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Article in *Journal of Food Research* · September 2013

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Effect of Moisture Content on Selected Physical and Mechanical Properties of Two Varieties of Tigernut (*Cyperus spp*)

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Received: July 22, 2013 Accepted: September 10, 2013 Online Published: September 26, 2013

doi:10.5539/jfr.v2n6p24

URL: <http://dx.doi.org/10.5539/jfr.v2n6p24>

Abstract

The effect of moisture content on some physical and mechanical properties of two varieties of tigernuts (*Cyperus esculentus*) was investigated. These properties include: geometric dimensions, linear dimensions, 1000 tuber weight, bulk density, tuber size, sphericity, angle of repose, porosity, coefficient of static friction and compressive strength. The moisture content levels used were 20, 25, 30, 35 and 40% wet basis (wb), and the two tigernut varieties used were yellow and brown types. The linear dimension, geometric diameter, sphericity, 1000-tuber weight, bulk density and angle of repose in both varieties increased with increasing moisture content. The average length, width and thickness of the yellow variety increases more than the brown variety at the determined moisture contents. True density of the yellow variety increased while the brown variety decreased with increase in moisture content. The porosity of the yellow variety reduces with increase in moisture content from 45.95 at 20% mc to 42.4 at 40% mc, while the brown variety decreased from 42.72 at 20% mc to 30.77 at 40% moisture content. The yellow variety had bigger size tubers than the brown variety and this has serious implications in packing, handling and transportation issues.

Keywords: moisture content, physical properties, tigernut, mechanical properties

1. Introduction

Tigernut (*Cyperus esculentus*) is an underutilized crop of the family *Cyperaceae* which produces rhizomes from the base and tubers that are somewhat spherical. It is a root crop which grows widely in wet places as a grass and is sometimes cultivated for its small and sweet tubers (Eteshola & Oraedu, 1996). Other common names of tiger nut are; earth almond, chufa, yellow nut sedge and Zulu nuts (Ekeanyanwu & Ononogbu, 2010).

Tigernut grows mainly in the middle belt and northern regions of Nigeria, it is known in Nigeria as 'Ayaya' in Hausa, 'Imumu' in Yoruba and 'Akiausa' in Igbo where three varieties (black, brown and yellow) are cultivated (Osagie & Eka, 1998). Among these, only two varieties, yellow and brown are readily available in the market. The yellow variety is preferred over others because of its inherent properties like its large size, attractive colour and fleshier nature. The yellow variety also yields more milk, contains lower fat and higher protein and less anti-nutritional factors especially polyphenols (Okafor et al., 2003; Belewu & Abodunrin, 2005; Ebringa, 2007).

In Nigeria markets, tigernuts are available in both fresh and dried forms. It's cultivation requires sandy soil and a mild climate. The tubers are planted between April and May and must be continuously irrigated until they are harvested in November and December. The tubers have to be properly dried before storage as the dried tubers possesses lesser weight. The tubers are regarded as a digestive tonic, having a heating and drying effect on the digestive system and enhances urine production (Galedar et al., 2010). The tubers are said to be aphrodisiac, possesses stimulating effect and are also used in the treatment of flatulence, indigestion, colic, diarrhea, dysentery, debility and excessive thirst (Chevallier, 1996).

The tubers contain up to 30% of non-drying oil which is used in cooking, soap making, starch and flour preparation (Carruthers, 1986; Shaker et al., 2009; Muhammad et al., 2011). The selected properties (geometric dimensions, linear dimensions, 100th tuber weight, bulk density, tuber size, sphericity, angle of repose, porosity, coefficient of static friction and compressive strength) are important in many problems associated with the design of machines and the analysis of the behavior of the product during agricultural process operations such as

handling, planting, harvesting, threshing, cleaning, sorting and drying. Solutions to problems in these processes involve knowledge of their physical and engineering properties (Irtwange, 2000; Varnamkhasti et al., 2008; Tavakoli et al., 2009). This study examined the effect of moisture content on the physical and mechanical properties of two varieties of tigernut (yellow and brown) that are useful in the design of harvesting and handling equipment.

