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Effect of moisture content on some physical properties of HQPM 5 quality protein maize (*Zea mays*)

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ABSTRACT

This study on HQPM 5 quality protein maize was performed to investigate the effect of moisture content on the selected physical properties, as the knowledge about the physical properties of this grain is important for designing processing machineries. For this purpose, moisture content of grains was varied from 9% to 25%, wet basis (wb). In this study moisture content range, the average length, width, thickness, surface area, volume, geometric mean diameter and arithmetic mean diameter of quality protein maize grains increased significantly ($P<0.01$) from 9.2476 to 10.2033 mm, 7.8684 to 8.2641 mm, 3.8572 to 4.7139 mm, 138.433 to 158.0703 mm^2, 107.40 to 138.83 mm^3, 6.6445 to 7.0822 mm and 7.1304 to 7.5485 mm respectively, with increase of moisture content. A nonlinear significant increase of grain sphericity from 68.7438 to 76.2248 was observed in the studied moisture range. Thousand grain weight, true density, porosity and angle of repose increased linearly ($P<0.01$) from 223 to 253 g, 1110 to 1290 kg/m^3, 22.2087 to 34.4594 and 24^o to 37.03^o, whereas bulk density decreased linearly ($P<0.01$) from 982.4 to 812 kg/m^3. In the considered range of moisture content, all of these physical properties exhibited moisture dependence according to linear relationships except the sphericity.

Keywords: Moisture content, Geometric dimensions, Physical properties, Quality protein maize

Maize (*Zea mays* L.) is the third major cereal crop in the world after wheat and rice and is used for both livestock feed and human consumption (Prasanna *et al.* 2001). The crop also finds other industrial and non-industrial uses. Maize contributes 15% of the world's protein and 19% of the calories derived from food crops (Vasal 2002). Millions of people in the world, and particularly in developing countries, derive a part of their protein and daily calorie requirements from maize. The crop is also an important component of Poultry and cattle feed, in India and developed nations where 78% of total maize production is used for livestock feed. In Africa, maize supplies at least one fifth of total daily calories and accounts for 17% to 60% of the total protein supply per day of individuals who are more susceptible to risk of protein or essential amino acid deficiencies (Krivanek *et al.* 2007). In spite of its rich nutritional value maize has not been considered as complete food for human due to the reason that maize proteins possess poor nutritional value because of reduced content of essential amino acids such as lysine and tryptophan than recommended for human nutrition.

However, this problem in maize has been overcome by the development of quality protein maize (QPM), in the late 1960s (Prasanna *et al.* 2001) and it produces 70% to 100% more lysine and tryptophan than ordinary modern and traditional varieties of tropical maize (Bjarnason and Vasal, 1992).The nutritional quality of the protein in QPM grain approaches that of protein derived from cow's milk (Prasanna *et al.* 2001). The adoption of QPM can contribute immensely to alleviation of malnutrition in maize-based economies in developing countries. For instance, it has been found to be of economic value to substitute normal maize in stock feeds as it requires small amount or no supplementary protein sources to balance the diet (Qi *et al.* 2017).

The physical properties of quality protein maize, like other grains, are vital and central for designing the processing equipment for further handling and post-harvest processing. Various types of cleaning, grading and separation equipment are designed on the basis of physical properties of seeds (Sahay and Singh 1994). Physical properties affect conveying characteristics of solid materials by air or water and cooling and heating loads of food materials.

Hence, the knowledge of these physical properties is necessary for designing processing machines like cleaner, grader and dehusker. Different researchers have determined the physical properties of different types of seeds and grains,

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viz. pigeon pea, buckwheat, chickpea etc. Sharma *et al.* (2017) has studied and compared physical and physiological properties of specialty maize inbred lines of QPM, but effect of moisture on physical properties of QPM has not been reported. Keeping this in view present study has evaluated the moisture dependent variation in the physical properties of quality protein maize.

