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RESEARCH PAPER

Effect of moisture content on some physical properties of maize and cowpea

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Abstract

Moisture dependent physical properties of maize and cowpea were investigated. The geometric, gravimetric and frictional properties were measured at different levels of moisture content from 7.9 to 14.6% db. for maize and 6.9 to 15.4% db. for cowpea. The results obtained showed that the changes in moisture content of maize and cowpea lead to minimum variation in geometric properties. The principal dimensions such as length, width, thickness, geometric mean diameter and surface area increased linearly while volume, weight and sphericity of maize and cowpea increased in a non-linear manner with increase in moisture content. An increase in bulk density and true density was observed whereas the porosity decreased nonlinearly in the fixed range of moisture content (7.9, 9.3, 9.9, 12.3 and 14.6 db.) for maize and (6.9, 9.4, 10.6, 12.5 and 15.4% db.) for cowpea. The highest angle of repose were found on the mild steel followed by galvanize steel and stainless steel.

Keywords: Geometric mean diameter, principal dimension, grading, processing, storage.

Introduction

Cowpea, like other grain legumes is an important foodstuff in tropical and subtropical countries (Chinma *et al*., 2008) because of its use mainly, as a grain crop, a vegetable or fodder for animals. Cowpea is highly valued for its ability to tolerate drought and the high protein content of about 25% (IITA, 2007). These qualities make it a choice crop for catering for the food security needs of societies. Maize has a wide range of production adaptability. Foods produced from it include; roasted maize, *langbe, guguru, aadun, tanfirin, tuwo massara, nni oka, ukpo oka, kokoro, kanu massara, fura, abari, kango, abodo, ogi, eko and kanjika* (Akubor, 2005). According to Enwere (1998), maize is richer in oil than any other cereal crop except oat and millet. It is high in calorie, carbohydrate, potassium, sodium, chlorine and sulphur. When considered as a whole, protein in maize is low in lysine, tryptophan but fair in sulphur containing amino acids such as methione and cysteine (Adebayo and Emmanuel, 2001). Information on physical properties of maize, like other agricultural materials, is necessary to design equipment for grading, handling, processing and storage etc. To design machines for cleaning, grading, sorting and packing etc., size and shape such as geometric mean diameter and sphericity are necessary to be known. The surface area and porosity are required to evaluate the rate of heat transfer for heating and drying and thus to design heat exchangers and driers etc. Bulk density, true density and porosity are required for the design of aeration, storage, transport and separation systems.

The design of post-harvest handling and processing machinery for cereals and grains depend greatly on the physical characteristics of the product. The physical characteristics are also in turn dependent on the moisture content and drying time of the grains. The physical properties are indispensable in tackling critical issues that have to do with the design of machines by enhancing the storability and increase the threshing, handling and processing of maize and cowpea.

This study seeks to examine the effect of moisture content on the size and shape properties, 1000-grain mass, filling and emptying angle of repose, bulk density, true density, static coefficient of friction and porosity of maize and cowpea varieties.

Materials and Methods

Sample preparation and procurement

The seed materials used for this research work were cowpea (*Phaseolus Vulgaris*) and maize (*Zea mays L.*) seeds. These grains were procured from Agricultural Development Program (ADP) office Alagbaka, Akure, Ondo state. Laboratory equipment used included measuring cylinder, weighing balance, tilting box, vernier caliper and oven. In order to determine 1000-unit mass (m1000), hundred (100) grains were selected randomly and weighed (Figures 1and 2). True-density (Td), bulk-density (bd) and volume (V) were determined using the displacement in liquid method. The initial moisture contents of the samples were noted on dry basis. The samples were then moistened to increase the moisture content, by adding known (calculated) quantity of water using Equation 1 (Zareiforoush *et al*., 2010).

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

Where Q is the mass of water to be added (kg), W_i is initial weight of the sample (kg), M_i is the initial moisture content of the sample (%, d.b), M_f is the final moisture content of the sample (%, d.b). The moistened samples were sealed in high density poly ethylene bags and kept in a refrigerator at 5±10ºC for 24 hours for uniform moisture distribution throughout the samples (Davies and El-Okene, 2009).

