Effect of moisture on physical properties of dekoko (*Pisum sativum var. abyssinicum*) seed

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Abstract: Dekoko is a cool season legume plant grown in northern Africa. It is a rich source of protein for people in the region. The effect of moisture on some of the physical properties of dekoko seed was studied because it frequently affects some important parameters for the design of mechanical unit operations. The moisture content of dekoko seed was determined according to ASAE standards S352.3 and all other physical properties following standard procedure described elsewhere. The length, width, thickness, geometric mean diameter, thousand seed mass, porosity, true density and angle of repose increased from 5.60 to 6.51 mm, 4.99 to 5.78 mm, 4.60 to 5.44 mm, 5.05 to 5.89 mm, 94.08 to 126.10 g, 39.36 to 48.14%, 1361.66 to 1470.77 kg/m^3 and 29.89° to 37.84° respectively. The sphericity increased from 90.05% to 91.14% with increase in moisture content from 10.28% to 19.67% and decreased from 90.83% to 90.55% with further increase of moisture content from 24.42% to 28.61%. Whereas, bulk density decreased from 829.89 kg/m^3 at 10.28% to 762.75 kg/m^3 at 28.61% moisture content. In the same moisture range, the lowest value of static coefficient of friction recorded when dekoko seed slide against mild steel (0.35 to 0.48,) and the highest value of static coefficient of friction noticed when dekoko seed slide against plywood (0.42 to 0.54). The static coefficient of friction of for galvanized iron increased from (0.37 to 0.51) as moisture increased from 10.28% to 28.61%. Generally, moisture content directly or indirectly affected the physical properties of dekoko seeds.

Keywords: dekoko seed, moisture content, static coefficient of friction, true density, angle of repose

Citation: Tamirat Redae Gebreselassie. 2014. Effect of moisture on physical properties of dekoko (*Pisum sativum var. abyssinicum*) seed. Agric Eng Int: CIGR Journal, 16(2): 143−150.

1 Introduction

Dekoko (*Pisum sativum var. Abyssinicum*) is a cool season crop plant belongs to the family *Fabaceae*. Ethiopia is one of the biggest producers of cool season crops such as beans and peas in Africa. Unfortunately, dekoko seed is the food legume plant cultivated only in northern Tigray region of Ethiopia with the local name of Raya. Due to its delicious taste and growing only in specific areas, the cost of dekoko seed is twice as much as those of the other cool season food legumes.

Grain legumes are protein-rich source of foods which are essential diets in many parts of the tropics particularly where meat is scarce and they play an important nutritional role in supplying essential amino acids especially lysine which is not present in sufficient quantities in staple cereal crops(Giller, 2001). The proximate composition of dekoko seed is reported to be 251 g protein, 19 g fat, 31.7 g total sugar, 370 g starch and 370 g neutral detergent fiber per kg DM. Besides, it contains arginine, asparagine and glutamine in larger proportion collectively contributed about 39% the total amino acids (Yemane and Skjelvag, 2002). Moreover, according to the study of Yemane and Skjelvag (2002), dekoko contains about 7% lysine and 3% sulphur containing amino acid of the total amino acids.

The study of physical properties of seeds as a function of moisture content is an important parameter to design mechanical unit operations which are used to convert crude crops to finished (industrially packed) products.

Received date: 2013-09-26 **Accepted date:** 2014-02-22

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Scherer and Kutzbach, (1978) reported the geometric seed dimensions such as length, width and thickness are important parameter to design sieve openings which are used in separation of foreign materials from desired products using size and shape difference. Bulk density and porosity are crucial properties in the development of aeration and drying systems of as these properties affect the resistance of stored mass to airflow (Jekayinfa, 2006). Separation of lighter particles from heaver particles using cyclone (pneumatic cleaning) depend on the true density of the seed (Tamirat, 2012). Furthermore, designing of conveyors and the slope of storage structures of various seeds depends on static coefficient of friction and angle of repose of the seeds were presented (Sitkei, 1986). However, information on physical properties of dekoko seed as function of moisture content is not reported in any books, articles and published notes. Therefore, the purpose of this study is to find out some of moisture dependent physical properties of dekoko seed such as length, width, thickness, sphericity, true density, bulk density, thousand seed mass, porosity, angle of repose, and static coefficient of friction.

