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Moisture dependent physical properties of maize kernels

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Abstract

Moisture dependent physical properties of maize kernels were investigated. The geometric, gravimetric and frictional properties were measured at different levels of moisture content from 8.7 to 21.7% d.b. The results obtained showed that the changes in moisture content of maize kernel lead to minimum variation in geometric properties. The principle dimensions such as length, width, thickness, geometric mean diameter and surface area increased linearly while volume, 1000 kernel weight and sphericity of maize kernels 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 (8.7, 13, 17.4 and 21.7% d.b). The highest coefficients of friction were found on the concrete surface followed by wooden slab and aluminum sheet.

Introduction

Maize, also known as corn, belongs to the family Poaceae. Maize (*Zea mays* L) is one of the most versatile emerging crops having wider adaptability under varied agricultural and climatic conditions. Globally, maize is known as queen of cereals because it has the highest genetic yield potential among the cereals. It is widely cultivated throughout the world and enormous quantity of maize is produced each year than any other grain. The United States produces 40% of the world's harvest. Other major maize producing countries are China, Brazil, Mexico, Indonesia, India, France and Argentina. In India, maize is the third most important food crops after rice and wheat. The major producers of maize in the country are Madhya Pradesh, Rajasthan, Gujarat, Bihar, Punjab, Andhra Pradesh, Karnataka and Uttar Pradesh which together contributes nearly 9% in the national food basket and more than Rs. 100 billion to the agricultural GDP at current prices apart from generating employment to over 100 million man-days at the farm and downstream agricultural and industrial sectors. The maize is cultivated throughout the year in all states of the country for various purposes in addition to food for human being, it serves as a quality feed for animals, as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, sweeteners, pharmaceutical, cosmetic, plastics, fabrics, gum, package and paper industries etc. Differences in kernel characteristics caused by genetic pattern, environmental conditions, or handling may influence the processing and utilization of maize. The characteristics of maize can be affected during shelling if grain is harvested at high moisture content, by postharvest handling, and by drying air temperatures.

The knowledge of engineering properties of biomaterials is fundamental in order to optimize the design of equipment's for post-harvest handling and processing of agricultural products. This information on engineering properties is useful for plant and animal breeders; engineers and food scientists. In addition, this information is helpful for data collection in the design of machines, structures, processes and controls; and in determining the efficiency of a machine or an operation. (Mohsenin, 1986; Srivastava *et al.*, 1990; Aviara *et al.*, 1999). The physical properties have been studied for various agricultural products by other researchers

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such as locust bean seed (Ogunjimi *et al*., 2002), pigeon pea (Baryeh and Mangope, 2003), amaranth seed (Abalone *et al*., 2004), rape seed (Calısır *et al*., 2005), Bambara groundnut (Adejumo *et al*., 2005), watermelon seed (Koocheki *et al*., 2007), pistachio nut and its kernel (Razavi *et al*., 2007), coriander seed (Coskuner and Karababa, 2007), tung seed (Sharma *et al*., 2011), carob bean (Karababa and Coşkuner, 2013), moringa seed (Aviara *et al*., 2013), barley (Sologubik *et al*., 2013). To date dry milling properties of maize kernels have been evaluated by (Mestres *et al*., 1991; Velu *et al*., 2006). However, literatures on the combined effects of moisture variations on physical properties of maize kernels appear to be scanty. Hence the objective of this study was to investigate the effect of moisture content on the geometric properties such as length, width, thickness, geometric and arithmetic mean diameter, surface area and sphericity, gravimetric properties like volume, 1000 kernel weight, bulk density, true density, porosity and frictional properties such as angle of repose and coefficients of friction of maize kernels.

Materials and Methods

Sample preparation

Maize (*Zea mays* L.) was used for all the experiments in this study. The dried kernels were procured from the local market in Perundurai, Tamil Nadu. The maize kernels were cleaned manually in order to remove the impurities such as dust, stone, sticks, immature and damaged kernels. The cleaned kernels were stored in a high density poly-ethylene sheet for further usage. The initial moisture content of the kernels was determined by drying samples in a hot air oven at $103\pm1^{o}C$ for 24 h (AOAC, 2000). The initial moisture content of the sample was 8.7% d.b. The samples were moistened to increase the moisture content to the desired three different levels, by adding calculated quantity of water using the following equation (Zareiforoush *et al*., 2010),

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

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 $5\pm10^{o}C$ for 7 days for uniform moisture distribution throughout the samples (Davies and El-Okene, 2009). After equilibration, the moisture content of the samples was determined before each experiment. Before conducting each experiment, the required quantity of the sample were withdrawn from the refrigerator and reconditioned at room temperature. All the physical properties were calculated at moisture levels (8.7, 13, 17.4 and 21.7% d.b). 100 matured kernels were randomly picked for the experiments.