Figure 1: Cowpea seeds

Figure 2: Maize seeds

Determination of physical properties of seeds

Size

The method of random sampling similar to the one used by (Dutta *et al.*, 1999) was used for the seeds. Three principal dimensions namely; length, width and thickness were measured using a micro-screw gauge and vernier calliper (least count 0.01mm) (Figure 3). As described by Tarighi *et al*. (2011), the geometric mean diameter was determined using the Equation 2;

$$D_g = (LWT)^{1/3} \qquad (2)$$

Where; D_g is the geometric mean diameter, cm; L is the length, cm; W is the width, cm; T is the thickness, cm.

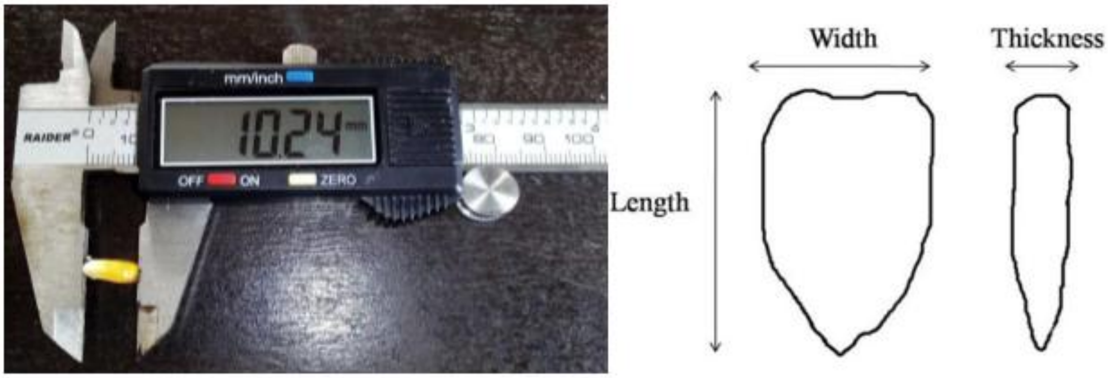

Figure 3: Vernier calliper

Surface area

The surface area was determined using the Equation 3;

$$S = \pi D_g^2 \quad (3)$$

Where; *S* is the surface area, cm^2; D_g is geometric mean diameter, cm.

Sphericity (Ø)

Sphericity of seeds was calculated based on the isoperimetric property of a sphere using the Equation 4 as used by Soyoye *et al.* (2018);

$$\emptyset = \frac{\sqrt[3]{(LWT)}}{L} \quad (4)$$

Bulk volume

The bulk volume was determined using the displacement method. Toluene C_7H_8 was poured into the measuring cylinder to a certain level which was recorded. The bulk mass was then poured into the cylinder with toluene C_7H_8 in it. The volume of toluene in the cylinder rose. The new volume was recorded and subtracted from the initial volume. The volume obtained from the subtraction is the bulk volume for the bulk mass. True density (ρp) and bulk density (ρb) were determined by toluene displacement method as indicated using Equations 5 and 6.

$$True\ density = \frac{Weight\ of\ sample}{Volume\ of\ liquid\ displaced} \quad (5)$$

$$Bulk\ density = \frac{Weight\ of\ sample}{Volume\ occupied} \quad (6)$$

The porosity was determined by Soyoye *et al.* (2018) using the equation 7.

$$Porosity = \left(1 - \frac{Bulk\ density}{True\ density}\right) \times 100\% \quad (7)$$

Angle of repose

The angle of repose was determined using the sliding box provided in the Department of Agricultural and Environmental Engineering. The dimension of the sliding box is 0.3×0.6 m. The seed were placed randomly in the box and allowed to lie in their natural resting position. The angle was increased gradually till when the seed slides or rolls away. The angle at which the seed slide is recorded. The procedure was repeated for 200 samples and across different surface which are; mild steel, stainless steel and galvanized steel, all which was used in the determination of the coefficient of friction.