2 Materials and methods

2.1 Determination of moisture content

Determination of moisture content is the primary task in studying the physical properties of dekoko seed. As the seeds were brought from local market, the foreign material and impurities were cleaned manually by hand and locally- made sieves. About 5-10 g of well mixed dekoko seeds were weighed in five replication, samples were dried in a circulating air oven set at 105 ± 2°C for 24 h according to ASAE standards S352.3 (ASAE, 1994). After drying was completed, the samples were removed from the oven and were placed in desiccators for 20 minutes to cool them to room temperature. Finally, the dried samples were weighed accurately using digital electronic balance and the initial moisture content of the dekoko seeds were calculated using Equation (1)

$$m_x = \left(\frac{(m_2 - m_1) - (m_3 - m_1)}{m_2 - m_1} \right) \times 100 \tag{1}$$

where, m_x is the moisture content % of the seed in w.b.

2.2 Conditioning of samples to desired moisture levels

To increase the initial moisture content of the seeds to different desired moisture levels for the study, samples were weighed by digital electronic balance and were conditioned by adding a calculated amount of distilled water based on Equation (2) (Dursun and Dursun, 2005; Tamirat, 2012). This was followed by thorough mixing and sealing in plastic bags,

$$Q = \left(\frac{100 - M_i}{100 - M_f} - 1 \right) W_i \tag{2}$$

where, Q is the mass of water to be added during rewetting in kg.

In order to distribute uniform moisture throughout the samples, samples were stored at 5±1°C for 7 days (Carmen, 1996). As it was mentioned in the above experimental procedure, the moisture content of the samples after equilibration was determined at the time of each experiment and calculated using Equation (1). The required amount of samples were withdrawn from the refrigerator and reconditioned at room temperature for at least an hour before conducting each test (Carmen, 1996). Mean value of five replications was recorded as data obtained.

2.3 Determination of physical properties

2.3.1 Geometric seed dimensions

The mean value of three geometric seed dimensions which are length (major-dimension in y-axis), width (medium-dimension in x-axis) and thickness (minor-dimension in z-axis) of dekoko seed were determined based on 100 randomly selected seeds. A stainless steel digital calliper (model DIN-862, Germany) with an accuracy of 0.01 mm was used to measure these dimensions. The arithmetic and geometric mean diameter were calculated using the relationship in Equation (3) and Equation (4) respectively (Mohsenin, 1986).

$$A_m = \frac{x + y + z}{3} \tag{3}$$

$$\Phi_g = (xyz)^{1/3} \tag{4}$$

where, A_m is the arithmetic mean diameter in mm and Φ_g is the geometric mean diameter in mm.

2.3.2 Sphericity

The sphericity was determined from the ratio of geometric mean diameter and the largest axial dimension of the seed using Equation (5) (Mohsenin, 1986; Tamirat, 2012).

$$\Psi = \left(\frac{\Phi_g}{y}\right) \times 100 \quad (5)$$

where, Ψ is the sphericity of the seed in %.

2.3.3 Thousand Seed mass

The seeds were counted using a seed counter (Numigral-Chopin, France) for thousand seed mass measurement. Random sample dockage free dekoko seed were poured on the hopper grain counter with pre-adjusted reading to 1 000 seeds. The instrument gradually counts 1000 seeds and delivered them into the received bucket. Then, the 1 000 seeds were weighed using a digital electronic balance reading 0.0001 g (Tamirat, 2012).

where, m_{1000} is the thousand Seed mass in gram.

