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Effect of Moisture Content on the Physical Properties of Tiger Nut (*Cyperus esculentus*)

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ABSTRACT

The effect of moisture content on the physical properties of the black variety of tiger nut was investigated using a completely randomized design , for four moisture content levels initially at 32% and sun dried to 27, 22 and 17% (wb) moisture contents. In these moisture contents, the major (length), intermediate (width), minor (thickness) and geometric diameter decreased with decreasing moisture content from 16.16 to 13.71, 14.51 to 12.46, 11.94 to 10.40 and 13.69 to 11.80 mm, respectively. The values of the width were generally the highest, followed by geometric mean diameter and thickness. The roots surface area decreased with decreasing moisture content but the sphericity decreased from 0.855 to 0.847 at 32 to 27% moisture content and increased thereafter from 0.847 to 0.864 at 27 to 17% moisture content. The particle density increased from 1.095 to 1.197 g cm^{-3} at 32 to 27% moisture content, decreased to 1.134 g cm^{-3} at 22% (wb) and increased thereafter to 1.175 g cm^{-3} at 17% moisture content. The bulk density decreased non-linearly with decreasing moisture content from 570.64 to 545.81 kg m^{-3}; the 1000-root mass also decreased with decreasing moisture content from 1341.82 to 1087.54 g. The porosity followed a polynomial function from 47.35 to 52.32% with decreasing moisture content at 32 and 17%, respectively. The angle of repose decreased non-linearly with tuber moisture content from 24.7° at 32% moisture content to 23.3° at 27% moisture content and increased sharply thereafter to 24.5° at 17% moisture content. The coefficient of friction decreased non-linearly from 0.57 to 0.39 at 32 to 17% moisture content, increased non-linearly from 0.52 to 0.58 and 0.30 to 0.38 at 32 to 22% moisture content for plywood, paper and rubber, respectively.

Key words: Black variety, sphericity, porosity, angle of repose, coefficient of friction

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 commonly known as earth almond, chufa, chew-fa, attadwe and Zulu nuts. It is known in Nigeria as Ayaya in Hausa, Ofio in Yoruba and Akiausa in Igbo where three varieties (black, brown and yellow) are cultivated. 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). Tigernut cultivation requires sandy soil and a mild climate. They are planted during April and may and must be irrigated every week until they are harvested in November and December. The tiger nut is not a nut but a tuber. Being cultivated through continuance irrigation they have to be properly dried before storage. The drying is usually sun-dried and can take up to one month. The drying process ensures a longer shelf time, preventing rot or any other bacterial infections securing therewith their quality and nutritious levels. Problems associated with drying include shrinkage, skin wrinkles and hard nut texture. However, when dried it has a smooth tender, sweet and refreshing taste. Tiger nut can be consumed raw, roasted, dried, baked or made into a refreshing beverage (Cantalejo, 1997). The tubers are regarded as a digestive tonic, having a heating and drying effect on the digestive system and alleviating flatulence. They also promote urine production and menstruation. The tubers are said to be aphrodisiac, carminative, diuretic, emmenagogue, stimulant and tonic. In Ayurvedic medicine, they are used in the treatment of flatulence, indigestion, colic, diarrhoea, dysentery, debility and excessive thirst (Chevallier, 1996). The tubers contain up to 30% of non-drying oil and it is used in cooking, making soap, starch and flour (Carruthers, 1986). Tigernut oil does not solidify at 0°C and stores well without going rancid.

The physical properties of tigernut tubers, like those of other agricultural materials such as fruits and vegetables are essential for the design of equipment for handling, harvesting and storing the tubers or determining the behavior of the tubers for its handling. Various types of cleaning, grading and separation equipment are designed on the basis of the physical properties of the agricultural materials. Physical properties affect the converting characteristics of solid materials by air or water and cooling and heating load of food products (Sahay and Singh, 1994). It is therefore necessary to determine these properties. The properties of different types of grains, seeds, fruits and vegetables have been determined by other researchers such as (Bart-Plange and Baryeh, 2003; Baryeh, 2001; Gupta and Das, 1998; Jain and Bal, 1997; Suthar and Das, 1996; Joshi, 1993; Deshpande *et al.*, 1993). Although, many researchers have worked on tiger nut (Eteshola and Oraedu, 1996), the physical properties of the black variety of tiger nut are however unknown. In addition, there is little information on the effect of moisture content on the physical properties of tiger nuts particularly the black variety. This paper therefore presents the effect of moisture content on the physical properties of black variety of tiger nut useful in the design of harvesting and handling equipment.