Static coefficient of friction

The coefficient of static friction was determined on three different structural surfaces, namely plywood, mild steel and rubber. The tilting table apparatus shown in Figure 4 was used. Each seed was placed on the surface and raised gradually by screw until the seed began to slide. The angle that the inclined surface makes with the horizontal when sliding begins was measured. The coefficient of static friction μ_s was calculated using Equation 8:

$$\mu_s = \tan\varphi \quad (8)$$

Figure 4: Tilting box

Where φ is the angle that the incline makes with the horizontal when sliding begins (Abdullah *et al*., 2011).

Moisture content

The moisture content (MC) of maize and Cowpea seeds were obtained as shown in Equation 9.

$$Moisture\ content\ (MC) = \frac{Weight\ of\ water}{weight\ of\ dry\ seeds} \times 100\ {}^{0}/_{0} \qquad (9)$$

The direct method was used, that is the oven dry method. The initial weight of the seeds were weighed and known, the weight of the can was also weighed and known, then the seeds and the can were placed in the oven at a temperature of $105^{0}C$ for 30 minutes interval it got to the point where the weight of the grains were just constant and the moisture content was calculated at that stage.

Results and Discussion

Seeds dimensions

The three axial dimensions and average diameters, increased with an increase in moisture content from 7.9 to 14.6% dry basis for maize and 6.9 to 15.4% dry basis for cowpea. Each principal dimension appeared to be linearly dependent on the moisture content as shown in Figures 5 and 6. Very high correlation was observed between the three principal dimensions, average diameters and moisture content indicating that; upon moisture absorption, seeds expand in length, width and thickness within the moisture range of from 7.9 to 14.6% dry basis for maize and 6.9 to 15.4% dry basis for cowpea. The average length, width, thickness, arithmetic and geometric diameters of 100 seeds varied from 11.335 to 12.45 mm, 7.93 to 8.29 mm, 4.49 to 4.89 mm, 7.99 to 8.55 mm and 7.45 to 7.99 mm, respectively as the moisture content increased from 7.9 to 14.6% dry basis for maize and 6.9 to 15.4% dry basis for cowpea. The seed diameters were increased with addition of moisture content, but it did not make significantly difference between the treatments ($p > 0.05$). The mean values and standard errors of the axial dimensions of the maize and cowpea seeds at different moisture contents are presented in Tables1 and 2, respectively.

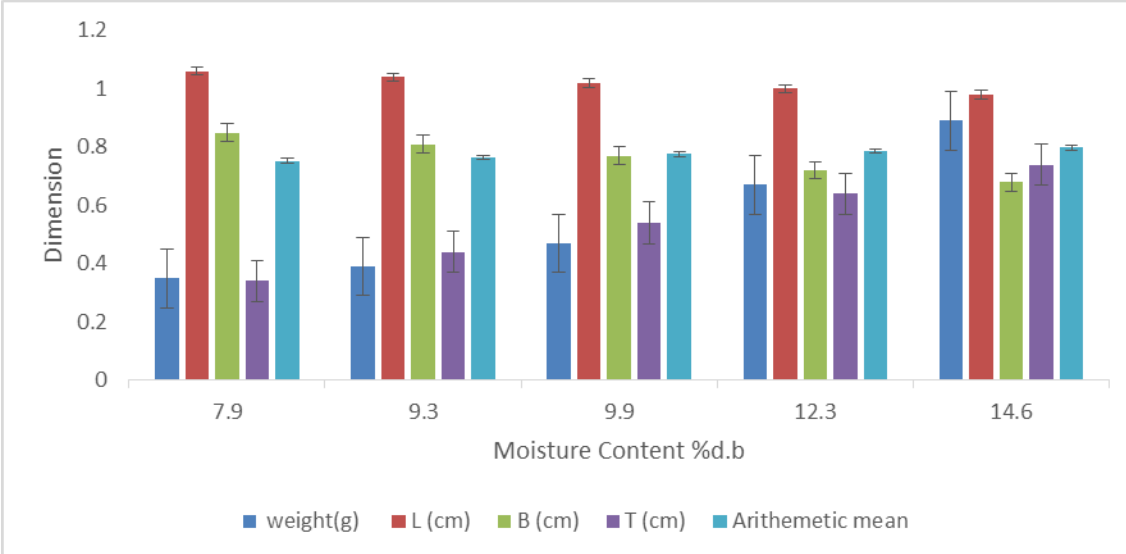

Figure 5: Variations of principal dimensions of maize seeds with respect to moisture content