2.3.4 Bulk density

The mass of the seeds filled in a cylinder divided by the volume of cylinder gave the bulk density. In order to measure the bulk density, excess amount of dekoko seeds were filled in to a known volume of stainless steel cylinder to overflowing without compacting the seeds and removed excess seeds by stainless steel ruler on the edge of the container (Zewdu and Solomon, 2007). Bulk density was calculated as is shown in Equation (6)

$$\rho_b = \frac{m_b}{v_c} \quad (6)$$

where, ρ_b is the bulk density in kg/m^3.

2.3.5 True density

True density was determined as the ratio of the mass of the seeds to the true volume of the seeds. True volume of the seeds was determined using liquid displacement method which is toluene ($C_6H_5.CH_3$). Due to low surface tension and less absorption by seeds, toluene is the best liquid for the determination of the true density of seeds than water (Konak et al., 2002 and Tamirat, 2012). True density was calculated as is shown in Equation (7)

$$\rho_t = \frac{m}{v_f - v_i} \quad (7)$$

where, ρ_t is the true density in kg/m^3.

2.3.6 Porosity

The porosity of the dekoko seed was determined using Equation (8) (Mohsenin, 1986).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad (8)$$

where, ε is the porosity in %.

2.3.7 Determination of angle of repose

Zewdu and Solomon (2007) reported method was used. A tapering hopper made of sheet metal with the top and bottom dimension of 300 mm × 300 mm and 100 mm × 100 mm, respectively and a height of 300 mm were used to measure the angle of repose. At 200 mm from the top, a circular disc of 100 mm diameter was fixed so that enough gaps were left between the hopper walls and the disc, which allows the seeds to flow through during the test. A horizontal sliding gate was provided right below the disc for sudden release of the seed during the test. The seeds were filled in the hopper and the horizontal sliding gate was suddenly opened. The height of the seeds piled on the circular disc was measured and used to calculate the angle of repose using Equation (9).

$$\theta = \tan^{-1}\left(\frac{h}{r}\right) \quad (9)$$

where, θ is the angle of repose in degree.

2.3.8 Determination of static coefficient of friction

The static coefficient of friction was determined for three different surfaces (plywood, galvanized iron and mild steel). A plastic cylinder of 155 mm diameter and 105 mm height was filled with the sample and placed on tilting table covered with the different surfaces and scale to read the tilting angle directly. The seed-filled cylinder was raised slightly so that it will not have contact with the surface. The table was raised gradually using a screw device till the cylinder just started to slide down and the corresponding tilting angle, α was recorded. The value of static coefficient fiction was calculated using Equation (10) (Mahapatra et al., 2002).

$$\mu = \tan\alpha \quad (10)$$

where, μ is the static coefficient of friction.

2.3.9 Statistical analyses

The mean values and regression analysis were determined using one-way analysis of variance (ANOVA) using SPSS version 16 (SPSS, 2007)

3 Results and discussion

3.1 Moisture content

Engineers consider moisture content while designing equipments. The initial moisture content dekoko seed was found 10.28% w.b. After calculated amount water was added to four levels of samples, moisture content 14.23%, 19.67%, 24.42% and 28.61% in w.b. were found.

3.2 Geometric seed dimensions

The geometric seed dimension such as length, width and thickness of dekoko seed were studied as the function of moisture content. Hence, 14% increment in length and 15.4% increment in thickness were shown as the moisture content increased from 10.28% to 28.61%. The length, width and thickness of dekoko seed increased significantly (p<0.05) from 5.60 to 6.51 mm, 4.99 to 5.78 mm, and 4.60 to 5.44 mm, respectively. The arithmetic and geometric mean diameters were increased in the same moisture range from 5.06 to 5.91 mm and 5.05 to 5.89 mm respectively. The same experimental investigation has been reported for black-eye pea (Hali et al., 2006). A linear increase with increasing in moisture content of the length and width of tef seed described (Zewdu and Solomon, 2007). Geometric mean diameter of cardamom seed increased from 7.86 to 8.4 mm linearly as the moisture content increase from 9.9% to 23.29% (Tamirat, 2012). The linear relationship between moisture content and the geometric seed dimensions were presented graphically in the (Figure 1) and can be given by Equations (11) to (14).

