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Physical properties of high quality maize (Swam 1 variety) seeds (*Zea mays*) as affected by moisture levels

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A study was conducted to evaluate the physical properties that affect equipment design, processing, storage and transportation of high quality protein maize (SWAM 1) seeds as a function of moisture content varying from 9.38 to 32.7% (db). The length, width, thickness and the geometric diameter increased linearly from 9.80 to 10.55, 8.60 to 9.06, 4.00 to 4.75 and 6.85 to 7.69 mm, respectively. The sphericity index, seed volume, seed surface area and thousand seed mass also increased linearly from 69.89 to 72.85, 99.36 to 138.56 mm, 124.55 to 157.76 mm^2 and 240.36 to 303.71 g, respectively. Bulk density, true density and porosity decreased linearly from 1.109 to 1.057 g/m^3 1.365 to 1.176 g/m^3 and 18.75 to 10.12%, respectively. Static coefficient of friction was found to increase on plywood, galvanized iron, aluminium and stainless steel surfaces and it increased logarithmically from 0.55 to 0.91; 0.52 to 0.81, 0.49 to 0.70, and 0.46 to 0.68, respectively. Angle of repose increased linearly on plywood, galvanized iron, aluminium and stainless steel surfaces from 18.91 to 29.05, 17.00 to 26.96, 15.93 to 23.98 and 15.55 to 22.19°, respectively.

Key words: High quality maize (SWAM 1), moisture content, physical properties.

INTRODUCTION

Maize (*Zea mays* L.) which is also referred to as corn is the most important cereal next to wheat and rice and it is widely distributed throughout the world (Ahn, 1993). It belongs to the tribe Tripsceae and family Gramineae. The stalk, leaves, silk, cob and kernels have a commercial value, with that of the kernel being the largest (Kochhar, 1981). Many areas of Africa are very suited to the crop and it has largely replaced traditional grains such as sorghum and millet (Ahn, 1993). In industrialized countries, maize is largely used as livestock feed and as raw material for industrial products, while in developing countries, it is mainly used for human consumption. Maize is an important source of carbohydrates, protein, iron, vitamin B and minerals. Africans consume maize as a starchy base in a wide variety of porridges, pastes, grits

and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled; and is playing an important role in filling the hunger gap after the dry season. The major varieties of corn are pod, flint, dent, sweet, pop, flour and waxy (Staackmann and Matz, 1977) and is a major staple food in Nigeria where it is utilized by the food industry in the manufacture of weaning foods.

The knowledge of physical properties constitutes important and essential engineering data in the design of machines, storage structure and processes. The value of this basic information is not only important to engineers but also to food scientist, processors and other scientists who may want to exploit these properties and find new uses (Işik and Ünal, 2007). Determination of physical properties as a function of moisture content are important to design equipment for handling, conveying, separation, drying, aeration, storing and processing (Sobukola and Onwuka, 2011). The size and shape are, for instance, important in their separation from undesirable materials and in the development of sizing and grading machinery

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(Mohsenin, 1970). The shape of the material is important for an analytical prediction of its drying behavior (Işik and Ünal, 2007). Bulk density, true density and porosity are major consideration in designing the drying and aeration and storage systems, as these properties affect resistance to air flow of the mass (Amin et al., 2004).

Information on the coefficient of friction is used in designing equipment for solid flow, storage systems, seed harvesting and handling systems (Amin et al., 2004) while angle of repose is used to study the flowability of seeds and other powdery materials on various surfaces. The angle repose is important in designing equipment for mass flow and structures for storage (Isik and Unal, 2007). These properties have been studied for various crops such as African breadfruit seeds (Omobuwajo et al., 1999); sorrel seeds (Omobuwajo et al., 2000); bambara groundnut (Baryeh, 2001); groundnut kernels (Olajide and Igbeka, 2003); hazel nut (Ozdemir and Akinci, 2004); rape seed (Calisir et al., 2005); green wheat (Al-Mahansneh and Rababah, 2007); white speckled red kidney bean grains (Isik and Unal, 2007); and recently locust bean seed (Sobukola and Onwuka, 2011). High quality maize such as SWAM 1 is a useful industrial raw material especially in the production of weaning foods, bakery products and its starch is used for industrial application. Hence, there is need for detailed information on the physical properties of these maize seeds within the moisture content range for storage and processing. Therefore, the objective of this study was to investigate some physical properties of maize hybrid (SWAM 1) seeds at different moisture contents. The properties investigated include principal dimensions, effective diameter, one thousand seed mass, sphericity, bulk and true densities, porosity, angle of repose and coefficient of static friction.