THEORETICAL BACKGROUND

According to Mohsenin (1978), the degree of sphericity, $\varnothing$, can be expressed as follows:

$$\varnothing = \frac{(WTL)^{0.333}}{L} \tag{1}$$

where L, W and T are the tuber major (length), intermediate (width) and minor (thickness) diameters.

The geometric mean diameter, D_g is given by Sreenarayanan *et al.* (1985) and Sharma *et al.* (1985) as:

$$D_g = (WTL)^{0.333} \tag{2}$$

Jain and Bal (1997) have also stated that sphericity, $\varnothing$, root volume V and root surface area, S, for a cono-spherically shaped tubers may be given by:

$$\varnothing = \left[\frac{B(2L-B)}{L^2}\right]^{0.333} \quad (3)$$

$$V = \frac{\pi B^2 L^2}{6(2L-B)} \quad (4)$$

$$S = \frac{\pi BL^2}{2L-B)} \quad (5)$$

where, $B = (WT)^{0.5}$

The surface area, S is given by:

$$S = \pi D_g^2 \quad (6)$$

According to Mohsenin (1970) the porosity, ε is given by:

$$\varepsilon = \left[\frac{\rho_p - \rho_p}{\rho_p}\right]100 \quad (7)$$

Where, ρ_b is the bulk density; ρ_p is particle or tuber density.

MATERIALS AND METHODS

Sample preparation: The black variety tigernuts were used and was obtained from wholesalers in Kotokoraba market, Cape Coast, in the Central Region of Ghana on October 25, 2009. It was then brought to the Department of Agricultural Engineering laboratory, University of Cape Coast for the research. The tubers had been prepared for both the local and international market making it suitable for the study. The initial moisture content of 32% (w b) was obtained by keeping a ground sample of 10 g in the oven at a temperature of 105°C for 24 h (Food Storage Manual, 1995). The desired moisture contents for lower values were obtained by drying to obtain a sample mass given by the relation Eq. 8:

$$M_f = M_i\left[\frac{100-m_i}{100-m_f}\right] \quad (8)$$

After using the above equation to obtain the desired moisture level, the moisture content of the samples were determined after they attained equilibrium. After drying the samples to the desired moisture levels, the various investigations of physical properties were carried out on the sample.

Dimension and size: The length, width and thickness of the tubers were determined using a micrometer screw gauge with 0.001 mm accuracy. 10 tubers each was randomly selected (Murray, 1992) from 10 sub-samples each containing 100-tubers. The three principal dimensions of the selected tubers were measured and their averages were taken. Several investigators including Dutta *et al.* (1988), Moshenin (1970) and Shepherd and Bhardwaj (1986) have measured these dimensions for other grains and seeds in a similar manner. The sphericity was calculated using Eq. 1 and 3, the volume using Eq. 4, the surface area using Eq. 5 and 6.

Bean mass and 1000-tuber mass: After the determination of the dimensions, all other measurements which followed were replicated five times at each moisture content considered and the averages were taken.

Five samples each of a given investigation were randomly selected and weighed on an electronic balance with 0.001 g accuracy. The mass was divided by 100 to obtain the bean mass. The mass of the 1000-beans was obtained by counting five 1000-tuber samples for the desired moisture content, weighed on an electronic balance and the weights were averaged. Similar methods have been used by other researchers including Aviara *et al.* (1999), Deshpande *et al.* (1993), Shepherd and Bhardwaj (1986) and Visvanathan *et al.* (1996).

Bulk density and porosity: To determine the bulk density of the tubers at given moisture content, 940 mL volume container was filled with tigernut tubers and the top leveled. No separate or additional manual compaction was done. The electronic balance was used for weighing and the bulk density was calculated as the ratio of mass to the volume of the beans. Several researchers including Baryeh (2001), Deshpande *et al.* (1993), Jain and Bal (1997), Sharma *et al.* (1985) and Suthar and Das (1996) have employed this method for other grains and seeds. The porosity of the tubers was calculated from the values of the bulk and particle densities obtained using Eq. 7.