$$y = 0.046m_x + 5.095 \quad R^2 = 0.96 \tag{11}$$

$$x = 0.041m_x + 4.584 \quad R^2 = 0.99 \tag{12}$$

$$z = 0.041m_x + 4.162 \quad R^2 = 0.93 \tag{13}$$

$$\Phi_g = 0.042m_x + 4.600 \quad R^2 = 0.97 \tag{14}$$

3.3 Sphericity

The sphericity increased from 90.05% at 10.28% moisture content to 91.14% at 19.67% moisture content. However, it decreased from 90.83% at 24.42 % moisture content to 90.55% with further increase the moisture content to 28.61% in w.b. A decrease in sphericity from 70.45% to 62.7% with increasing in moisture content from 5.6% to 21.43% and then increased to 69.32% with further increase in the moisture content to 29.6% has been reported for teff seed (Zewdu and Solomon, 2007). A linear increased in sphericity with increasing in moisture content for cardamom seed with correlation coefficient (R^2=0.98) has been noticed (Tamirat, 2012) and for faba bean with correlation coefficient (R^2=0.99) has been described (Altuntas and Yildiz, 2007). The mathematical regression relationship and graphical representation between sphericity and moisture content are cited in Equation (15) and (Figure 2) respectively.

$$\Psi = -0.009m_x^2 + 0.387m_x + 87.09 \quad R^2 = 0.96 \tag{15}$$

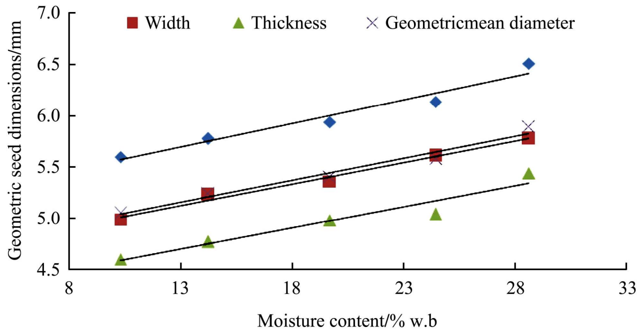

Figure 1 Effect of moisture content on geometric seed dimensions of dekoko seeds

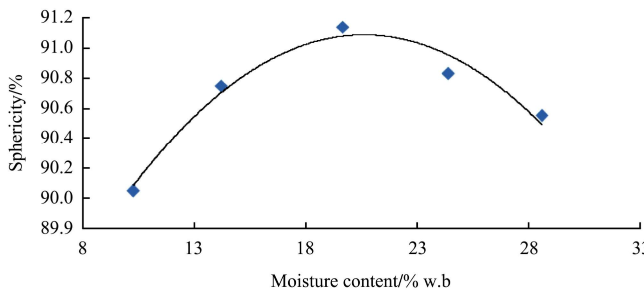

Figure 2 Effect of moisture content on Sphericity of dekoko seeds

3.4 One thousand seed mass

In grain industry, thousand seed mass which is directly proportional to flour yield is taken as quality measuring parameter. Whereas, in engineering design, m_{1000} is used to determined the equivalent diameter which can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces (Seyed et al., 2010). As the moisture content increased from 10.28 to 28.61%, the thousand seed mass of dekoko seed increased from 94.08 to 126.10 g significantly (p<0.05) as shown in the (Figure 3). Similar experimental observation has been confirmed for chick pea (Konak et al., 2002). Moreover, the same practical observation was reported in increasing of thousand seed mass from 0.257 g at 5.6% to 0.421 g at 29.6% w.b for teff seed (Zewdu and Solomon, 2007). The effect of moisture content on thousand seed mass of dekoko seed was found to be linear and was illustrated in Equation (16)