Kernel dimensions

The three major dimensions such as length (L), width (W) and thickness (T) of randomly picked 100 maize kernels were measured using screw gauge with an accuracy of 0.01 mm. Figure1 shows the characteristic dimensions of a maize kernel. The average diameter of the samples was calculated by using the arithmetic mean and geometric mean of three principal dimensions. The geometric mean diameter (D_g) and the arithmetic mean diameter (D_a) were calculated for the major dimensions using the following equations (Mohsenin, 1986; Galedar *et al*., 2008).

$$D_g = (LWT)^{\frac{1}{3}} \tag{2}$$

$$D_a = \frac{(L+W+T)}{3} \tag{3}$$

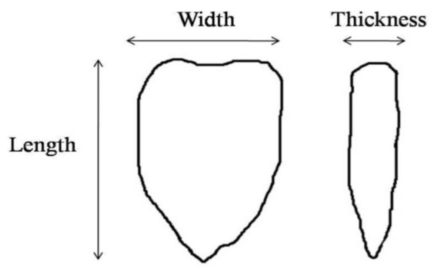

Figure 1. Characteristic dimensions of a maize kernel

1000 kernel weight

1000 kernel weight is used in handling and processing of grains. In earlier day's 1000 kernel weight were used in determining the density of kernels. To determine the 1000 kernel weight, one hundred maize kernels were counted manually and then these kernels were weighed by means of an electronic weighing balance with 0.01 g accuracy and finally extrapolating this mass to 1,000 kernels.

Surface area and volume

The surface area (S) and volume (V) were found using the following equations (McCabe *et al*., 1986; Jain and Bal, 1997).

$$S = \pi D_g^2 \tag{4}$$

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \quad (5)$$

Where, $B = \sqrt{WT}$; W is width, mm; L is length, mm.

Sphericity

The sphericity (Φ) is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area of the grain. Sphericity was calculated using the following relationship (Mohsenin, 1986).

$$\Phi = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (6)$$

Bulk and true density

Bulk density (ρ_b) was determined by filling the container with known volume of maize sample and weighing the contents. The ratio of the mass and volume was expressed as bulk density (Varnamkhasti *et al*., 2008). Since the bulk density includes the inter-granular spaces, it is necessary to avoid any compaction of the samples in the container. The true density (ρ_t) is the ratio between the mass of the sample and the true volume of the samples, was determined by toluene displacement method (Mohsenin, 1986). Toluene was used instead of water because it is less absorbed by the kernel and due to its low surface tension, it fills the intergranualar spaces (Demır *et al*., 2002; Kabas *et al*., 2007).

Porosity

The porosity is the fraction of the space in the bulk seeds which is not occupied by the seeds (Mohsenin, 1986). The porosity (ε) of the samples were computed from the bulk and true densities using the following equations.

$$\epsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) x\ 100 \quad (7)$$

Angle of repose

The angle of repose (Θ) is the angle between the base and the slope of the cone formed on a free vertical fall of the mass to a horizontal plane. The filling or static angle of repose is the angle with the horizontal at which the kernels will form a heap when piled. This was determined using a topless and bottomless cylinder which was placed at the centre of a raised circular plate. The plate was filled with maize kernels. The cylinder was raised slowly until it formed a heap on a circular plate. The height of the cone was measured and the filling angle of repose (θ_f) was calculated by the following relationship. (Ozguven and Vursavus, 2005; Galedar *et al*., 2008)

$$\theta_f = tan^{-1}\left[\frac{2H}{D}\right] \quad (8)$$

where, H and D are the height and diameter of the cone (cm) respectively.

The emptying or dynamic angle of repose was determined using a box provided with removable sliding door. The box was filled with the maize kernels and then the front sliding door was quickly moved upwards, allowing the kernels to form a heap. The emptying angle of repose (θ_e) was calculated from the height of samples at two points (h1 and h2) in the heap and the horizontal distance between two points (x1 and x2), using the following equation (Jain and Bal, 1997)

$$\theta_e = \tan^{-1}\left[\frac{h_2 - h_1}{x_2 - x_1}\right] \quad (9)$$

Coefficients of friction

The static coefficient of friction for maize kernels was determined with respect to three different surfaces such as concrete, wood and aluminum. A known mass of the samples were filled in a cylinder and with the cylinder resting on the surface, it was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006; Varnamkhasti *et al*., 2008). The co-efficient of friction (μ) was calculated by using the following equations,

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

where α is the angle of tilt.