Particle density: For the particle density, a sample of 100-tubers selected randomly from 10 sub samples of 100-tubers each was used. For each sub-sample, 10 tubers were selected. The tubers were used to displace methanol in a measuring cylinder after their masses had been measured. The particle density was found as an average of the ratio of their masses to volume of methanol displaced by the tubers. This method has been used by Baryeh (2001) and Singh and Goswani (1996) for cumin seeds and bambara groundnuts respectively.

Angle of repose: To determine the dynamic angle of repose, a plywood measuring 12 cm in diameter was used and the tubers were allowed to fall from a height of 15 cm to form a natural heap. The angle of repose is taken to be the arctangent of the ratio of height of the conical heap to the diameter of the cone. This method has been used by other investigators (Joshi *et al.*, 1993; Kaleemullah and Gunasekar, 2002; Karababa, 2005).

Coefficient of friction: The coefficient of static friction was obtained by filling a PVC cylinder of 10 cm diameter and 5 cm height with the tubers and placed on the friction surface. The cylinder was pulled up slightly (3 mm) to avoid contact between it and the friction surface. 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 by means of a bolt and nut arrangement. The angle at which the tubers just began to slide down was recorded as the static angle of friction between the beans and the friction surface. Baryeh (2001, 2002), Dutta *et al.* (1988), Joshi *et al.* (1993), Singh and Goswani (1996) and Shuthar and Das (1996) have used this method for other grains and seeds. The coefficient of static friction was determine on three structural surfaces of plywood, paper, rubber and found as $\mu = \tan \theta$.

RESULTS

The results of the effects of moisture content on the various physical properties of tigernut tubers are as presented in Fig. 1 to 10.