MATERIALS AND METHODS

Quality protein maize (HQPM 5) grain was procured from Department of Plant Breeding, ICAR, Ludhiana for this study. The grains were cleaned manually to separate foreign matter, broken and immature seeds and then stored at room temperature (25±2°C) in plastic bins for further study. Moisture content of the sample was determined by hot air oven method as described by Nimkar and Chattopadhyay (2001). Test samples of desired moisture content were set up by including estimated measure of distilled water finished by blending and sealing in LPDE packs. The normal starting moisture content was observed to be 9% wb. The grain moisture content range was selected between 9% to 25% wet basis because the harvesting is being practiced at about higher moisture content, i.e. 25% and transportation, storage, handling and processing operations of the crop are performed at about lower and safe moisture content, i.e. 9%.

The weight of the samples was recorded on an analytical balance of accuracy 0.001g in triplicate, and their average value was recorded. The sample was divided into lots that were conditioned for moisture content in the range of 9–25% wb by adding predetermined amounts of distilled water calculated from the following Eq. 1:

$$Q = \frac{W \times (Mf - Mi)}{(100 - Mf)} \tag{1}$$

where, Q = mass of water to be added (g); W = Quantity of sample (g); M_i= initial moisture content of the sample (% wb); M_f = desired moisture content of the sample (% wb).

The samples were kept at 5°C in a refrigerator for one week for uniform distribution of moisture throughout the sample. Before each test, the required quantity of sample was taken out of refrigerator and allowed to attain ambient temperature before carrying out the experiment. All experiments were replicated in triplicate manner and average values were used in the analysis.

To determine the average size, 100 grains were randomly selected, and length (L), width (W), thickness (T) of the grains were measured using a digital micrometer (least count 0.01 mm). The geometric mean diameter (D_g) and volume (V) were calculated by using following Eqs. 2 to 7 (Mohsenin 1986):

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

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

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

Where, $B = (WT)^{0.5}$. (5)

The surface area (A_s) of quality protein maize grain was obtained using the geometric mean diameter by analogy of a sphere (Deshpande and Ojha, 1993) as:

$$A_s = \pi D^2_g \tag{6}$$

where, A_s = Surface area.

Sphericity (ϕ) of quality protein maize was calculated using the following relationship (Mohsenin 1986):

$$\phi = D_g/L \times 100 \tag{7}$$

Thousand grain weight was determined by randomly selecting 100 grains from the overall sample, measuring their weight on a digital electronic balance with an accuracy of 0.001 g, and multiplying by 10 to get the mass of 1000 grains (Altuntas *et al.* 2005).

Bulk density (ρ_b) was considered as the ratio between the mass of a sample of grain and the total volume occupied by it. It was determined using a container of known volume (Deshpande and Ojha 1993).

True density (ρ_t), defined as the ratio between the mass of the sample grains and the actual volume occupied by it, was determined for five moisture contents (in the range of 9% –25% wb using toluene displacement method with three replications (Singh and Goswami 1996).

Porosity (ε) of the grain bed was defined as the fraction of space in a bed of grains that is not occupied by the grains. The percentage porosity was calculated using the following Eq. 8 (Mohsenin 1986):

$$\varepsilon = \left(1 - \frac{pb}{pt}\right)100 \tag{8}$$

Angle of repose is the angle with the horizontal at which the material will stand when piled. The angle of repose was determined using a topless and bottomless cylinder of known dimension. The cylinder was placed at the center of a raised circular plate and was filled with quality protein maize grains. The cylinder was raised slowly until the grains formed a cone on the circular plate of known diameter. To determine the angle of repose, the grains were allowed to fall freely from a hopper over a disc of known diameter to assume a natural slope. The angle of repose was then calculated from the measurement of the height and the radius of the cone using the following Eq. 9:

$$\phi = \tan^{-1}\frac{2H}{D} \tag{9}$$

where, θ = Angle of repose, degrees, H = Height of cone formed, mm, and D = Diameter of cone, mm.

The experimental results were subjected to analysis of variance (ANOVA) using AGRES (version 7.01) software and least significant difference test was used to describe the means with 99% confidence.