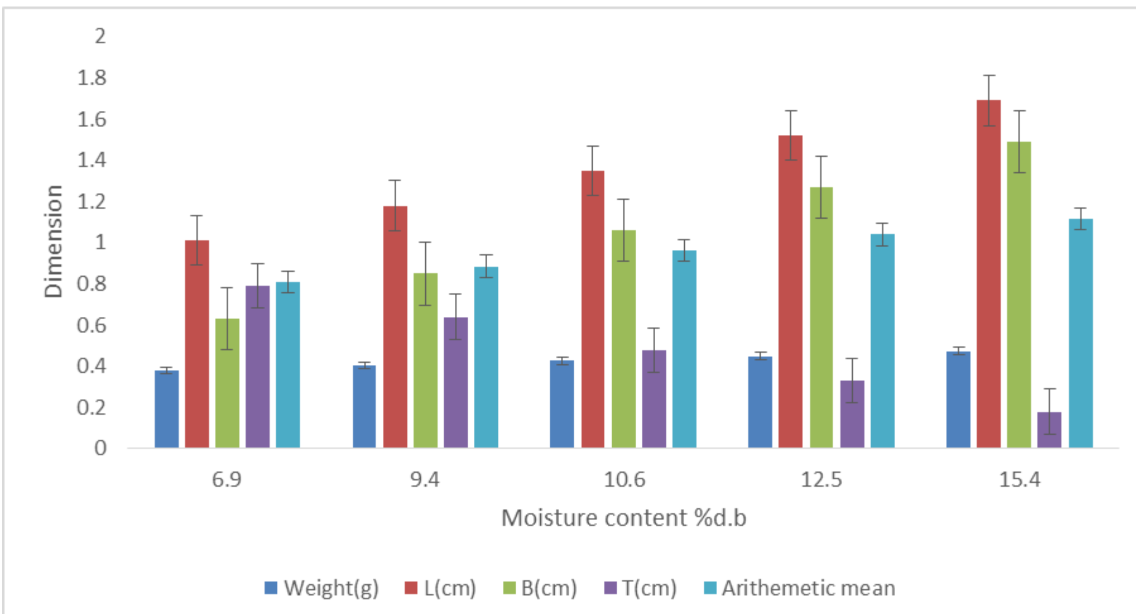

Figure 6: Variations of principal dimensions of cowpea seeds with respect to moisture content

Surface area, volume of seeds and bulk density

The surface area and volume of maize seeds increased from 1.9 to 3.2mm^2 and from 0.40 to 0.59 mm^3 for cowpea while it increased from 1.43 to 2.16 and 0.30 to 0.54 for maize while the moisture content increased from 7.9 to 14.6% dry basis for maize and 6.9 to 15.4% dry basis for cowpea but this difference were not statistically significant ($p > 0.05$) (Figure 7). The variation in surface area and volume with moisture content of corn and cowpea seeds can be represented by the equations above. Similar trends have been reported by Baryeh (2002) for gram, Karababa (2006) and Ã–zarslan (2002) for cotton; and (Konak *et al*., 2002) for chick pea seed.

The values of the bulk density at different moisture levels varied from 0.72 to 1.80 kgm^{-3} for maize and from 0.66 to 1.97 kgm^{-3} for cowpea (Figures 7 and 8). This was due to the fact that, an increase in mass owing to moisture seed in the sample was lower than accompanying volumetric expansion of the bulk (Pradhan *et al*., 2008).