$$m_{1000} = 1.657m_x + 76.56 \quad R^2 = 0.98 \tag{16}$$

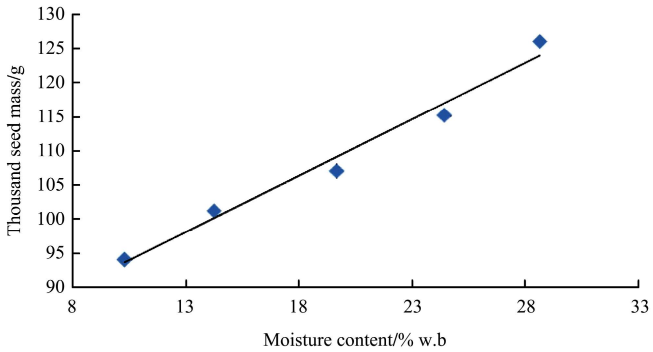

Figure 3 Effect of moisture content on m_{1000} of dekoko seeds

3.5 Bulk and true density

The bulk density that is an important parameter in aeration and drying system of dekoko seed decreased with increase in moisture content. The relative reduction of the bulk density which was not significant (p>0.05) form 829.89 to 762.75 kg/m^3 in the moisture range 10.28% to 28.61% is due to the volumetric expansion bulk of the seed is higher than that of the mass of the seed which gained the water. Whereas, as the moisture content increased from 10.28% to 28.61%, true density that is crucial physical property in separation of desirable particles from undesirable particles increased linearly 1 361.66 to 1 470.77 kg/m^3. A 12.3% linear decrease in bulk density with increasing in the moisture content was observed in green gram (Nimkar and Chattopadhyay, 2001). In agreement to this, a reduction of bulk density with increasing in moisture content is shown for sorghum seeds (Mahapatra et al., 2002) and for wheat, rye, maize, rape seed and barley (Scherer and Kutzbach, 1978). On the other hand, at various moisture levels, the true density of black cumin seed increased linearly with increasing moisture content to 18.75% (Seyed et al., 2010). The effect of moisture content on both bulk and true densities as shown on (Figure 4) described mathematically using Equation (17) and Equation (18) respectively.

$$\rho_b = -3.547m_x + 867.9 \quad R^2 = 0.99 \tag{17}$$

$$\rho_t = 5.598m_x + 1321 \quad R^2 = 0.90 \tag{18}$$

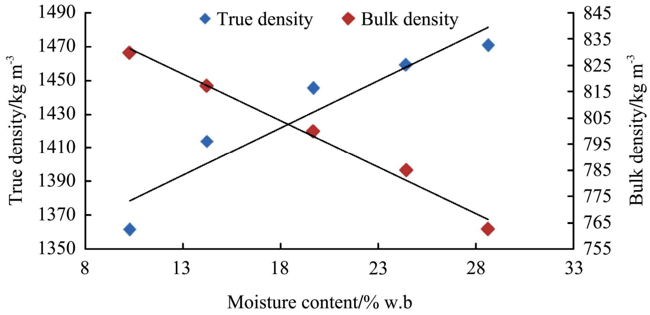

Figure 4 Effect of moisture content on both true and bulk densities dekoko seeds

3.6 Porosity

Porosity expressed as the free air space between the piles of the seeds or void fraction between the heaps of seeds. Porosity is crucial factor in modelling and designing of various heat and mass transfer process applications of drying and cooling. The porosity of dekoko seed increased from 39.36% to 48.14% as the moisture content increase from 10.28% to 28.61% as shown (Figure 5). Similar observations have been reported. Increasing of porosity with increasing moisture content was reported for green gram (Nimkar and Chattopadhyay, 2001) and for rice (Kibar et al., 2010). An increment of 1.68% in porosity with in 10.06% to 35.06% moisture range was noticed for pea seed (Yalcin et al., 2007). Decreasing of porosity with increasing moisture content has been reported for dried pomegranate (Kingsly et al., 2006). The correlation between moisture content and porosity of dekoko seed was found to be linear with positive slope of the Equation (19)