RESULTS AND DISCUSSION

Size and shape

Geometrical Parameters: The length (L), width (W), thickness (T), geometric mean diameter (D_g) and arithmetic mean diameter (D_a) increased significantly ($P \leq 0.01$) from 9.2476 to 10.2033 mm, 7.8684 to 8.2641 mm, 3.8572 to 4.7139 mm, 6.6445 to 7.0822 mm and 7.1304 to 7.5485 mm respectively, with increase of moisture content from 9% to 25% wb of quality protein maize grains (Fig 1 a-e). The increase in size could be attributed to the expansion of the grain as a result of moisture absorption in the intercellular spaces inside the grains (Solomon and Zewdu 2009). The dependence of these properties with moisture content could be represented by the following equations:

$$L = 0.0695x^2 - 0.1849x + 9.3658 \quad (R^2 = 0.9828) \tag{10}$$

$$W = 0.0038x^2 + 0.0894x + 7.7487 \quad (R^2 = 0.9481) \tag{11}$$

$$T = -0.0658x^2 + 0.6178x + 3.2783 \quad (R^2 = 0.9838) \tag{12}$$

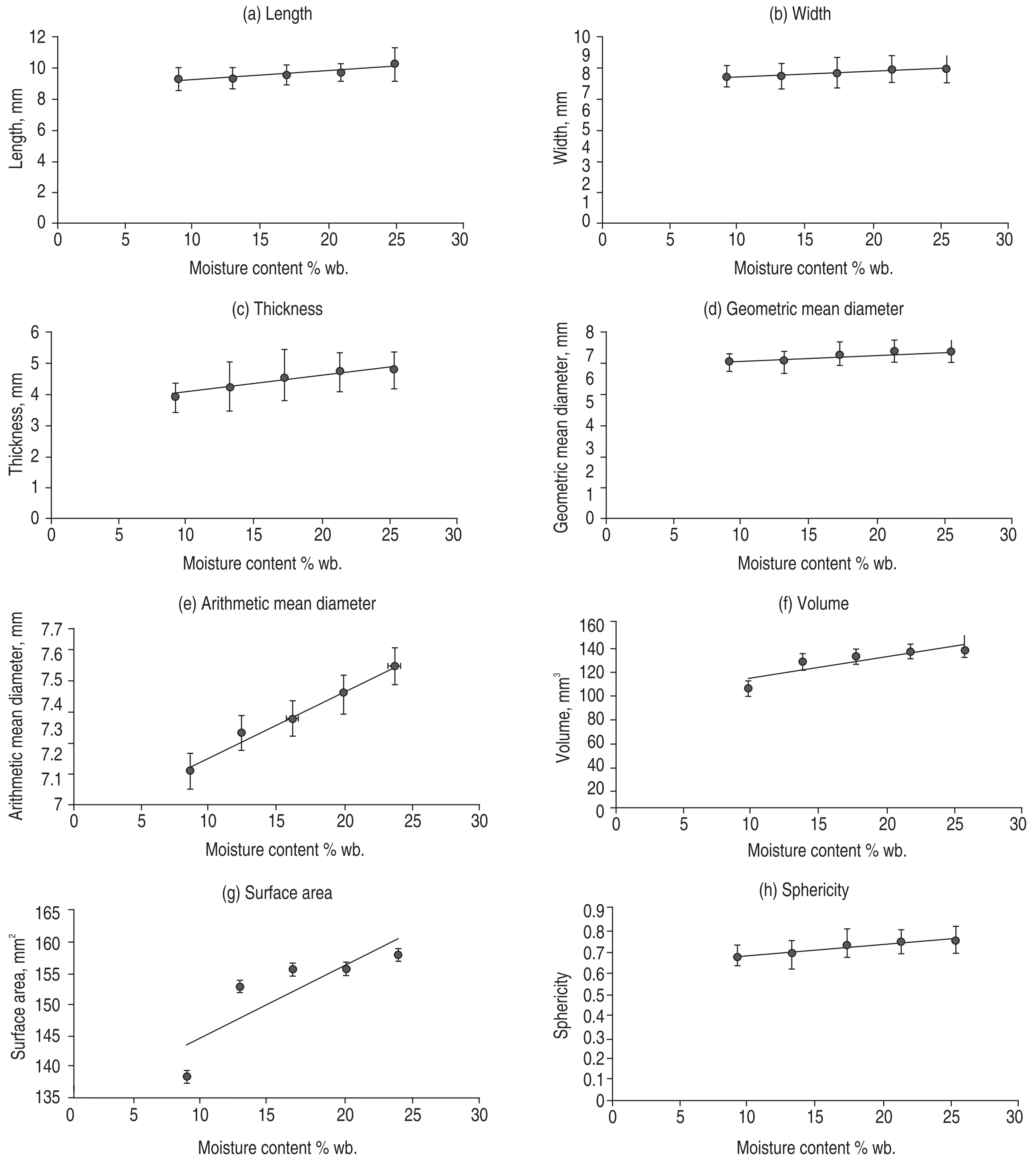


Fig 1 Effect of moisture content on (a) length (b) width (c) thickness (d) geometric mean diameter (e) arithmetic mean diameter (f) volume (g) surface area and (h) sphericity of quality protein maize

$$D_g = -0.0223x^2 + 0.2551x + 6.3745 \quad (R^2 = 0.891) \tag{13}$$

$$D_a = -0.0027x^2 + 0.1155x + 7.0301 \quad (R^2 = 0.9858) \tag{14}$$

where x is the moisture content of grain in% wb.

Similar trends were reported in this moisture content range for jatropha (Dutta *et al.* 1988), guna, chickpea and neem nut.

Volume: Volume (V) was calculated from the spatial dimensions of the quality protein maize grains. Volume displayed significant differences with change in moisture content of the grain. The values of the volume (Fig 1f) increased from 107.4 to 138.83 mm^3 in the moisture range from 9% to 25% wb. The increase in volume might have been caused by a proportional increase in the length, width and thickness. The relationship between moisture content (% wb) and volume (V) of the grain could be represented by the following polynomial equation:

$$V = -3.0121x^2 + 25.186x + 87.016 \quad (R^2 = 0.9569) \tag{15}$$

Similar trend in the entire moisture range was observed where an increase in volume of the grains, was reported for okra and pea grain (Yalcin *et al.* 2007).

Surface area: The surface area increased (Fig.1g) from 138.433 to 158.0703 mm^2 with increase in moisture content from 9% to 25% wb. The relation between surface area and moisture content is given by the equation:

$$A_S = -1.9462x^2 + 15.893x + 125.93 \quad (R^2 = 0.922) \tag{16}$$

Other researches also reported similar trend in surface area in whole moisture range for grains of jatropha, karanja kernel (Pradhan et al. 2008), rice, fenugreek (Altuntas *et al.* 2005).

Sphericity

Sphericity (Φ) was calculated from the geometric mean diameter and the main axis (L) of quality protein maize. The results of sphericity presented in Fig.1h. Sphericity displayed significant differences with change in moisture content of the grain. The values of the sphericity increased from 0.6874 to 0.7622 in the moisture range from 9 to 25% wb. According to Dutta *et al*. (1988), the quality protein maize can be considered as spherical since the sphericity value was more than 0.70 from higher moisture range i.e. 17% to 25% wb. The increase in sphericity might have been caused by a proportional increase in the width and thickness as compared to length of the quality protein maize grain. The relationship between moisture content (% wb.) and sphericity (Φ) of the grain could be represented by the following polynomial equation:

$$\Phi = -0.0033x^2 + 0.0407x + 0.6432 \quad (R^2 = 0.9027) \tag{17}$$

Similar trend in the entire moisture range of 10.20% to 18.30% db were observed where an initial increase in sphericity of the grains, followed by its decrease, were reported for okra and pea grain (Yalcin *et al.* 2007).