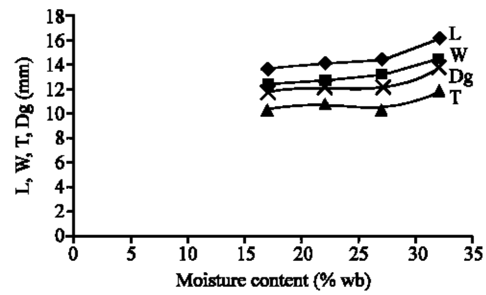

Fig. 1: Linear dimensions against moisture content

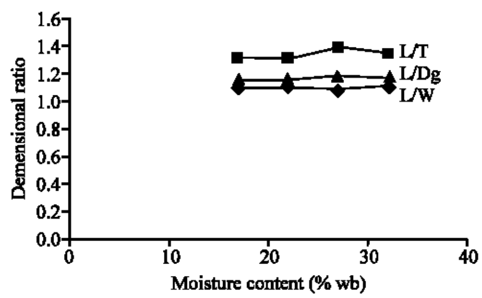

Fig. 2: Dimensional ratio variation with moisture content

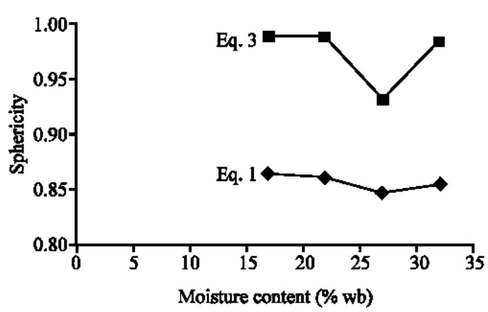

Fig. 3: Sphericity versus moisture content

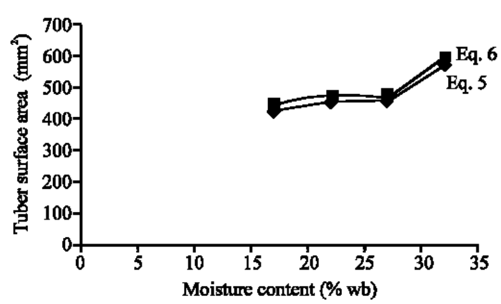

Fig. 4: Surface area against moisture content

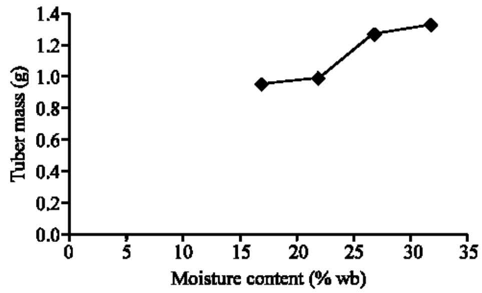

Fig. 5: Tuber mass against moisture content

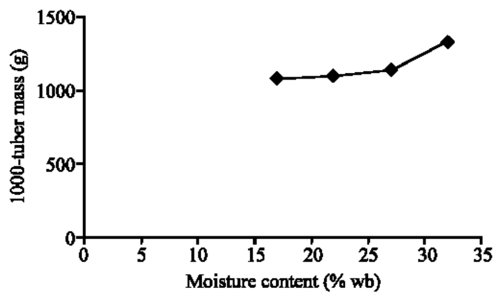

Fig. 6: 1000-tuber mass against moisture content

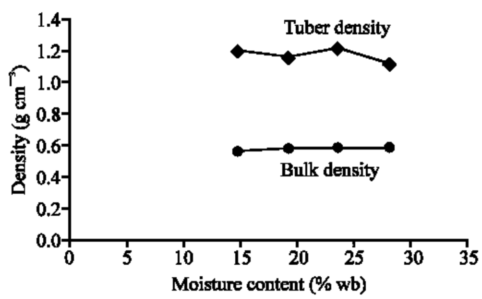

Fig. 7: Tuber and bulk densities against moisture content

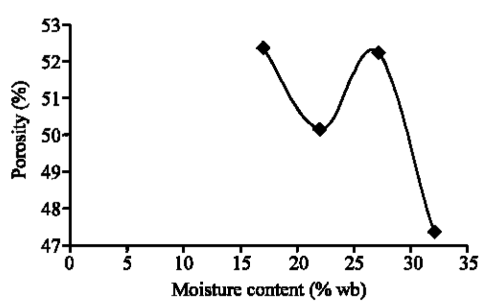

Fig. 8: Porosity against moisture content

DISCUSSION

Seed dimensions and size: Figure 1 displays the variations of mean length, width, thickness and geometric diameters of the tubers with tuber moisture content. All the linear dimensions decreased

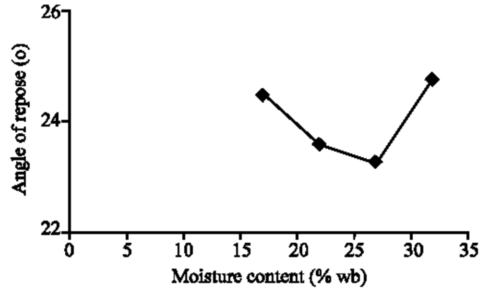

Fig. 9: Angle of repose against moisture content

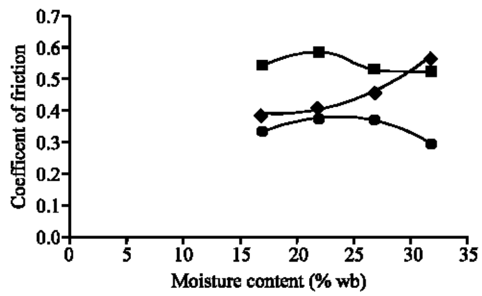

Fig. 10: Coefficient of friction versus moisture content

with decreasing tuber moisture content. This trend is probably due to enough air voids as they as they loose moisture and thereby making the tubers display appreciable dimensional change. Very low correlation was observed between these dimensions and tuber moisture content. This indicates that on moisture reduction, the tubers contract in length, width, thickness and geometric diameter within the moisture range of 32-27% (wb). The total mean reduction from 32-17% tuber moisture content was largest along the length and least along the tuber geometric diameter and thickness. The dimensions and their frequencies suggest that sieving is a good method of bean separation from particles.

The L/W, L/T/, L/D_g ratio variations with moisture content shown in Fig. 2 exhibits the highest ratio in L/T, followed by L/D_g and L/W in descending order. This means that the values of W are generally the highest, followed by Dg and T. The ratios did not appreciably increase with increase in moisture content. The ratios are within the range reported for bambara groundnut by Baryeh (2001).