$$\varepsilon = 0.458m_x + 35.19 \quad R^2 = 0.98 \tag{19}$$

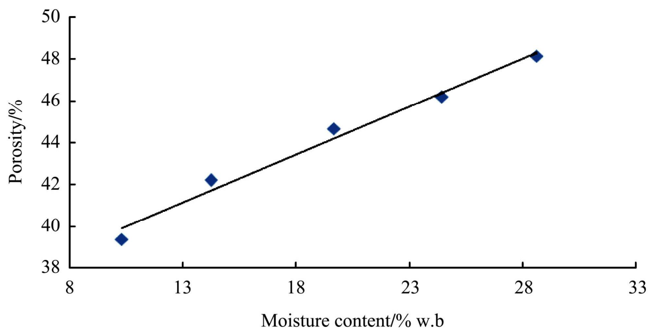

Figure 5 Effect of moisture content on porosity dekoko seeds

3.7 Angle of repose

Practical investigation showed that angle of repose of dekoko seed increased from 29.89° to 37.87° as moisture content increase from 10.28% to 28.61% as shown in (Figure 6). Angle of repose, which is dependent on moisture content, is a critical parameter in designing of hoper openings and slide wall slopes of storage bins (Seyed, et al., 2010). A linear increase in angle of repose with increasing in moisture content has been noted for faba bean (Altuntas and Yildiz, 2007) and experimental investigation indicated that angle of repose of cardamom seed that is higher slope angle than dekoko seed increased from 72.6° to 73.8° in the moisture range 9.9% to 23.29%. This higher angle slope resulted in due to the fact cardamom seed has elliptical shape than circular shape (Tamirat, 2012). Furthermore, other researchers presented that increasing in angle of repose with increasing the moisture content for canola and sunflower meal pellets (White and Jayas, 2001) and barley seeds (Aghajani, et al.,2012) have been reported. A linear relationship between moisture content and angle of repose presented in Equation (20)

$$\theta = 0.417 m_x + 25.83 \quad R^2 = 0.94 \tag{20}$$

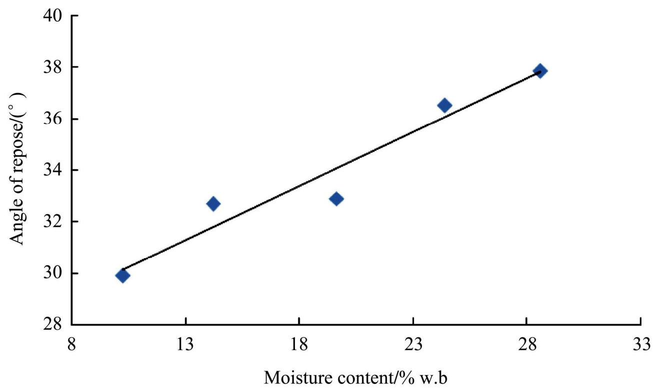

Figure 6 Effect of moisture content on angle of repose of dekoko seeds

3.8 Static coefficient of friction

The coefficient of static friction determined at different moisture content levels on three different surface materials of plywood, galvanized iron and mild steel increased following a linear relationship as moisture content increased from 10.28% to 28.61% for both surfaces (Figure 7). The highest static coefficient of friction was recorded when the dekoko seed was against plywood (0.42 to 0.54). However, the lowest static coefficient of friction was noticed when the dekoko seed was against mild steel (0.35 to 0.48). The static coefficient of friction between dekoko seed and galvanized iron surface increased from (0.37 to 0.51) as the moisture content increased from 10.28 to 28.61%. The trend observed was in agreement with the studies made on (Konak et al., 2002; Mahapatra et al., 2002; Sahoo and Srivastava, 2002). The relationship between static coefficient of friction and moisture content was found to be linear as is shown in Equation (21 to 23).