MATERIALS AND METHODS

Materials and preliminary operation

The high quality maize seeds recently developed (SWAM 1 variety) were obtained from Research and Development Centre (RESDEC) now Institute of Food Security, Environmental Resources and Agricultural Research (IFSERAR) of the University of Agriculture, Abeokuta, Nigeria. They were cleaned manually to remove all unwanted materials such as chaffs, cobs, stones, insects and damaged or unhealthy seeds. The initial moisture content was determined by oven drying method at 105 ± 1°C for 24 h (AOAC, 1980) and was found to be 9.38% (db). In order to obtain maize seed of different moisture levels (9.38, 16.92, 19.93, 24.70, 27.89 and 32.70%) applicable during processing, the method reported by Sobukola and Onwuka (2011) was used. After conditioning, the seeds were kept in polyethylene bags and placed in the refrigerator at 5°C for equilibration to occur. Similar methods have been used by Karababa and Coşkuner (2007). Before starting a test, the required quantity of seed was taken from the refrigerator and allowed to equilibrate to the room temperature for about 2 h (Singh and Goswami, 1996; Cetin, 2007). All measurements (except principal dimensions) were obtained in 10 replicates at the six moisture levels, while principal dimensions were obtained at 100 replicates at the different moisture levels.

Determination of physical properties

The thousand seed mass of the seeds were determined at the six moisture levels. It was determined by direct weighing of clean 1000 seeds of SWAM 1 at each moisture level by means of an electronic balance (Mettler, model AE 240, Switzerland) with an accuracy of 0.001 g (Aviara et al., 1999).

The three linear dimensions namely length L, width W and thickness T, of the seeds at the different moisture levels were measured using a micrometer screw gauge (Model 436-25M, Starret, Brazil) to an accuracy of 0.01 mm. Effective diameter, (De), sphericity, (Φ), kernel volume (V) and surface area (S) were calculated as a function of the linear dimensions.

The effective diameter (De) of the seed at the six different moisture levels was calculated using the following formula (Jain and Bal, 1997):

$$De = (LWT)^{1/3} \tag{1}$$

According to Mohsenin (1970), the degree of sphericity (Φ) was calculated using the expression below:

$$\Phi = \frac{(LWT)^{1/3}100}{L} \tag{2}$$

Jain and Bal (1997) have reported that kernel volume, V and kernel surface area S can be estimated using relationship (3) and (4):

$$V = \frac{\pi B^2 L^2}{6(2L-3)} \tag{3}$$

$$S = \frac{\pi B L^2}{2L-B} \tag{4}$$

Where

$$B = (WT)^{0.5} \tag{5}$$

The bulk density is the ratio of the mass sample of the kernels to its total volume. It was determined by filling a 500 ml container with seeds from a height of 150 mm, striking off the top level without the seeds being compacted in any way and then the content was weighed (Singh and Goswami 1996). Bulk density was then calculated as a ratio between the kernel weight and the volume of the cylinder as shown in equation 6:

$$\rho_b = \frac{Kernel weight}{500ml} \tag{6}$$

The true density (ρ_t) was determined using toluene displacement method. Toluene was used in place of water because it is absorbed by seeds to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Aydin, 2002). 500 ml of toluene was placed in a 1000 ml graduated measuring cylinder. 300 g of seed were then immersed in toluene. The amount of displacement was recorded. True density (ρ_t) was obtained as the ratio of kernel weight to volume of displaced toluene (Aviara et al., 1999; Ogunjimi et al., 2002; Omobuwajo et al., 1999).
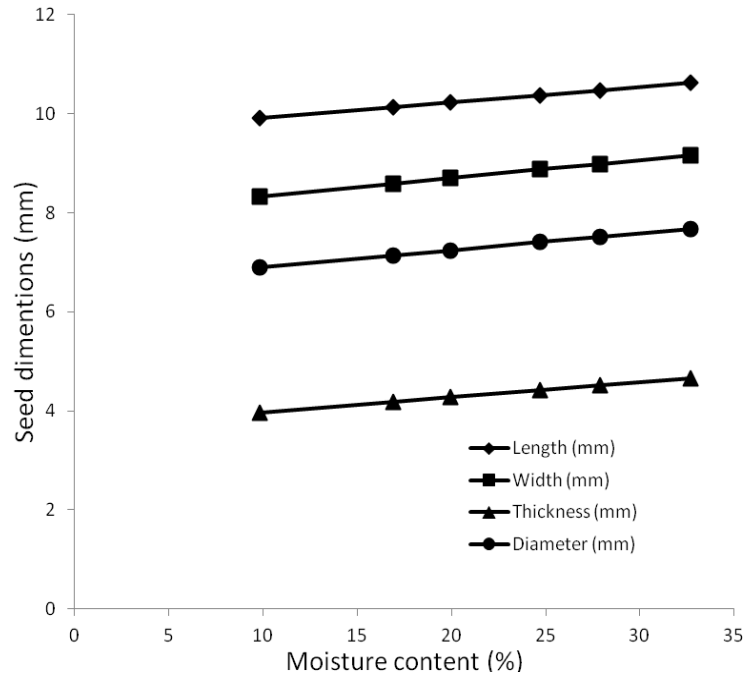
Figure 1. Effect of variation in moisture content on seed dimensions of SWAM 1 maize.

$$\rho_t = \frac{30g}{V_2 - V_1} \qquad (7)$$

Where, V_2 = Final volume and V_1 = initial volume.

Porosity (ε) was calculated using the relationship between bulk and true densities according to Mohsenin (1970) as follows:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (8)$$

Where, ρ_t = true density; ρ_b = bulk density.

The static coefficient of friction which is a dimensionless quantity used to calculate the force of friction was determined on four surfaces: plywood, galvanized iron, aluminium and stainless steel. These materials are common materials used for handling and processing of agricultural seeds and construction of storage and drying bins. This was measured using a hollow metal cylinder 50 mm in diameter and 50 mm high and opened at both ends. It was filled with seeds at the desired moisture content and placed on an adjustable tilting table such that the metal cylinder did not touch the table surface. The tilting surface was raised gradually by means of a screw device until the cylinder just started to slide down. The angle of the surface was read from a scale and coefficient of friction (μ) was taken as the tangent of this angle (Dutta et al., 1988; Joshi et al., 1988; Singh and Goswami, 1996).

$$\mu = \text{Tan } \alpha \qquad (9)$$

Where μ = coefficient of the static friction and α = the angle of tilt in degrees.

The dynamic angle of repose or the emptying angle was determined on four surfaces namely plywood, galvanized iron, stainless steel and aluminium sheet. This was determined by using a topless and bottomless cylinder of 30 cm diameter and 50 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 70 cm and was filled with the seeds. The cylinder was raised slowly until it formed a cone on a circular plate. The height of the cone was measured carefully with a meter rule while the base radius traced out was also measured with a divider (Maduka and Faborode, 1990; Owolarafe et al., 2007). The angle of repose (θ) was estimated using the relationship below:

$$\theta = \frac{Tan^{-1}(2H)}{D} \qquad (10)$$

Where H = height of the cone; D = diameter of the cone; θ = angle of repose.

RESULTS AND DISCUSSION

The variations of axial dimensions (L, W and T) and De of SWAM 1 maize seeds with respect to moisture levels are shown in Figure 1. All dimensions increased linearly as moisture levels increased. The increase was from 9.8 to 10.5 mm (7.14% increase), 8.2 to 9.06 mm (10.49% increase), 4.00 to 4.75 mm (18.75% increase) and 6.85 to 7.69 mm (12.2% increases) for L, W, T and De, respectively when moisture levels increase from 9.38 to 32.70%.   The linear relationship between the axial dimensions (L, W and T), De and moisture levels (M_c) are shown below:
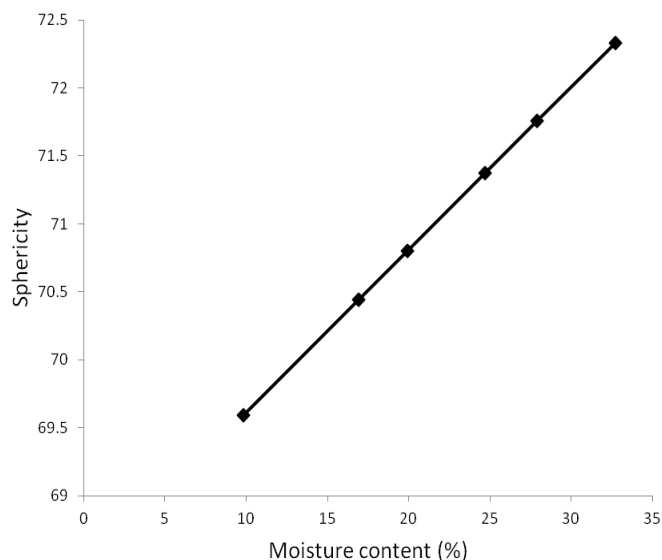
Figure 2. Effect of variation in moisture content on sphericity of SWAM 1 maize.