2. Materials and Methods

2.1 Sample Preparation

The yellow and brown varieties of tigernut used for this study was obtained at a local market in Akure, Nigeria. The tubers were cleaned manually to remove all foreign matter such as dirt, stones, immature and broken seeds. The initial moisture content of the samples was determined by oven drying method at 103 °C for 48 hours as used by Sacilik *et al.*, (2003). Selected samples were moistened with a calculated quantity of distilled water and conditioned to raise their moisture content to the desired different levels. Equation (1) was used to calculate the quantity of distilled water used according to Coskun et al. (2006).

$$Q = w_i \left(\frac{m_f - m_i}{100 - m_f} \right) \quad (1)$$

Where Q = mass of added water (kg),

w_i is the initial mass of the sample (kg),

m_i is the initial moisture content of the sample (% *d. b.*) and

m_f is the final moisture content of the sample (% *d. b.*).

Five levels of moisture contents were obtained for both varieties, 20, 25, 30, 35 and 40% (wb). The samples were then stored in an airtight polythene and kept at 5 °C in a refrigerator for a week to achieve uniform moisture distribution within the sample.

2.2 Linear Dimensions, Sphericity and 1000 Tuber Weight

Average size was determined using 100 tubers that were randomly picked from each of the five conditioned samples. Three linear dimensions of the tubers namely; length L , width W and thickness T were measured with digital vernier caliper with accuracy of 0.001 mm and their equivalent diameter (D_g) determined obtained using Equation (2) by Sreenarayanan et al. (1985).

$$D_g = (LWT)^{0.333} \quad (2)$$

The sphericity of the tubers was calculated according to Mohsenin, 1978 as shown in Equation (3).

$$\phi = \frac{(LWT)^{0.333}}{L} \quad (3)$$

Where L = length (mm)

W = width and (mm)

T = thickness (mm)

One thousand tuber weight (W_{1000}) was determined using the method described by Baryeh (2002). The 100 seeds were weighed with the aid of an electronic balance and multiplied by 10 to give the mass of 1000 seeds.

2.3 Density, Porosity and Angle of Repose Determination

The true density and volume were determined using the toluene displacement method. Toluene was used in place of water because it is not easily absorbed by the seeds. The volume of toluene displaced was found by immersing a weighed quantity of tigernuts in toluene (Singh & Goswami, 1996). Bulk density was calculated from the mass of bulk tigernuts tubers divided by the volume of the container (Garnayak et al., 2008). The porosity, ϵ of the tubers was calculated from the values of the bulk and true densities obtained using Equation (4) by Mohsenin, (1970).

$$\varepsilon = \frac{[(\rho_g - \rho_b)100]}{\rho_g} \quad (4)$$

Where ρ_g = bulk density (kg m^{-3})

ρ_b = true or particle density (kg m^{-3})

The static angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined through the use of the apparatus consisting of a plywood box of two plates fixed and adjustable. The box was filled with the sample, and then the adjustable plate was inclined gradually allowing the seeds to flow and assume a natural slope (Tabatabeefar, 2003; Varnamkhasti et al., 2008; Tavakoli et al., 2009).

2.4 Coefficient of Static Friction Determination

The coefficients of static friction were determined on three structural surfaces namely: galvanized steel, glass, stainless steel. The static coefficient of friction was determined using an inclined plane (Suthar & Das, 1996). The friction surface was part of a special construction, which is hinged at one end so that it can be lifted gradually at the unhinged end using a screw device as used by Bart-Plange, and Baryeh (2003). The angle at which the tubers just began to slide down was recorded as the static angle of friction between the tubers and the friction surface. Baryeh (2001, 2002), Dutta et al. (1988), Joshi et al. (1993), Singh and Goswami (1996) and Suthar and Das (1996) used this method for other grains and seeds. The coefficient of friction was calculated using Equation (5) as:

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

Where μ = coefficient of friction and

θ = angle of tilt in degrees.

2.5 Compressive Strength

The tests were conducted using a universal testing machine (UTM) controlled by a micro-computer where results, statistics and graphs were automatically generated. The breaking force at peak and the Young modulus for the tubers were determined.