Table 1: Physical properties of maize with respect to the moisture content

Moisture content	Weight (g)	L (cm)	B (cm)	T (cm)	Ap (cm)	Ac (cm)	Roundness	Sphericity	Vol. (ml)	True density (g/ml)	Porosity (%)	Surface area	Angle of repose	Arithmetic mean	Bulk density
7.9	0.35	1.06	0.85	0.34	0.65	0.42	1.5983	0.6371	0.304	1.22	36.57	1.43265	29.727	0.75250	0.7260
9.3	0.39	1.04	0.81	0.44	0.71	0.43	1.6530	0.6885	0.363	1.00	0.29	1.61511	32.027	0.76397	0.9961
9.9	0.47	1.02	0.77	0.54	0.76	0.45	1.7078	0.7400	0.422	0.78	0.20	1.79757	34.327	0.77543	1.2661
12.3	0.67	1.00	0.72	0.64	0.82	0.46	1.7625	0.7914	0.481	0.56	0.17	1.98002	36.627	0.78690	1.5362
14.6	0.89	0.98	0.68	0.74	0.88	0.47	1.8173	0.8429	0.54	0.35	0.10	2.16248	38.927	0.79837	1.8062

Table 2: Physical properties of cowpea with respect to the moisture content

Moisture content	Weight (g)	L (cm)	B (cm)	T (cm)	Ap (cm)	Ac (cm)	Roundness	Sphericity	Vol. (ml)	True density (g/ml)	Porosity (%)	Surface area	Angle of repose	Arithmetic mean	Bulk density
6.9	0.3796	1.01	0.63	0.79	0.63	0.41	1.5715	0.7914	0.4025	1.00	28.1856	1.98061	37.990	0.80867	0.6650
9.4	0.4033	1.18	0.85	0.64	0.70	0.46	1.5892	0.7223	0.4516	1.00	0.5166	2.30186	36.317	0.88560	0.9924
10.6	0.427	1.35	1.06	0.48	0.77	0.50	1.6069	0.6531	0.5007	0.99	0.4166	2.62310	34.643	0.96253	1.3198
12.5	0.45	1.52	1.27	0.33	0.83	0.55	1.6246	0.5840	0.5498	0.99	0.3566	2.94435	32.970	1.03947	1.6472
15.4	0.4744	1.69	1.49	0.18	0.90	0.60	1.6423	0.5148	0.5989	0.99	0.3266	3.26559	31.297	1.11640	1.9746

The relationship between the three principal dimensions (L, W, T), average diameters (D_a, D_g) and moisture content (Mc) are linear and can be represented by the following equation:

Maize

$L = 0.068(Mc) + 10.43$ $R^2 = 0.979$
$W = 0.021(Mc) + 7.832$ $R^2 = 0.978$
$T = 0.012(Mc) + 4.629$ $R^2 = 0.969$
$Da = 0.033(Mc) + 7.84$ $R^2 = 0.968$
$B = 0.214mc + 0.418$ $R^2 = 0.9999$

cowpea

$L = -0.02mc + 1.08$ $R^2 = 0.996$
$w = 0.136mc + 0.146$ $R^2 = 0.916$
$T = 0.1mc + 0.24$ $R^2 = 0.916$
$Da = 0.0115mc + 0.741$ $R^2 = 0.968$
$B = -0.043mc + 0.895$ $R^2 = 0.9984$