Figure 3. Effect of variation in moisture content on thousand seed mass (g) of SWAM 1 maize.

$$L = 0.0309\,M_c + 9.6105\ (R^2 = 0.9202) \quad (11)$$

$$W = 0.0364\,M_{c\,+}\,7.975\quad (R^2\ 0.8934) \quad (12)$$

$$T = 0.0301\,M_c + 3.6732\ (R^2 = 0.8896) \quad (13)$$

$$De = 0.0342\,M_c + 6.5603 \qquad (R^2 = 0.923) \quad (14)$$

Where, Mc is the moisture level (%)

The increase in linear dimension may be due to the fact that as moisture content increases, these seeds tend to swell due to moisture absorption. The effective diameter of maize seeds was found to be higher than the thickness of the seeds. Similar findings were reported for millet (Jain and Bal, 1997), sakiz faba beans (Haciseferoğullari et al., 2003); popcorn kernels (Karababa et al., 2003) and sweet corn (Karababa and Coşkuner, 2007).

The sphericity index (Φ), variation with moisture levels of maize seed is shown in Figure 2. The values of Φ for different moisture levels increased linearly from 69.898 to 72.852 (4.24% increase) as moisture level increased from 9.38 to 32.70%. The Φ of maize is higher than the values reported for grain wheat (Karababa and Coşkuner, 2007); barbunia bean seed (Cetin, 2007) and safflower (Baumler et al., 2006). Such high values suggested that these high quality maize might be expected to roll rather slide on the surface and this is a property quite important in the design of grain hoppers (Al-Mahasneh and Rababah, 2007). It indicated maize seeds can be treated as sphere for an analytical prediction of their drying behavior. The mathematical relationship between moisture level and Φ is given below:
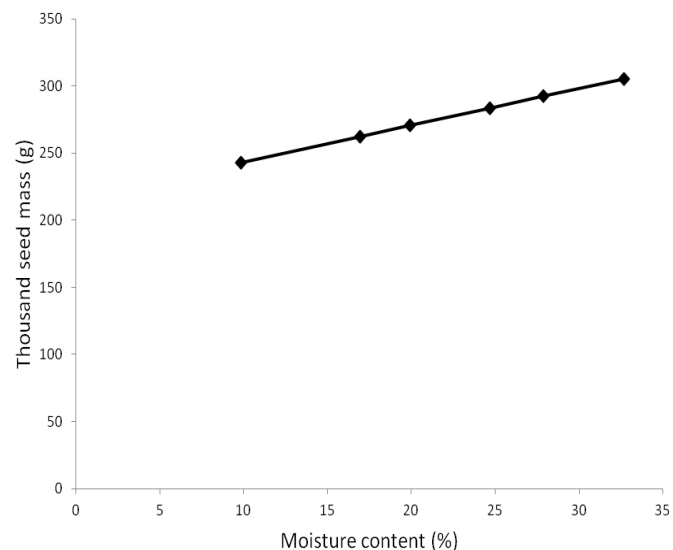
$$\Phi = 0.1197 M_c + 68.418\ (R^2 = 0.8432) \quad (15)$$

The one thousand maize seed mass was found to increase linearly from 240.36 to 303.71 g (26.36% increases) as moisture level increased from 9.38 to 32.70% as shown in Figure 3. The linear relationship between a thousand mass and moisture level is expressed as Equation 16.

$$M_{1000} = 2.7376 M_c + 216.04\ (R^2 = 0.9845) \quad (16)$$

Deshpande et al. (1993), Öğüt (1998), Baryeh (2001), Mahapatra et al. (2002), Dursun and Dursun (2005) and Cetin (2007) have also found similar relationship to be true for soybeans, white lupin, bambara groundnut, sorghum, caper seed and barbunia beans, respectively.

