decrease in true density values with an increase in moisture content might be attributable to the relatively higher true volume as compared to the corresponding mass of the seeds owing to the absorption of water. A decrease in true density with moisture content increase has been reported for wheat (Tabatabaeefar 2003), pistachio nuts (Kashaninejad et al. 2006), *Garcinia kola* seeds (Igbozulike and Aremu 2009), Hungarian vetch seeds (Taser et al. 2005), spinach seeds (Kilickan et al. 2010), and Malayasian rice MR219 seeds (Bashar et al. 2014). The relationship between true density and moisture content is shown in Fig. 6, which is expressed by the following regression equation:

$$\rho_t = 1.4841–0.0076M_c \qquad (R^2 = 0.916) \qquad (15)$$

The seed bulk density at different moisture content levels was found to vary between 0.98 and 0.69 g/cm^3 and decreased with an increase in moisture content (Fig. 7). Similar behavior has been reported for black cumin seeds (Taghi Gharibzahedi et al. 2010), sunflower seeds (Gamea 2013), and almond nuts and kernels (Mirzabe et al. 2013). Knowledge of density values is helpful in designing cleaning, separation, and conveyance systems for the seeds. The seed bulk density has the following regression equation:

$$\rho_b = 1.9714–0.0191M_c \qquad (R^2 = 0.973) \qquad (16)$$

The coefficient of friction was found to increase with an increase in moisture content from 0.67 to 0.87, 0.59 to 0.75,

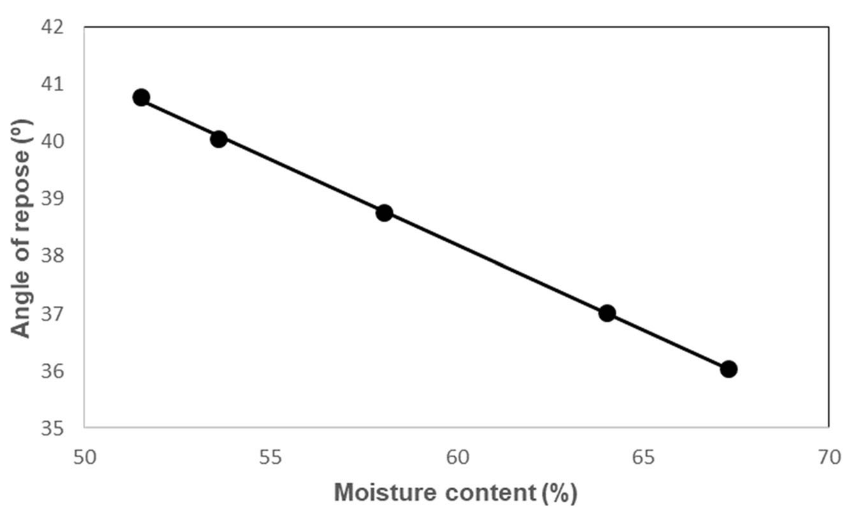

Fig. 9 Effect of moisture content on angle of repose of fluted pumpkin seeds

and 0.58 to 0.63 for wood, steel, and glass surfaces, respectively (Fig. 8).

At all moisture content levels, the static coefficient of friction was the highest against wood and the lowest against glass. It was observed that moisture has a significant effect on the coefficient of friction due to the increase in adhesion at higher moisture values. The coefficient of friction is important in selecting appropriate materials for different types of machinery, especially components requiring flow. It also finds application in the design of loading and unloading equipment, such as hoppers, and for storage systems, such as silos. Similar findings were recorded for wheat (Tabatabaeefar 2003), *Garcinia kola* (Igbozulike and Aremu 2009), black cumin seeds (Taghi Gharibzahedi et al. 2010), and sunflower seeds (Gamea 2013).

The linear relationship between moisture content and the static coefficient of friction for wood, metal, and glass surfaces are shown in eqs. (17), (18), and (19), respectively:

$$\mu_w = 0.0132M_c - 0.0177 \qquad \left(R^2 = 0.992\right) \qquad (17)$$

$$\mu_m = 0.0085M_c + 0.1655 \qquad \left(R^2 = 0.903\right) \qquad (18)$$

$$\mu_g = 0.003M_c + 0.4274 \qquad \left(R^2 = 0.964\right) \qquad (19)$$

The angle of repose of the seeds showed a decrease from 40.79° to 36.05° as moisture content increased from 51.50 to 67.30% (Fig. 9). These values are below 45°, which is the highest possible angle of repose for most agricultural products (Mohsenin 1986), and are in the same range as that of Guna seeds (Aviara et al. 1999). A decrease in the angle of repose with a moisture increase has been reported for black-eyed pea seeds (Altuntas and Demirtola 2007). Data on the angle of repose is useful in the design of storage systems for seeds. The relationship between the angle of repose and moisture content can be expressed by the following regression equation:

$$\theta_r = 56.073 - 0.2978M_c \qquad \left(R^2 = 0.9997\right) \qquad (20)$$

Conclusions

An investigation of various physical properties of fluted pumpkin (*Telfairia occidentalis)* seeds revealed that the dimensions of the seeds increased uniformly as the moisture content increased. While true density and bulk density decreased linearly with an increase in moisture content, mass also increased linearly with moisture content. The static coefficient of friction on all surfaces decreased as moisture content decreased and varied according to the surface. Wood had the highest coefficient of friction while glass had the lowest at all moisture content levels. The angle of repose increased with a decrease in moisture content. The study clearly shows that the properties of fluted pumpkin seeds investigated are dependent on their moisture content. These results are of value for engineers, technologists, and scientists who are interested in the mechanization of and postharvest value addition to fluted pumpkin seeds.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

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