Thousand grain weight

Thousand grain weight increased from 223 g to 253 g as the moisture content increased from 9% to 25% wb ($P \leq 0.01$). It was found to be a linear function of moisture content and the relationship could be expressed using the following equation:

$$W_s = 1.095x^2 - 1.205x + 232.59 \quad (R^2 = 0.9731) \tag{18}$$

where, W_s= Thousand grain mass, g and x = Moisture content, % wb.

Similar linear increase had been observed by Dutta *et al.* (1988) for gram, Deshpande and Ojha (1993) for soybean, Singh and Goswami (1996) for cumin seeds.

Bulk density

Bulk density (ρ_b) of quality protein maize at different moisture content varied significantly ($P \leq 0.01$) and decreased from 982.4 to 812 kg/m^3 when moisture content increased from 9% to 25% wb. This behavior could be attributed to the fact that the increased mass of the sample associated with increased moisture was lower than the volume expansion experienced by the grains. This would cause the effect of having greater compaction (higher bulk density) in dry quality protein maize compared with wet grains. The relationship of bulk density (ρ_b) of quality protein maize and moisture content can be expressed by the following equation:

$$\rho_b = 11.5x^2 - 27.9x + 832.8 \quad (R^2 = 0.9864) \tag{19}$$

Similar trends were found for Koto and Manisoba cultivar of buckwheat (Parde *et al.* 2003) at moisture content (wb) range of 14.8%–17.9% and 13.0%–17.0%, respectively and for chickpea in the entire studied range.

True density

It was found that the true density of quality protein maize increased from 1143.333 to 1250 kg/m^3 as the moisture content of the quality protein maize increased from 9% to 25% wb. It could be seen that true density had a linear relationship with moisture content and could be represented as:

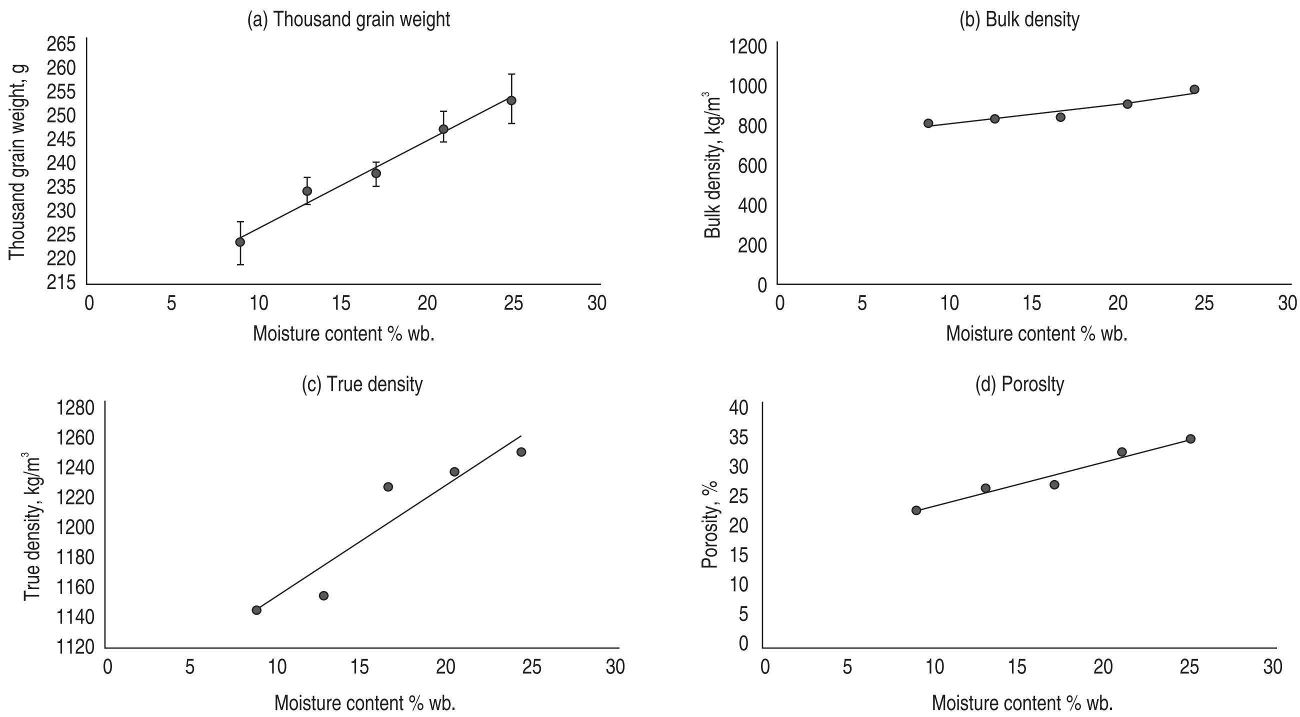
$$\rho_t = -4.0477x^2 + 53.953x + 1084.7 \quad (R^2 = 0.9099) \tag{20}$$