3. Results and Discussion

3.1 Effect of Moisture Content on Tigernut Dimensions

Figure 1 shows the variations of average values of the length, width, thickness and geometric diameters of the two varieties of the tiger tubers with increasing moisture content. All the linear dimensions increased with increasing tuber moisture content for both varieties. This is probably due to the air voids trapped in the cell vacuoles as they absorb moisture and thereby making the tubers display appreciable dimension change. This indicates that when the moisture is increased, the tubers increase in length, width, thickness and geometric diameter within the moisture range of 20-40% (wb) for yellow and brown varieties. The geometric dimension and their frequencies suggest that sieving will be a good method of separating the tubers from particles.

3.2 Effect of Moisture Content on Sphericity

The values of sphericity were calculated using Equation (3) by using the data on geometric mean diameter and the length of the tigernuts and the results obtained are presented in Figure 2. These figures indicate that the sphericity increased with increasing moisture content in both varieties from 0.86 to 0.89 for the yellow and 0.91 to 0.94 for the brown type.

3.3 Effect of Moisture Content on Mass of Tigernuts

Figure 3 shows the variation of tuber mass with moisture content. The tuber mass increased linearly from 0.32 to 0.42 g and 1.13 to 1.43 g, respectively, for the yellow and brown varieties as the moisture content increases. The figure shows that the lower the moisture content the lower the tuber mass. Transportation of the tuber is therefore advisable at low moisture content because of the reduction in weight.

3.4 Effect of Moisture Content on 1000-Tuber Mass

The variation of 1000-tuber weight with moisture content for both varieties of tigernut is shown in Figure 4. The figures show that the tuber mass increased with tuber moisture content. The variation can be expressed mathematically as $W_{1000}=1.28mc+87.8$ with a correlation coefficient, R^2 of 0.87 in the yellow variety and $W_{1000}=0.52mc+20.4$ with a correlation coefficient, R^2 of 0.91 in the brown variety. The 1000-tuber mass ranged from 113 g to 143 g in the yellow variety and 32 g to 42 g in the brown variety for the sampled moisture content. The result showed that there were significant differences between the mean values of the 1000-tuber weight of the

tigernuts at the 1% probability. Similar patterns have been reported for guna seeds, soyabean, cocoa beans, cumin seeds and bambara groundnuts (Aviara et al., 1999; Baryeh, 2001; Deahpande et al., 1993; Bart-Plange & Baryeh, 2003; Singh & Goswami, 1996; Visvanathan et al., 1996). The weights indicate that blowers can be used to transport the tubers in a processing plant.

3.5 Effect of Moisture Content on Bulk Density

The bulk density increased linearly with increasing moisture content from 590 to 630 kg m⁻³ in the yellow variety and from 600 to 640 kg m⁻³ in the brown variety as shown in Figure 5. The bulk density increases in both varieties were very close to each other. The increase in bulk density was due to an increase in mass due to moisture gain in the sample which was higher than the volumetric expansion of the bulk (Pradhan et al., 2008). A similar increasing trend in bulk density has been reported by Baryeh and Mangope (2002) for QP- 38 variety pigeon pea and Kingsley et al. (2006) for dried pomegranate seeds and Nikoobin et al. (2009) for chickpea seeds.

3.6 Effect of Moisture Content on True Density

The change in true density with moisture content for both varieties of tigernut is shown in Figure 5. Here, the density of the yellow type increases in a non-linear manner starting from 1260 kg m⁻³ to 1370 kg m⁻³ as the moisture content increases while the brown type decreases also in a non-linear manner from 1030 kg m⁻³ to 910 kg m⁻³ as the moisture content increases from 20% to 40%. The variation in tuber density may be due to a low decrease in mass of the tuber as well as the smaller sizes of the brown variety compared to its volumetric decrease as tuber moisture content decreases. These results suggest that the tubers are likely to have high terminal velocities because of their densities, making pneumatic separation from lighter particles very feasible.

3.7 Effect of Moisture Content on Porosity

Porosity of materials usually is dependent on the bulk as well on true densities, therefore the magnitude of the varieties were calculated using the data on the bulk and true densities using Equation 4 and the results are presented in Figure 6. The porosity of the yellow variety reduces from 45.9% to 42.4% while that of the brown type reduces from 42.7% to 30.8% as the moisture content increases from 20% to 40%. This has to do with the changes in the mass and density values of the sample as it absorbs more water. High porosity at low moisture content indicates that high numbers of tubers can be stored at low moisture content than at high moisture content due to an increase in the cohesion of the cell structure of the tigernuts as the moisture content increases.