Results and Discussion

Kernel dimensions

The average values of the three principal dimensions of a maize kernel namely, length, width and thickness were determined. These values at different moisture contents are presented in Table 1. The graph indicates that, on moisture absorption, the maize kernel expands in length, width and thickness within the moisture range of 8.7 to 21.7% d.b. The average length, width and thickness of the kernels varied from 10.59 to 11.87 mm, 8.11 to 8.75 mm and 4.81 to 5.52 mm, respectively as the moisture content increased from 8.7 to 21.7% d.b. The arithmetic and geometric mean diameter ranged from 7.84 to 8.61 mm and 7.42 to 8.30 mm as the moisture content increased from 8.7 to 21.7% d.b., respectively. The relationship between the principle dimensions and geometric mean diameter with respect to moisture content can be represented using regression equation,

$$L = 9.629 + 0.102M \quad R^2 = 0.979 \quad (11)$$

$$W = 7.588 + 0.050M \quad R^2 = 0.922 \quad (12)$$

Table 1. Axial dimensions of maize kernel (standard deviation in parentheses)

Moisture content %d.b	Length mm	Width mm	Thickness mm	Geometric mean diameter, mm	Arithmetic mean diameter, mm
8.7	10.59 (0.67)	8.11 (0.10)	4.81 (0.21)	7.42 (0.08)	7.84 (0.19)
13.0	10.84 (0.83)	8.15 (0.28)	4.97 (0.62)	7.56 (0.35)	7.99 (0.32)
17.4	11.44 (0.47)	8.44 (0.39)	5.30 (0.74)	7.96 (0.38)	8.39 (0.29)
21.7	11.87 (0.54)	8.75 (0.38)	5.52 (0.54)	8.30 (0.41)	8.61 (0.45)

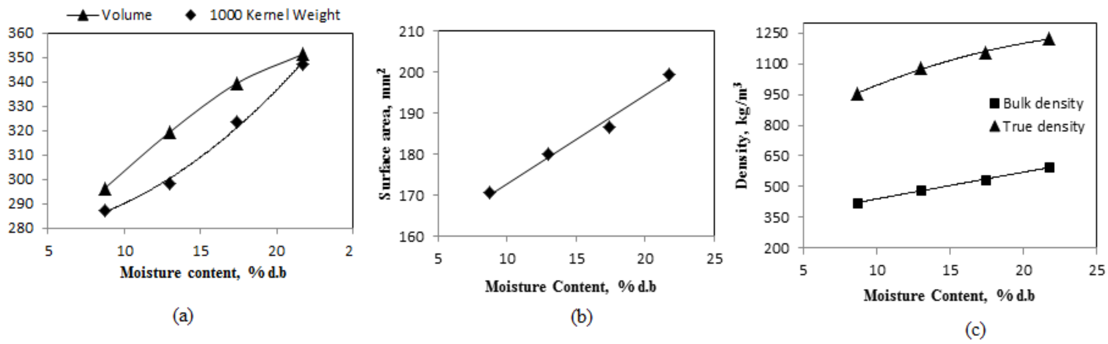

Figure 2. Effect of moisture content on (a) 1000 Kernel weight & Volume, (b) Surface area and (c) Density of maize kernels

$$T = 4.288 + 0.056M \quad R^2 = 0.985 \tag{13}$$

$$D_g = 6.744 + 0.070M \quad R^2 = 0.969 \tag{14}$$

The length, width, thickness, arithmetic and geometric mean diameter of the maize kernel was found to increase linearly with increase in the moisture content. Similar results were observed for various products such as cucurbit seeds (Milani *et al.*, 2007), soybean (Kibar and Ozturk, 2008).

1000 kernel weight

From the Figure 2, it is observed that the 1000 kernel weight increased linearly from 287.25 to 347.25 g as the moisture content increased from 8.7 to 21.7% d.b. The relationship between the 1000 kernel weight (W1000) and moisture content (M) can be expressed by the following equation

$$W_{1000} = 277.5 - 0.452M + 0.170M^2 \quad R^2 = 0.995 \tag{15}$$

Similar trends of increase have been reported by (Tavakoli *et al.*, 2009) for soybeans and (Bamgboye and Adebayo, 2012) for jatropha seeds.