Sphericity: The sphericity, ⌀, variation with tuber moisture content is shown in Fig. 3. The sphericity graph given by Eq. 3 gives higher values compared to the one by Eq. 1. This is due to the shape assumptions for the two equations. The elliptical shape assumed in Eq. 1 is closer to the shape of the tigernut tubers used in this study compared with the cono-spherical shape assumed in Eq. 3.The sphericity decreased from 0.855 to 0.847 and 0.985 to 0.931 at 32 to 27% moisture content and increased thereafter from 0.847 to 0.864 and 0.931 to 0.989 at 27 to 17% moisture content for Eq. 1 and 3, respectively. Both equations gave a non-linear variation of sphericity with moisture content. The polynomial relation given by Eq. 1 may be expressed mathematically as:

$$\varnothing = 4E\text{-}05M^3 - 0.003M^2 + 0.070M + 0.347 \text{ with a correlation coefficient } R^2 = 1$$

Baryeh (2001) found the sphericity of bambara ground to increase for grain moisture content from 20 to 5%. The results indicate that the tuber is quite far from the shape of a sphere and that the moisture content does not greatly affect the sphericity. This means that a sieving or separating machine with circular holes will not easily let tubers through its holes. During unloading the tubers will not roll away too far from intended unloading spot.

Surface area: The variation of the tuber surface area with moisture content is displayed in Fig. 4. The surface area decreases with decreasing moisture content for both Eq. 5 and 6 from 573.18 to 426.91 mm^2 and 594.97 to 444.82 mm^2, respectively. Equation 6 displays higher values for tuber surface area than Eq. 5. This is again due to the different shape assumptions of the tuber for the two equations. There is 25.5 and a 25.2% decrease in surface area from a moisture content of 32-17% for Eq. 5 and 6, respectively. The results suggest that it is advisable to store the tubers at 17% (wb) moisture content or below when the surface area is lowest for the tubers to present less surface area for moisture absorption during storage.

Mass: Figure 5 displays the variation of individual tuber mass with moisture content. The tuber mass decreases with decreasing moisture content with values ranging from 1.3±0.46 g at 32% (wb) to 0.95±0.36 g at 17% (wb). The mass did not change significantly as the moisture content decreased. The figure shows that the lower the moisture content the lower the tuber mass. Transportation is therefore advisable at low moisture content. Furthermore, there is a need to use blowers and pneumatic methods of separating the tubers.

1000-tuber mass: Figure 6 shows the 1000-tuber mass, M_{1000}, variation with tuber moisture content. The figure shows that the tuber mass increases polynomially with tuber moisture content. The variation can be expressed mathematically as $M_{1000} = 0.156M^3 - 9.805M^2 + 206.4M - 358.5$ with a correlation coefficient, R^2, of 1. The 1000-tuber mass ranged from 1341.82 to 1087.54 g at moisture contents ranging between 32 and 17% (w b). The analysis of variance showed that there were significant differences between the mean values of the 1000-tuber mass of the tigernuts moisture content.

Similar patterns have been reported for guna seeds, soybean, cumin seeds, neem seeds and bambara groundnuts (Aviara *et al.*, 1999; Baryeh, 2001; Deshpande *et al.*, 1993; Singh and Goswani, 1996; Visvanathan *et al.*, 1996). The weights indicate that blowers can be used to transport the tubers in a processing plant.

Tuber and bulk density: The variation of tuber and bulk densities with moisture content is shown in figure 7. The bulk density decreased non-linearly with decreasing moisture content from 0.570 to 0.546 g cm^{-3} at moisture content of 32 to 17% but not appreciably. The tuber density however increased from 1.095 to 1.197 g cm^{-3} at moisture content of 32 to 27%, decreased again to 1.134 and thereafter increased to 1.175 g cm^{-3}. The variation in tuber density may be due to a lower decrease in mass of the tuber as compared to its volumetric decrease as tuber moisture content decreases. The results suggest that the tubers are likely to have high terminal velocities making pneumatic separation from lighter particles very feasible.

Porosity: Figure 8 shows the variation of porosity with tuber moisture content. The porosity increased from 47.35 to 52.22% at moisture content of 32 and 27%, decreased from 52.22 to 50.11% at moisture content of 27 to 22% and finally increased to 52.32% at 17% moisture content. The variation of porosity followed a non-linear function with moisture content and is expressed mathematically as:

$$\varepsilon = -0.015M^3 + 1.080M^2 - 25.31M + 244.2$$

with a correlation coefficient of $R^2 = 1$

This trend is probably due to a decrease and increase in the cohesion of the cell structure of the tigernuts as it dries. High porosity at low moisture content indicates that high number of tubers can be stored at low moisture content than at high moisture content.