The variation of kernel volume (V) and surface area (S) with seed moisture content for SWAM 1 seeds are displayed in Figures 4 and 5, respectively. The volume of seeds increased linearly from 99.36 to 158.56 mm³ (39.45% increase) with increase in moisture level from 9.38 to 32.70%. The linear relationship between V and moisture content is shown in Equation 17.

$$V = 1.6076\,M_c + 84.976\ (R^2 = 0.9729) \quad (17)$$

Similar results have been reported for popcorn (Karababa, 2006); safflower (Baumler et al., 2006); millet (Baryeh, 2002); rape seed (Calisir et al., 2005); sweet corn (Karababa and Coşkuner, 2007) and white lupin (Öğüt, 1998). The kernel surface area increased linearly with increase in moisture content of the seeds. There was an increase from 124.58 to 157.76mm² (26.60% increase)
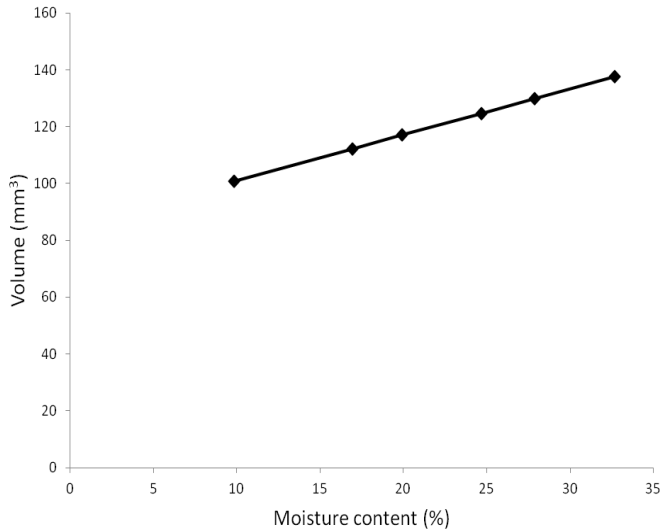
Figure 4. Effect of variation in moisture content on volume of SWAM 1 maize.
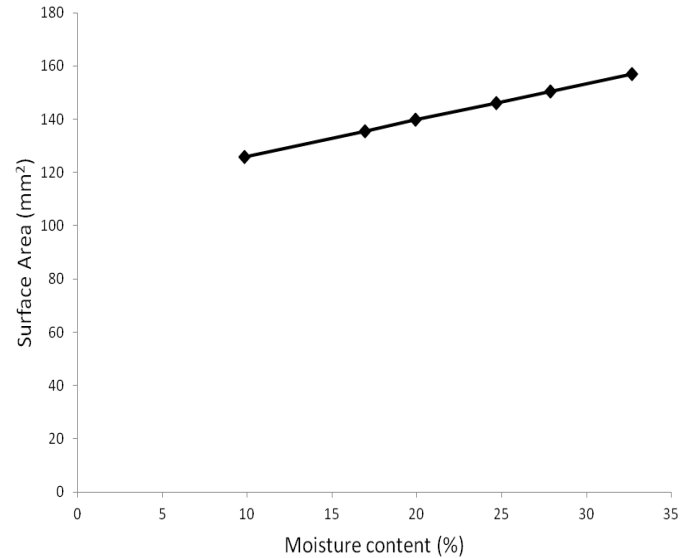

Figure 5. Effect of variation in moisture content on surface area of SWAM 1 maize.
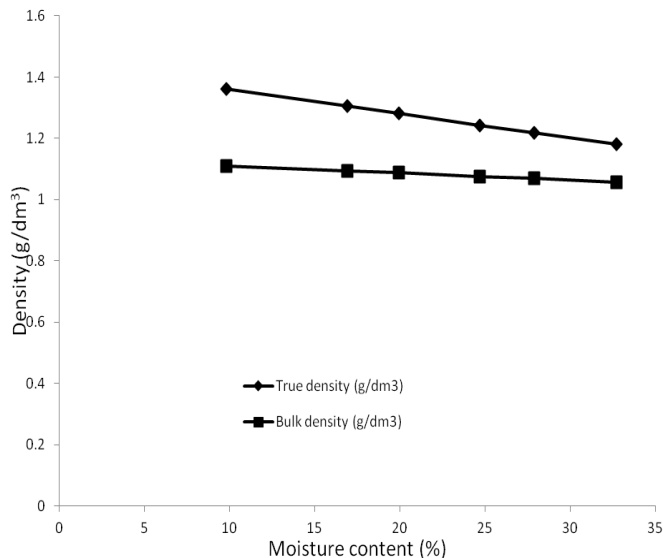