3.8 Effect of Moisture Content on Angle of Repose

Figure 7 shows the effect of moisture increase on the angle of repose for the tigernut varieties. The values were found to increase from 20.3° to 23.7° and 21.3° to 24.3° respectively, for the yellow and brown varieties at the moisture range of 20% to 40%. This increasing trend of angle of repose with moisture content occurs because surface layer of moisture surrounding the particle hold the tigernuts together by the surface tension (Prashan et al., 2008). These results were similar to those reported by Aluntas and Yildiz (2007) and Garnayak et al. (2008) for faba bean grains and jatropha seed, respectively.

3.9 Effect of Moisture Content on Static Coefficient of Friction

The variation of the coefficient of static friction with moisture content for the 2 varieties is shown in Figure 8 for three structural surfaces. At all moisture content levels, the static coefficient of friction was the highest for both varieties on galvanized steel and the least for stainless steel. The least value of static coefficient of friction may be due to smoother and more polished surface of the stainless steel than the other materials used. The reason for the increased friction coefficient at higher moisture content may be due to the water present in the tigernut tubers, offering a cohesive force on the surface of contact. As the moisture content of grains increases, the surface of the samples becomes stickier. Water tends to adhere to surfaces and the water on the moist tuber surface would be attracted to the surface across which the sample is being moved. Other researchers found that as the moisture content increased, the static coefficient of friction increased also (Baryeh & Mangope, 2002; Altunta & Yildiz, 2007; Pradhan et al., 2008). Knowledge of coefficient of friction of agricultural materials on various surfaces has long been recognized by engineers concerned with rational design of grain bins and other storage structures in grain handling (Varnamkhasti et al., 2008; Tavakoli et al., 2009).

3.10 Compressive Strength

The breaking force at peak and the Young modulus for the yellow variety were lower and reduces with increase in moisture content while the brown variety had a slightly higher values which increases at low moisture and then reduces as the moisture increases. Force at peak for the yellow variety reduces from 124.8 N at 20% moisture to 88.1 N at 40% moisture while it was 142.7 N and 167.3 for the same moisture range for the brown

variety. The Young modulus values for the yellow variety reduces from 313.7 N mm^{-1} at 20% moisture to 224.7 Nmm^{-1} at 40% moisture while for the brown type it increase at low moisture (847.7 N mm^{-1} and 20%) and then increase as the moisture level increases (852.4 N mm^{-1} and 40%).

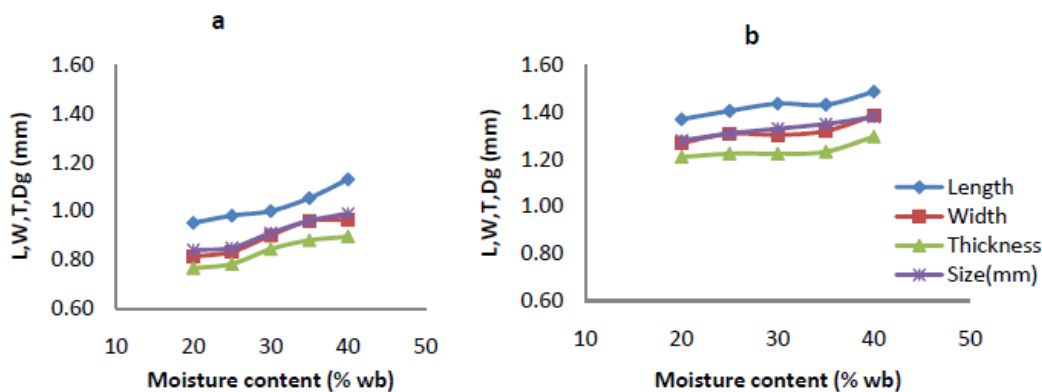


Figure 1. Linear dimensions against moisture content of the yellow (a) and brown (b) varieties of tigernut