where ρ_t is the true density of quality protein maize in kg/m^3.

A similar trend of true density has been reported by Nimkar and Chattopadhyay (2001) for green gram.

Porosity

It was observed that when moisture content increased from 9% to 25% wb porosity increased significantly ($P \leq 0.01$) from 22.2087% to 34.4594%. The relationship between the value of porosity (ε) and the moisture content can be expressed as:



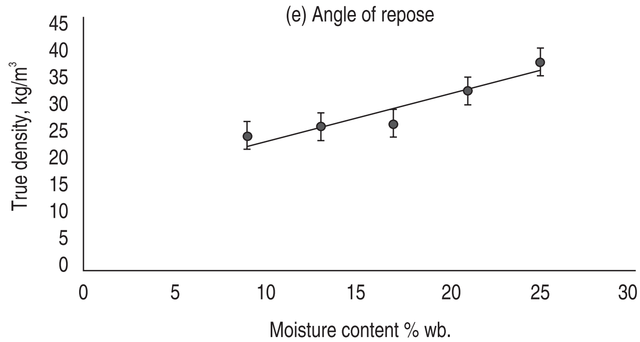


Fig 2 Effect of moisture content on (a) thousand grain weight (b) bulk density (c) true density (d) porosity and (e) angle of repose of quality protein maize.

$$\varepsilon = 0.1242x^2 + 2.3215x + 19.997 \quad (R^2 = 0.9584) \tag{21}$$

Similar behaviors were reported for pigeon pea seeds (Shepherd and Bhardwaj 1986).

Angle of repose

The experimental results of angle of repose with respect to moisture content exhibited a significant increase of angle from 24° to 37.03° ($P \leq 0.01$) with moisture content from 9% to 25% wb. The trend could be due to the fact that moisture in the surface layer of the grain kept them bound together by surface tension (Pradhan *et al.* 2008). The angle of repose is of paramount importance in the design of hopper openings, side walls and storage structures in the bulk of grains per ramp. The linear relationship between the angle of repose and the moisture content can be described by the following equation:

$$\delta = 0.9114\times^2 - 2.2206\times + 25.512 \quad (R^2 = 0.9802) \tag{22}$$

where, θ = Angle of repose, degree, μ = Moisture content,% wb.

Similar behavior of the angle of repose with respect to moisture content were observed for buckwheat varieties Koto, Koban and Manisoba (Parde *et al.* 2003), jatropha and karanja (Pradhan *et al.* 2008).The results of thousand grain weight, bulk density, true density, porosity and angle of repose are presented in Fig 2 a to e.

Conclusion

Effect of moisture content on physical properties of quality protein maize grains was studied. In the present study, the values of physical dimensions (length, width, thickness) and other properties of quality protein maize viz. geometric mean diameter, arithmetic mean diameter, surface area, volume, thousand grain weight, true density, porosity and angle of repose increased linearly ($P \leq 0.01$) except sphericity which shoued non linear behaviour whereas bulk density decreased ($P \leq 0.01$) with increasing moisture content in this range from 9% to 25% wb. This study provides information for quality protein maize that would be useful in the design and development of handling and post-harvest processing machinery.

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