Figure 6. Effect of variation in moisture content on density of SWAM 1 maize.

as moisture content increased from 9.38 to 32.70%. The linear relationship between the surface area and the moisture content of maize seeds can be represented by the equation below:

$$S = 1.3612\ M_c + 112.58\ (R^2 = 0.9731) \tag{18}$$

Similar relationship was reported for popcorn (Karababa, 2006); sweet corn (Karababa and Coskuner, 2007) and millet (Baryeh, 2002). The ratio between volume and sur-

face area is usually called the characteristic length. Characteristic length has important role in the case of irregular shape objects. Some of its applications include determination of projected area of particles moving in turbulent air stream, which can be useful in designing grain cleaners, separators and pneumatic conveyors. As the ratio between surface area and volume increases, the rate of heat and mass transfer from kernel increases, which affects several unit operations such as drying, cooling and heating.

The variations of bulk density, (ρ_b) and true density (ρ_t) of maize seeds with moisture levels are shown in Figure 6. The bulk densities were observed to decrease linearly from 1109 to 1057 kg/mm^3 (4.69% increase) as moisture level increased from 9.38 to 32.70%. The linear relationship between bulk density and moisture level can be expressed by Equation 19.

$$\rho_b = -0.0023\ M_c + 1.1328\ (R^2 = 0.9425) \tag{19}$$

This decrease was due to the higher rate of increase in volume relative to the increase in weight. Similar relationships have been reported for white lupin (Öğüt, 1998), gram seed (Chowdhury et al., 2001), millet (Baryeh, 2002), chicken pea (Konaki et al., 2002), rape seed (Calisir et al., 2005), safflower (Baumler et al., 2006) and sweet corn (Karababa and Coşkuner, 2007). However, linear increasing trends were reported for sunflower (Gupta and Das, 1997), coffee (Chandrasekar and Viswanathan, 1999), cashew nut (Balasubramanian, 2001) and pistachio (Kashaninejad et al., 2006).

The true density of maize decreased linearly from 1365 to 1176 kg/m^3 (13.85% decrease) with increasing moisture
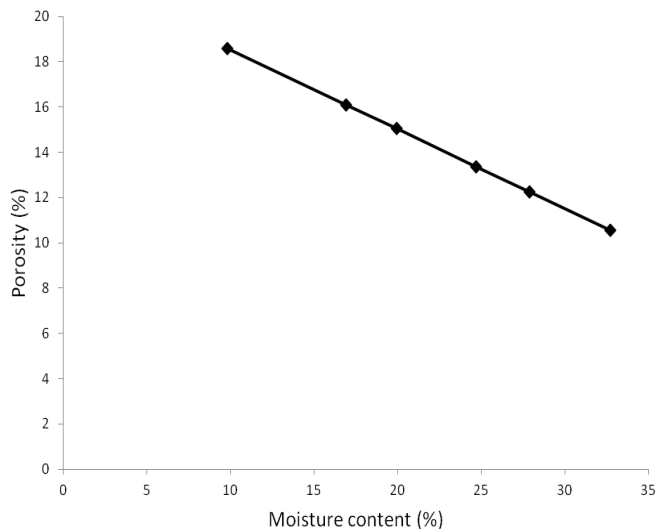
Figure 7. Effect of variation in moisture content on porosity of SWAM 1 maize.

Figure 8. Effect of variation in moisture content on angle of repose on various surfaces of SWAM 1 maize.

content from 9.38 to 32.70%. The linear relationship can be represented by Equation 20:

$$\rho_t = -0.0079\,M_c + 1.4384\ (R^2 = 0.9944) \tag{20}$$

This decrease in true density may be due to higher rate of increase in seed volume relative to weight increase. Similar results were reported for gram seed (Chowdhury et al., 2001), chicken pea (Konaki et al., 2002), hazel nut (Aydin, 2002), popcorn (Karababa, 2006) and sweet corn (Karababa and Coşkuner, 2007). However, a linear increasing trend was reported for sunflower (Gupta and Das, 1997), white lupin (Öğut, 1998), coffee (Chandrasekar and Viswanathan, 1999), cashew nut (Balasubramanian, 2001), millet (Baryeh, 2002) and cacao (Bart-Plange and Baryeh, 2003). Thus, these seeds have lower weight increase in comparison with volume increase as their moisture content increases. At all moisture levels, it was observed that true density was greater than bulk density. Similar relationships have been reported for sweet corn (Karababa and Coşkuner, 2007) and barbunia beans (Cetin, 2007).