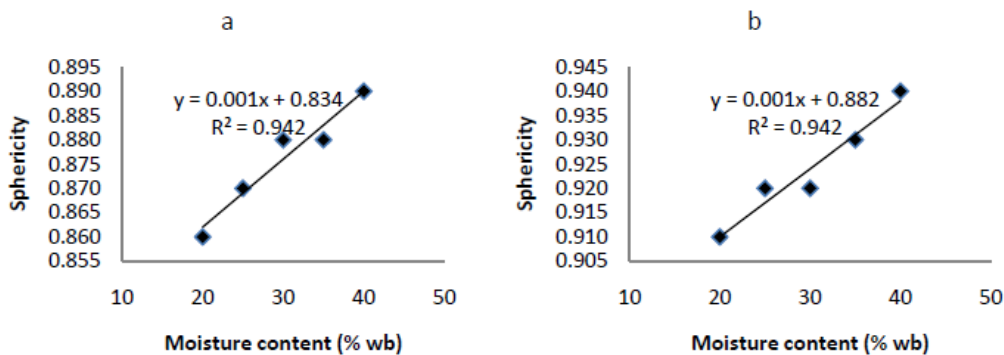


Figure 2. Sphericity against moisture content at different moisture levels of the yellow (a) and brown (b) varieties of tigernut

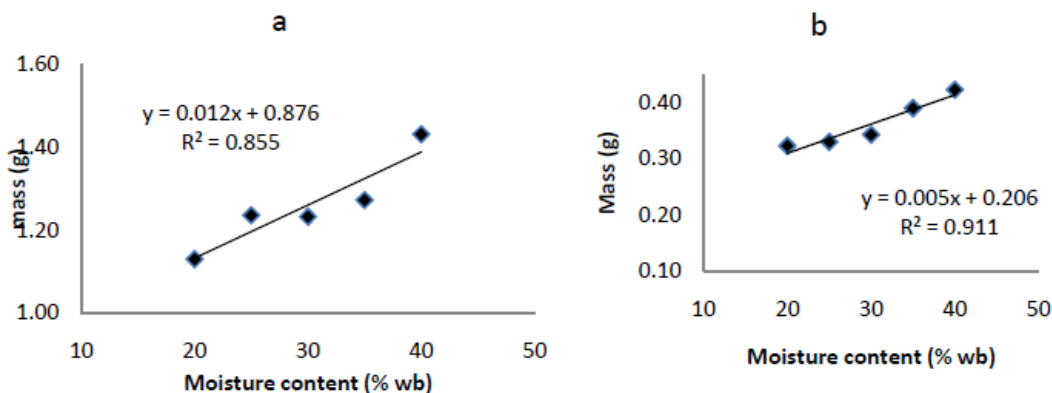


Figure 3. Mass of tuber against moisture content at different moisture levels of the yellow (a) and brown (b) varieties of tigernut

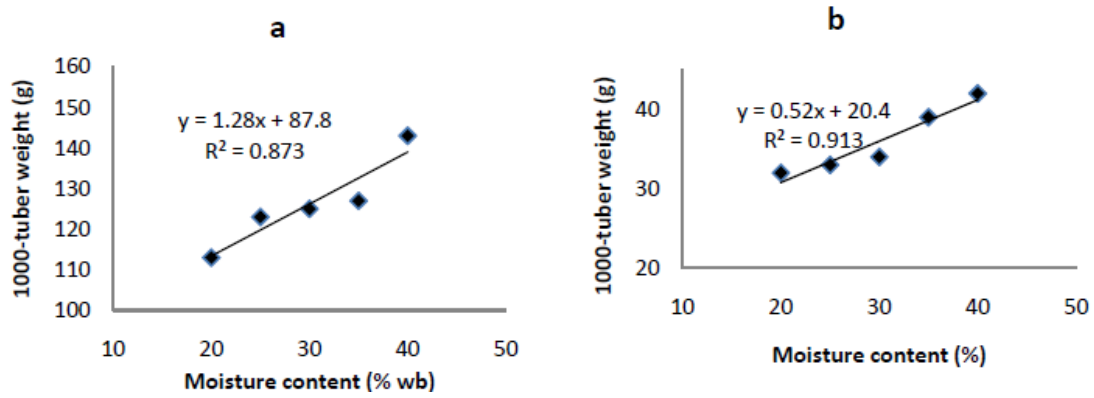


Figure 4. 1000- tuber weight against moisture content at different moisture levels of the yellow (a) and brown (b) varieties of tigernut