Angle of repose: The variation of the angle of repose with moisture content is displayed in Fig. 9. The angle of repose decreased non-linearly with tuber moisture content from 24.7° at 32% moisture content to 23.3° at 27% moisture content and increased sharply thereafter to 24.5° at 17% moisture content. The variation is similar to what Baryeh (2001) recorded in wetting bambara groundnut. However, Avaria *et al.* (1999) recorded a linear increase in angle of repose with moisture content of guna seeds. The differences could be due to difference in the surface roughness of tubers as they dry.

Coefficient of friction: The variation of the coefficient of static friction, μ, with moisture content is displayed in Fig. 10 for three structural surfaces. The coefficient of friction decreased non-linearly from 0.57 to 0.39 with decreasing moisture content from 32 to 17% moisture content for plywood structural surface. However, there was an increase in coefficient of friction from 0.52 to 0.58 and 0.30 to 0.38 from 32 to 22% moisture content and decreased to 0.55 and 0.34 at 17% moisture content for paper and rubber structural surfaces respectively. The friction coefficient was highest for plywood at 32% moisture content after which the static coefficient of friction for the rest of the moisture content was highest for paper. The coefficient of friction for the three structural surfaces displayed a polynomial function with moisture content and are expressed mathematically as:

$$\mu_{plywood} = 0.001M^2 - 0.036M$$

with correlation coefficient $R^2 = 1$

$$\mu_{paper} = 0.001M^3 - 0.036M^2 + 0.324M - 2.002$$

with correlation coefficient $R^2 = 0.999$

$$\mu_{rubber} = 0.001M^2 - 0.056M + 0.275M - 2.002$$

with correlation coefficient $R^2 = 0.992$

Baryeh (2001) and Chandrasekar and Viswanathan (1999) have also reported same conclusion for plywood for bambara and coffee beans, respectively. The coefficient of static friction is important in the design of conveyors because friction is necessary to hold the tubers to the conveying surface without slipping or sliding backward. If a rubber surface is to be used for conveying the tubers, it will be advisable to roughen the surface to increase friction between the beans and the surface. On the other hand, discharging requires less friction to enhance the discharging process. Therefore, knowledge of coefficient of friction of agricultural materials on various surfaces has long been recognized by engineers concerned with rational design of grain bins, silos and other storage structures. In design of agricultural machinery, however, the need for this information has been recognized rather recently (Hintz and Schinke, 1952).

CONCLUSIONS

The investigation on the effects of moisture content on the various physical properties of the tigernut tubers revealed the following conclusions:

- All the linear dimensions decreased with decreasing tuber moisture content
- The sphericity decreased form 0.855 to 0.847 at 32 to 27% moisture content and increased thereafter from 0.847 to 0.864 at 27 to 17% moisture content
- The surface area decreases with decreasing moisture content for both Eq. 5 and 6 from 573.18 to 426.91 mm^2 and 594.97 to 444.82 mm^2, respectively
- The tuber mass decreases with decreasing moisture content with values ranging from 1.30 to 0.95 g at the moisture content range of 32 to 17% (wb)
- The 1000-tuber mass also decreased with decreasing moisture content from 1341.82 to 1087.54 g
- The bulk density decreased non-linearly with decreasing moisture content from 0.570 to 0.546 g cm^{-3} at moisture content of 32 to 17%
- The tuber density increased from 1.095 to 1.197 g cm^{-3} at moisture content of 32 to 27%, decreased again to 1.134 and thereafter increased to 1.175 g cm^{-3}
- The porosity increased from 47.35 to 52.22% at moisture content of 32 and 27%, decreased from 52.22 to 50.11% at moisture content of 27 to 22% and finally increased to 52.32% at 17% moisture content
- The angle of repose decreased non-linearly with tuber moisture content from 24.7° at 32% moisture content to 23.3° at 27% moisture content and increased sharply thereafter to 24.5° at 17% moisture content
- The coefficient of friction decreased non-linearly from 0.57 to 0.39 from 32 to 17% moisture content, increased non-linearly from 0.52 to 0.58 and 0.30 to 0.38 from 32 to 22% moisture content for plywood, paper and rubber, respectively

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