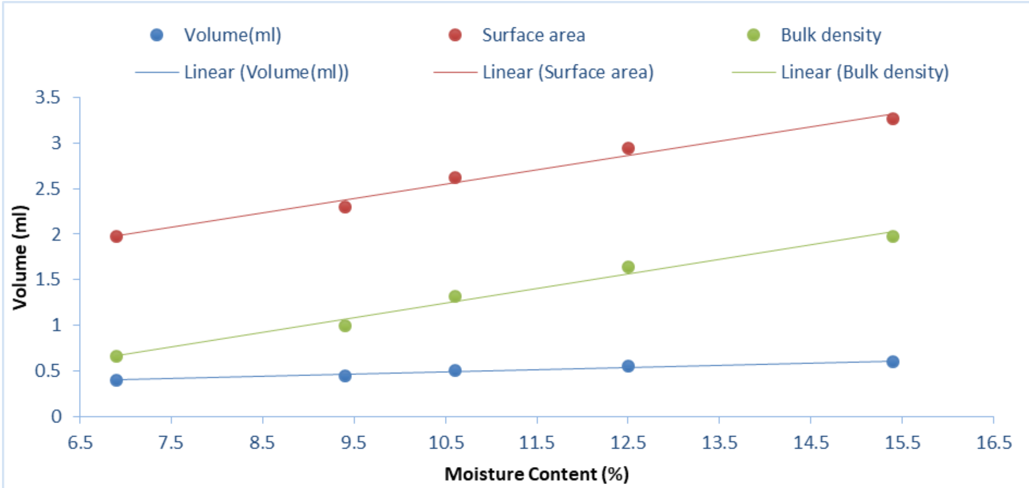

Figure 7: Effect of moisture content on volume, bulk density and surface area of cowpea seeds

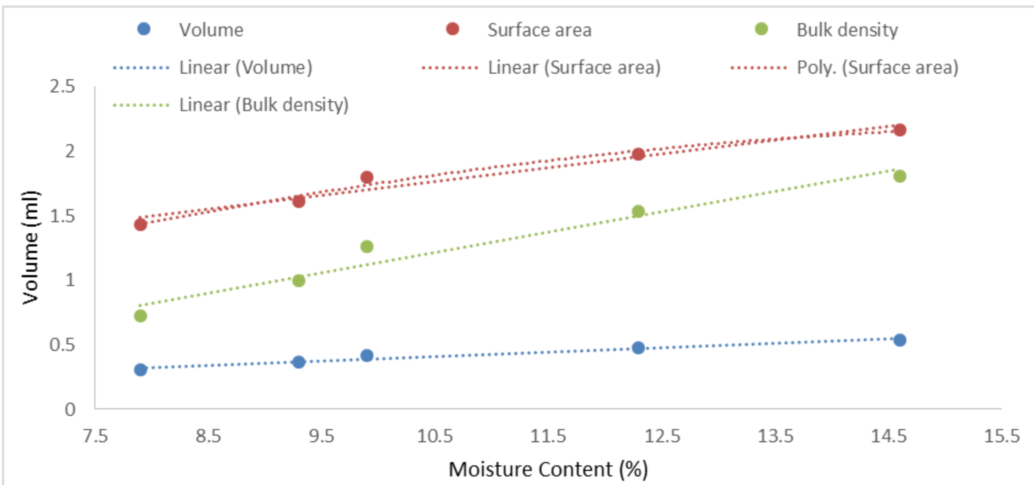

Figure 8: Effect of moisture content on volume, bulk density and surface area of maize seeds

True density and sphericity

The true density varied from 1.22 to 0.35 g/ml for maize and decreases from 1.00 to 0.99g/ml for cowpea when the moisture level increased from 7.9 to 14.6% dry basis for maize and 6.9 to 15.4% dry basis for cowpea. The sphericity decreased from 0.79 to 0.52 for cowpea and increases from 0.6 to 0.84 for maize when the moisture level increased from 7.9 to 14.6% dry basis for maize and 6.9 to 15.4% dry basis for cowpea (Figures 9 and 10). Baryeh and Mangope (2002), Altuntaş and Yildiz (2007), Garnayak *et al*. (2008) and Pradhan *et al*. (2008) reported similar trends in the case of pigeon pea vetch seeds, faba bean grains, jatropha seed and karanja kernel, respectively. The true density, sphericity and the moisture content of seeds can be correlated as follows:

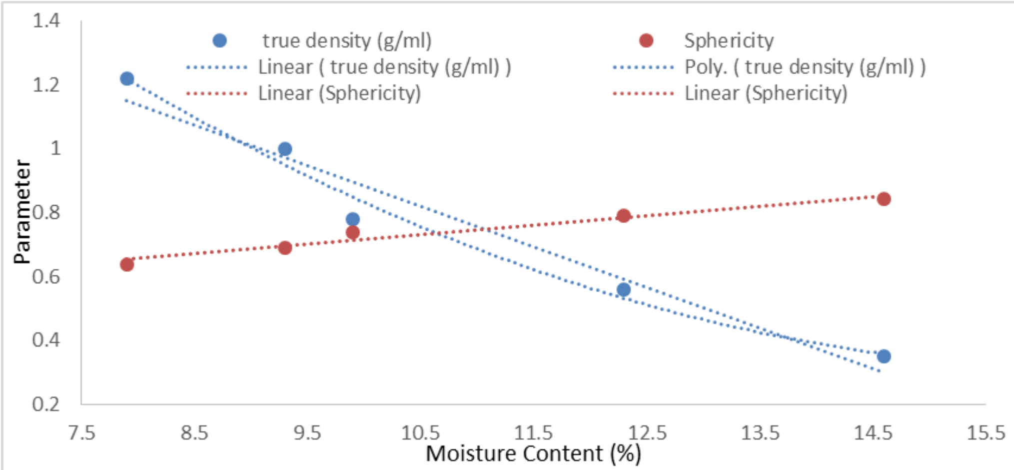

Figure 9: Effect of moisture content on true density and sphericity of maize seeds

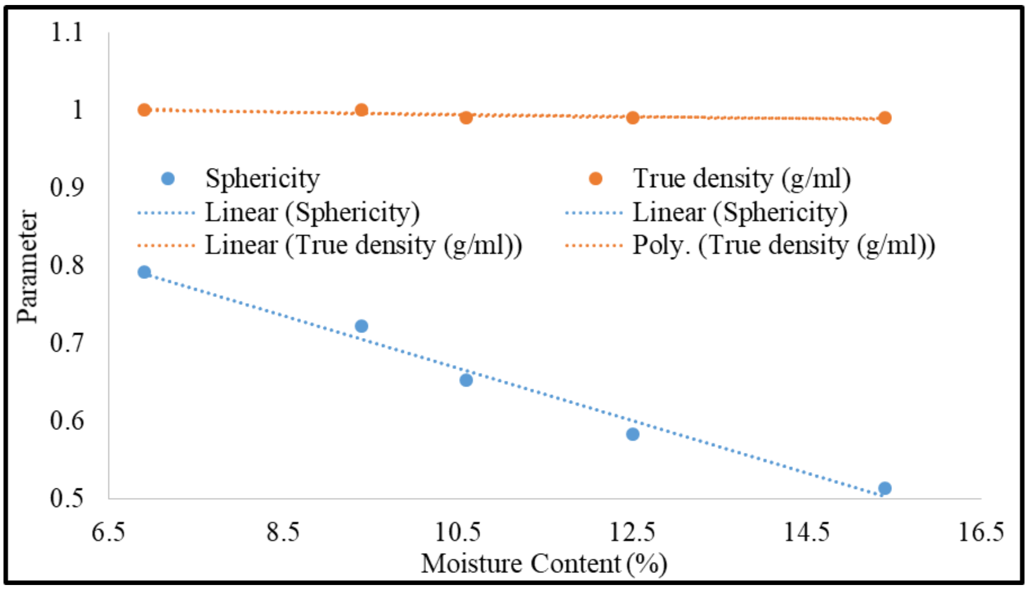

Figure 10: Effect of moisture content on true density and sphericity of cowpea seeds

Angle of repose

Figure 11 showed that the variation of the static angle of repose with seed moisture content increased from 29.72° to 38.93° for maize and decreases from 37.99° to 31.29° ($p < 0.05$). The increasing trend of angle of repose for maize with moisture content occurs because the surface layer of moisture surrounding the particle holds the aggregate of grain together by the surface tension (Pradhan *et al*., 2008). The values of the angle of repose (θ) for corn seeds and cowpea bear the following relationship with its moisture content (Mc). These results were similar to those reported by Garnayak *et al*. (2008) for jatropha and Pradhan *et al*. (2008) for karanja kernel.