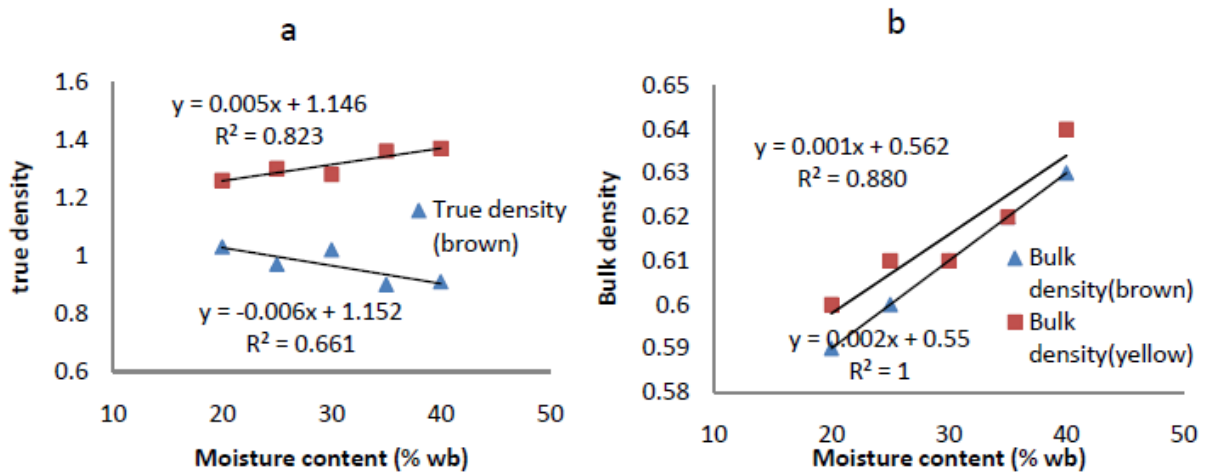


Figure 5. True density and bulk density variations with moisture content at different moisture levels levels of the yellow (a) and brown (b) varieties of tigernut

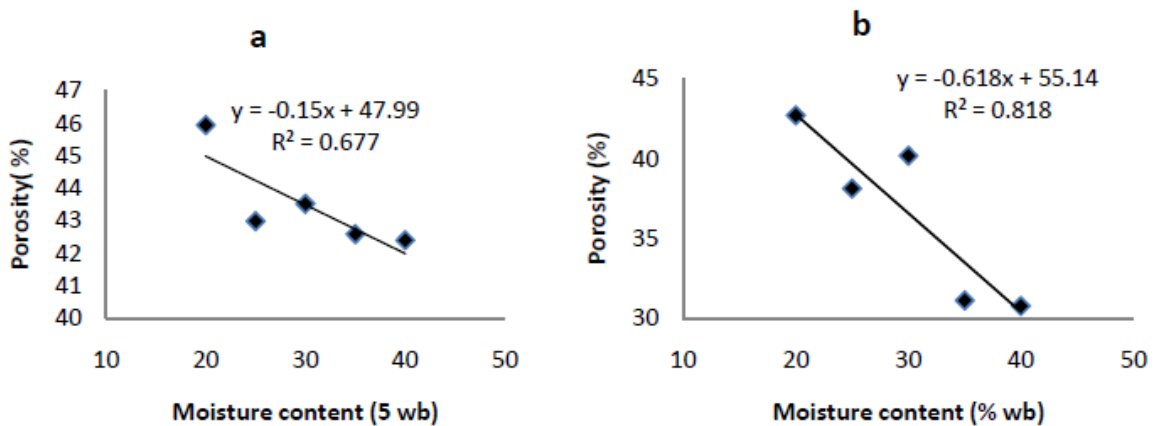


Figure 6. Porosity against moisture content at different moisture levels of the yellow (a) and brown (b) varieties of tigernut