$$\mu_{pw} = 0.006 m_x + 0.352 \quad R^2 = 0.96 \tag{21}$$

$$\mu_{gi} = 0.008 m_x + 0.279 \quad R^2 = 0.97 \tag{22}$$

$$\mu_{ms} = 0.007 m_x + 0.264 \quad R^2 = 0.98 \tag{23}$$

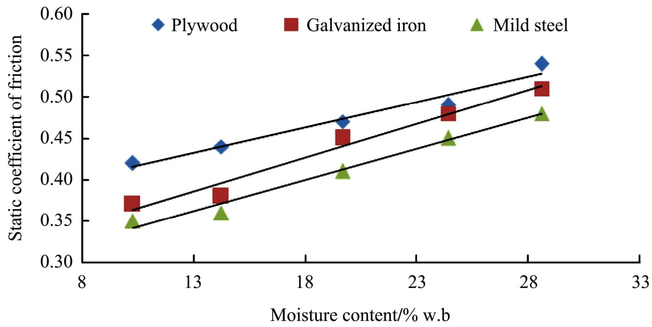

Figure 7 Effect of moisture static coefficient of friction of dekoko seed

4 Conclusions

Through a series of experimental analyses in this study, the following conclusions were drawn on the effect of moisture content on dekoko seeds. The geometric seed dimensions of dekoko seed increased with increasing moisture content. The relative reduction of bulk density from 829.89 to 762.75 kg/m^3 with increasing in moisture content confirm that the increasing in mass resulting from the moisture gain of the seed sample is lower than that of the volumetric expansion of the seed. Whereas, the increase in true density from 1 361.66 to 1 470.77 kg/m^3 could be attributed to the relative lower true volume of the seed as compared to the corresponding mass of the seed which absorbed water. The porosity and angle of repose of the dekoko seed increased as the moisture content increase from 10.28% to 28.61%. The sphericity increased from 90.05% to 91.14% with increasing moisture content from 10.28% to 19.67% and decreased from 90.83% to 90.55% with further increasing of moisture content from 24.42% to 28.61%. The static coefficient of friction of dekoko seeds increased with increasing in moisture content from 10.28% to 28.61% on three different surfaces. The highest static coefficient of friction was noticed when dekoko seeds were touched the plywood (0.42 to 0.54) this also result in due to higher resistance the flow of the seed against the plywood and the lowest static coefficient of friction was recorded when the dekoko seeds were slide against mild steel (0.35 to 0.48). The static coefficient of friction between dekoko seeds and galvanized iron surface increased from 0.37 to 0.51 within the studied moisture content range. From the experimental findings, it generalized that moisture content is affected the physical properties of dekoko seed which are important parameters needed to design the processing unit operations such as mechanical and pneumatic cleaning, transportation or conveying, processing and storage.

Acknowledgments

I would like to express my profound gratitude to Professor Yeong Joong Jeon for supporting me financially and I would like to extend my thanks to Mechanical Engineering department technicians and Chemical Engineering staffs for unlimited support during my research works.

Nomenclatures

m_1 container weight, g

m_2 container + sample weight before drying, g

m_3 container + sample weight after drying, g

M_i initial moisture content of the sample, % w.b.

M_f final moisture content of the seed sample, % w.b.

W_i initial mass of the sample of to be rewetted, kg

y length of the seed, mm

x width of the seed, mm

z thickness of the seed, mm

m_b the mass of the seed filled in cylinder, g

V_c the volume of cylinder, cm^3

ρ_t true density, kg/m^3

m the mass of seed, g

V_i initial volume of toluene, mL

V_f the sum of the initial volume of toluene (V_i) plus volume of the seed, mL

R coefficient of determination

h height of piled seed in the determination of angle of repose, mm

r radius of disc in the determination of angle of repose, mm

α angle of tilt in determination of static coefficient of frication, deg

μ_m static coefficient friction of the seed on mild steel surface

μ_{gi} static coefficient of friction of the seed on galvanized iron surface

μ_{pw} static coefficient of friction of the seed on plywood surface

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