Surface area

The surface area of maize kernel was calculated with Eq. (4) by using the geometric mean diameter and the results obtained are presented in Figure 2. The surface area of the maize kernel increased from 170.57 to 199.50 mm^2 as the moisture content increased from 8.7 to 21.7% d.b. The relationship between moisture content and surface area (S) appears to be linear and can be represented by the regression equation:

$$S = 151.4 + 2.152M \quad R^2 = 0.967 \tag{16}$$

There is a 16.9% increase in surface area from moisture content of 8.7 to 21.7% d.b. similar results have been obtained by (Tavakoli *et al.*, 2009) for soy beans and (Karaj and Müller, 2010) for jatropha seeds.

Volume

Volumetric change based on the moisture content of maize kernel is shown in Fig. 2. The volume of a single maize kernel varied from 296.27 mm3 to 351.28 mm^3 as the moisture content increased from 8.7 to 21.7% d.b. An increase 18.5% in volume of was recorded for coriander seed in used moisture range. The relationship between kernel volume, V and moisture content can be written as

$$V = 230.1 + 8.898M - 0.152M^2 \quad R^2 = 0.999 \tag{17}$$

A linear relationship between the volume and moisture content for grains were observed by previous researchers (Altuntaş *et al.*, 2005; Baümler

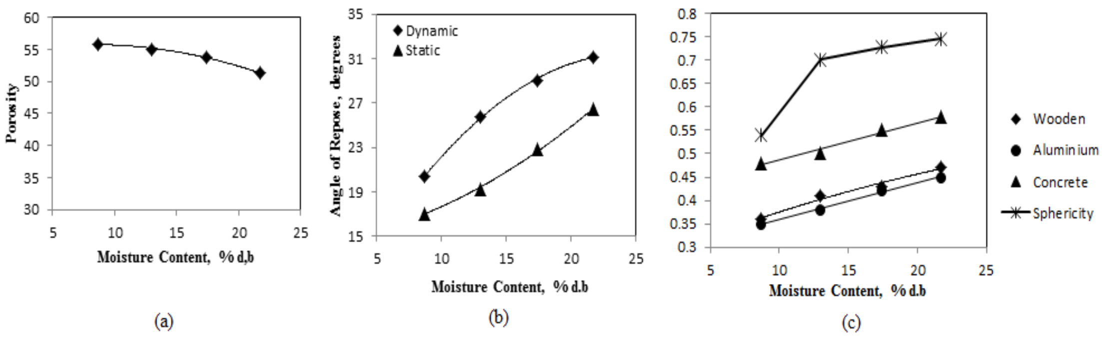

Figure 3. Effect of moisture content on (a) Porosity, (b) Angle of repose and (c) Co-efficient of friction of maize kernels

et al., 2006).

Sphericity

The relationship between sphericity and moisture content of grain is shown in Figure 3. The sphericity of the samples increased with the increase in moisture content. The sphericity of maize kernel varied from 0.53 to 0.745 as the moisture content increased from 8.7 to 21.7% d.b respectively. The relationship between the sphericity and moisture content can be represented using the following polynomial expression,

$$\varphi = 0.053 + 0.073M - 0.001M^2 \qquad R^2 = 0.967 \quad (18)$$

A positive variation of sphericity depending on the increase of moisture content was also observed in some seeds such as sunflower seeds (Gupta and Das, 1997), almond nuts (Aydin, 2003), coriander seeds (Coskuner and Karababa, 2007) and sesame seeds (Darvishi, 2012).

Bulk and true density

The bulk density and true density of the maize kernels at different moisture levels varied from 421.47 to 594.57 kg/m^3 and 954.23 to1220.87 kg/m3 with the moisture range of 8.7 to 21.7% d.b. respectively. A nonlinear increase in bulk density and true density was observed for different moisture levels (Figure 2). This increase in true density may be due to the higher rate of increase in mass than the volumetric expansion of the kernels. The bulk density of the maize kernel decreases with increase in the moisture content from 8.7 to 21.7% d.b. Similar trend was reported for ground nut kernels (Firouzi *et al.*, 2009). The empirical relationship between bulk density (ρ_b) and true density (ρ_t) with moisture content (M) and can be expressed by the following equations

$$\rho_b = 307.9 + 13.30M - 0.008M^2 \qquad R^2 = 0.996 \quad (19)$$

$$\rho_t = 638.2 + 8.898M - 0.756M^2 \qquad R^2 = 0.997 \quad (20)$$

Similar relationship of bulk density and true density with moisture content was also observed by (Polat *et al*., 2007) for pistachio nut and kernels, (Balasubramanian and Viswanathan, 2010) for minor millets.