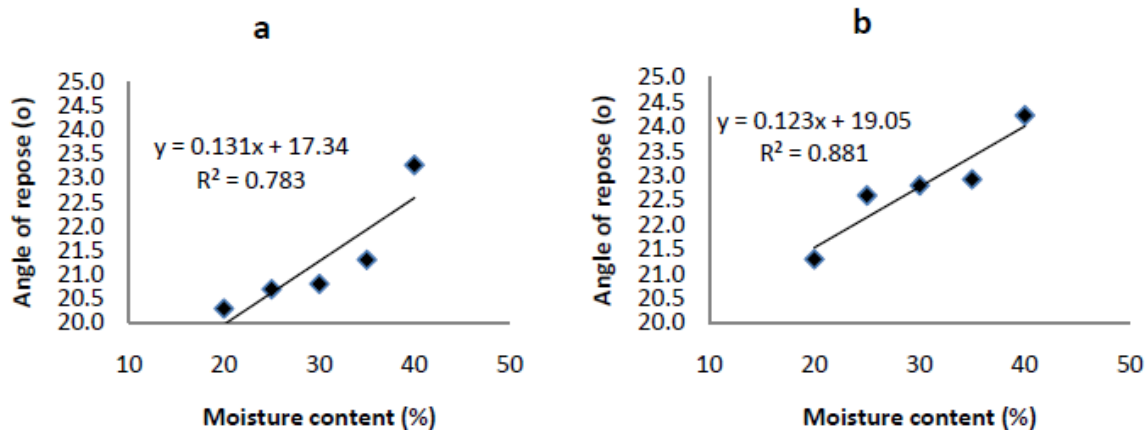


Figure 7. Angle of repose against moisture content at different moisture levels of the yellow (a) and brown (b) varieties of tigernut

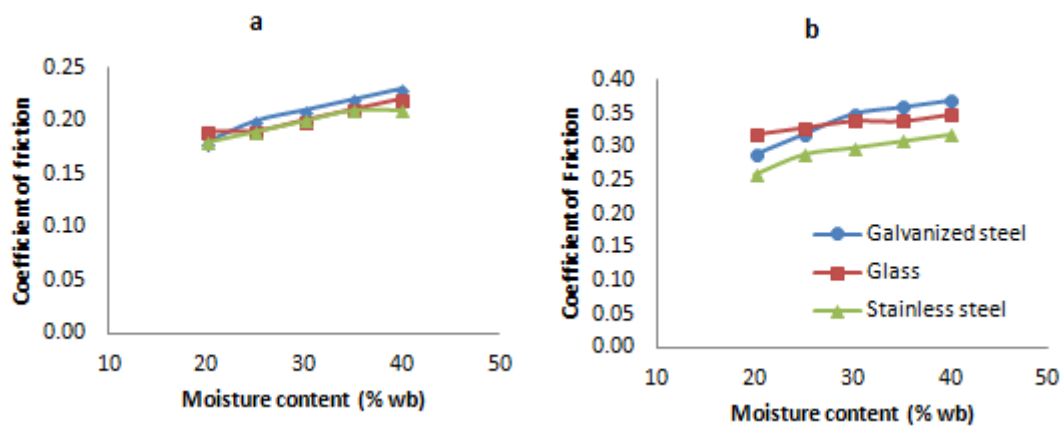


Figure 8. Coefficient of friction on different surfaces against moisture content at different moisture levels of the yellow (a) and brown (b) varieties of tigernut

4. Conclusions

The following conclusions are drawn from the investigations on selected physical and mechanical properties of two varieties of tigernuts (*Cyperus spp.*) at five different moisture content levels. Physical and mechanical properties of tigernuts are dependent on their moisture contents. All the linear dimensions increased with increased moisture content for both varieties. The average length, width, thickness, geometric mean diameter, sphericity, volume, bulk density, thousand weight, tuber mass and angle of repose also increased. As the moisture increase in the samples, the porosity values reduce while bulk density increases. True density of the yellow variety increase significantly while the brown variety reduces with increase in moisture of the samples. The variation of the coefficient of static friction for three structural surfaces (glass, galvanized steel and stainless steel) at different moisture levels suggests the flow function of the samples on the materials of construction of the handling equipment. At all moisture content levels examined, the static coefficient of friction was the highest for both varieties on galvanized steel and the least for stainless steel. The least static coefficient of friction may be due to smoother and more polished surface of the stainless steel than the other materials used.

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