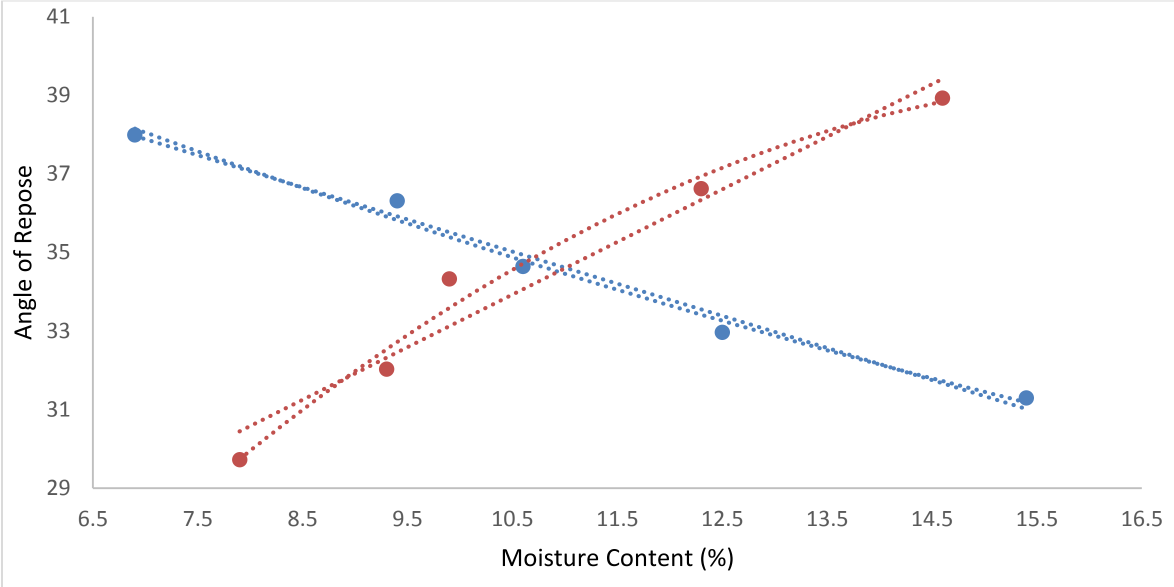

Figure 11: Effect of moisture content on angle of repose of maize and cowpea seeds

Conclusions

The following conclusions were drawn from the investigation on physical properties of maize for moisture content range of 7.9 to 14.6% db. and physical properties of cowpea for moisture content range of 6.9 to 15.4% db.

i. The maize dimensions such as average length, width, thickness and arithmetic diameter of the maize ranged from 0.98 to 1.06 cm, 0.68 to 0.85 cm, 0.34 to 0.74 cm, and 0.75 to 0.79 cm as the moisture content increased from 7.9 to 14.6% db. respectively. The dimension such as average length, width, thickness and arithmetic diameter of the cowpea ranged from 1.01 to 1.69 cm, 0.63 to 1.49 cm, 0.18 to 0.79 cm, 0.80 to 1.12 cm as the moisture content increased from 6.9 to 15.4% db. respectively.
ii. As the moisture content of maize and cowpea increased from 7.9 to 14.6% and 6.9 to 15.4% db. the weight, volume, surface area and sphericity of maize were varied from 0.35 to 0.89g, 0.30 to 0.54g/ml, 1.43 to 2.16cm^2 and 0.64 to 0.84 respectively. As the moisture content increase from 7.9 to 14.6% db. The weight, volume, surface area and sphericity of cowpea were varied from 0.38 to 0.47 g, 0.40 to 0.59 ml, 1.98 to 3.26 cm^2 and 0.79 to 0.58 respectively.
iii. As the moisture content increased from 6.9 to 15.4% db., the bulk density and true density of maize were found to increase from 0.73 to 1.81 g/ml and 0.35 to 1.22 g/ml and that of cowpea increase from 0.66 to 1.97 g/ml and 0.99 to 1.00 g/ml whereas the porosity of maize was found to decrease from 36.57 to 0.10 % and that of cowpea was found to decrease from 28.18 to 0.33 % with increase in moisture content.
iv. At all moisture contents, the static and dynamic angle of repose were found be increasing. The mild steel offered the maximum friction for sliding followed by galvanize steel and stainless steel.
v. Size and shape properties were used in calculation of heating and cooling loads of food materials. Density and porosity were used in design of storage structures and cyclone separators. Angle of repose and friction properties finds application in designing of hopper, chutes, pneumatic conveyors, screw conveyors and belt conveyors.

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