Porosity (ε) was calculated as a function of the bulk density and true density of the seeds. The porosity was found to decrease linearly from 18.75 to 10.12% (46.03%) with increase in moisture level from 9.38 to 32.70% as shown in Figure 7. A linear relationship between ε and varying moisture level was obtained by Equation 21.

$$\varepsilon = -0.3511\,M_c + 22.042\ (R^2 = 0.9783) \tag{21}$$

Higher porosity provides better aeration and water vapour diffusion during deep bed drying. Similar trend was re-

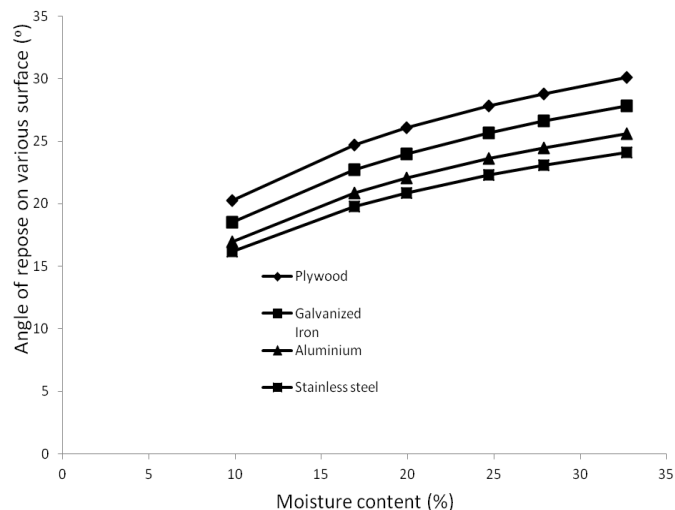ported for hazel nut (Aydin, 2002), gram (Dutta et al., 1988), sunflower (Gupta and Das, 1997) and popcorn (Karababa, 2006). However, porosity was reported to increase with increase in moisture content for millet (Baryeh, 2002), rape seed (Calisir et al., 2005) and soybeans (Desphande et al., 1993).

The angle of repose, (θ), of maize seeds increased logarithmically from 18.91 to 29.05° (53.62% increase); 17.00 to 29.96° (58.59% increase); 15.95 to 23.98° (50.53% increase) and 15.15 to 22.19° (39.87% increase) on plywood, galvanized iron, aluminium and stainless steel sheet surfaces with increase in moisture content from 9.38 to 32.70% (Figure 8). The logarithmic relationship between θ and moisture content on plywood (PW), galvanized iron (GFe), aluminium (Al) and stainless steel sheet (SS) can be represented by the following equations:

$$\theta_{PW} = 8.2006\ \ln(M_c) + 1.5173\ (R^2 = 0.8967) \tag{22}$$

$$\theta_{GFe} = 7.732\ \ln(M_c) + 0.8625\ (R^2 = 0.8403) \tag{23}$$

$$\theta_{Al} = 7.2013\ \ln(M_c) + 0.5049\ (R^2 = 0.9141) \tag{24}$$

$$\theta_{SS} = 6.6015\ \ln(M_c) + 1.109\ (R^2 = 0.8991) \tag{25}$$

At higher moisture content, seeds tend to stick together resulting in better stability and less flowability and hence, resulting in increase in the angle of repose. Similar trends have been observed for chick pea (Konak et al., 2002); okra (Sahoo and Srivastava, 2002); green gram (Nimkar and Chattopadhyay, 2001); canola and sunflower meal pellets (White and Jayas, 2001) and arecanut kernels (Kaleemullah and Gunasekar, 2002). At all moisture levels,
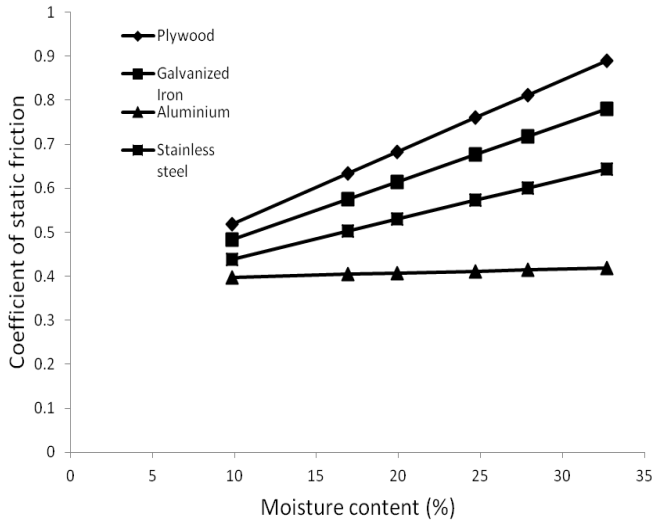
Figure 9. Effect of variation in moisture content on coefficient of static friction of SWAM 1 maize.

the highest angle of repose was on plywood followed by galvanized iron and then aluminium sheets. The least angle of repose was on stainless steel and this may be because of smoother and more polished surface of the stainless steel sheet relative to other materials used, thus causing the seeds to form flatter piles. Consequently, the data on frictional properties will be useful in hopper design for gravity flow, since the angle of inclination of the hopper walls should be greater than angle of repose to ensure continuous flow of the material.

Variations of static coefficient of friction (μ) of high quality maize seeds with moisture level for different surfaces are displayed in Figure 9. The static coefficient of friction on the four surfaces (plywood, galvanized iron, aluminium and stainless steel) increased linearly with increase in moisture level. It increased from 0.55 to 0.91 (65.45% increase); 0.52 to 0.81 (55.78% increase); 0.49 to 0.70 (42.86% increase) and 0.48 to 0.68 (41.67% increase) on plywood, galvanized iron, aluminium and stainless steel surfaces, respectively as moisture level increased from 9.38 to 32.70%. The mathematical relationship between μ and moisture level on plywood (PW), galvanized iron (GFe), aluminium (Al) and stainless steel sheets (SS) can be represented by the following equations:

$$\mu_{PW} = 0.0162 M_c + 0.3599 \ (R^2 = 0.9580) \tag{26}$$

$$\mu_{GFe} = 0.0131 M_c + 0.3549 \ (R^2 = 0.9135) \tag{27}$$

$$\mu_{Al} = 0.00094 M_c + 0.3885 \ (R^2 = 0.9619) \tag{28}$$

$$\mu_{SS} = 0.009 M_c + 0.3500 \ (R^2 = 0.8713) \tag{29}$$

The increase in μ with increase in moisture level may be

due to the adhesion between the seed and the material surfaces at higher moisture levels. At all moisture levels, the least static coefficient was on stainless steel. This may be because of the smoother and more polished surface of the stainless steel relative to other materials used. The static coefficient of friction at all moisture level was highest on plywood followed by galvanized iron and aluminium. This can be attributed to the surface roughness which is largest on plywood. This order has been reported for pumpkin seeds (Joshi et al., 1988); cumin seeds (Singh and Goswami, 1996); sunflower (Gupta and Das, 1997), bambara groundnuts (Baryeh, 2001) and sweet corn (Karababa and Coşkuner, 2007). However, Amin et al. (2004) reported that no variation existed between plywood and galvanized iron for pulse grains. Tunde-Akintunde and Olajide (2005) also reported low static coefficient of friction values on plywood for soybean as compared to results obtained for maize and locust bean seeds in this work. Tsang-Mui-Chung et al. (1984), Dutta et al. (1988) for gram seed, Joshi et al. (1988) for pumpkin seeds, Carman (1996) for lentil seeds, Öğüt (1998) for white lupin and Aydin (2002) for hazel nuts reported that as moisture level increased, static coefficient of friction increased. This is because, the seeds may become rough and static coefficient of friction is increased.

Conclusions

Axial dimensions (length, width and thickness), geometric mean diameter, mass of 1000 seeds, surface area, volume and sphericity of high quality maize seeds (SWAM 1) was observed to increase linearly with increase in moisture levels. The bulk density, true density and porosity however decreased linearly with increase in moisture levels. Static coefficient of friction of the seeds on all surfaces increased linearly, while the angle of repose increased logarithmically with increase in moisture contents.

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