Porosity

The magnitude of variation in porosity depends on bulk as well as true densities. The porosity of maize kernels was found to slightly decrease from 55.83 to 51.30 % with increase in moisture content from 8.7 to 21.7% d.b. (Figure 3). The relationship between the porosity and moisture content (M) can be expressed by the following equation

$$\epsilon = 54.20 + 0.390M - 0.024M^2 \qquad R^2 = 0.995 \quad (21)$$

A similar trend was reported for soybean (Deshpande *et al.*, 1993), pistachio nuts and kernels (Polat *et al.*, 2007) and minor millets (Balasubramanian and Viswanathan, 2010).

Angle of repose

The static and dynamic angle of repose for maize kernels varied from 17.06 to 26.42^o and 20.37 to 31.14^o respectively, at different levels of moisture content. Both the angle of repose for maize kernels increased polynomially with increase of moisture content from 8.7 to 21.7% d.b. (Figure 3). The increase in angle of repose with moisture content may be due to the surface tension which holds the surface layer of moisture surrounding the particle together with the aggregate of grain. The relationship can be expressed using the following equation

$$\theta_f = 14.20 + 0.157M + 0.018M^2 \qquad R^2 = 0.998 \quad (22)$$

$$\theta_e = 4.875 + 2.173M - 0.044M^2 \qquad R^2 = 0.999 \quad (23)$$

Table 2. Relationship between moisture content and coefficients of friction for various surfaces

Surface	Equation	R^2
Concrete	$\mu = 0.404 + 0.008M$	0.977
Wood	$\mu = 0.295 + 0.008M$	0.974
Aluminum	$\mu = 0.280 + 0.007M$	0.997

A similar result of nonlinear increase in angle of repose with increasing seed moisture content has also been noted by for gram (Chowdhury *et al*., 2001), coriander seeds (Coskuner and Karababa, 2007) and for pistachio nuts and kernels (Galedar *et al*., 2008).

Coefficients of friction

The coefficients of friction for maize kernels were determined with respect to wooden, concrete and aluminum sheet metal surfaces are presented in Figure 3. At all moisture content ranges, coefficients of friction were greatest for maize kernel, against concrete and least for aluminum sheet metal. The coefficient of friction increased significantly as the moisture content of the kernel increased. The relationship between the coefficients of friction and moisture content of the nut on three different surfaces is presented in table 2. Concrete slab had the highest coefficient of friction (0.48) at the lowest moisture content (8.7%) followed by wooden surface (0.36) and aluminum sheet (0.35). Even at the highest moisture content (21.7%), again concrete slab (0.58) had the highest coefficient of friction followed by wooden surface (0.47) and aluminum sheet (0.45). Similar increasing trend was observed by (Aydin, 2003) for almonds, (Altuntaş *et al*., 2005) for fenugreek, (Milani *et al.,* 2007) for cucurbit seeds, (Bamgboye and Adebayo, 2012) for jatropha.

Conclusion

The following conclusions are drawn from the investigation on physical properties of maize kernels for moisture content range of 8.7 to 21.7% d.b. The kernel dimensions such as average length, width, thickness, geometric mean diameter and arithmetic diameter of the maize kernels ranged from 10.59 to 11.87 mm, 8.11 to 8.75 mm, 4.81 to 5.52 mm, 7.42 to 8.30 mm and 7.84 to 8.61 mm as the moisture content increased from 8.7 to 21.7% d.b. respectively. As moisture content increased from 8.7 to 21.7% d.b, 1000 kernel weight, volume, surface area, and sphericity of maize kernels were varied from 287.25 to 347.25 g, 296.27mm^3 to 351.28 mm^3, 170.57 to 199.50 mm^2 and 0.53 to 0.745 respectively. As the moisture content increased from 8.7 to 21.7% d.b., the bulk density and true density were found to increase from 421.47 to 594.57 kg/m^3 and 954.23 to 1220.87 kg/m3 whereas the porosity was found to decrease from 55.83 to 51.30 % with increase in moisture content. At all moisture contents, the static and dynamic angle of repose were found be increasing. The coefficients of friction varied from 0.48 to 0.58, 0.36 to 0.47 and 0.35 to 0.45 for concrete, wood and aluminum sheet, respectively. The concrete surface offered the maximum friction for sliding followed by wooden slab and aluminum sheet. 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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