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MOISTURE DEPENDENT PHYSICAL PROPERTIES OF MAIZE (*PMH-1*)

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Physical properties of maize were evaluated as a function of moisture content. The obtained data provide help in the designing of post-harvest handling machinery. In the moisture range of 10–18% wet basis (w.b.), the length of the rewetted grain increased from 10.01 to 10.65 mm, width increased from 8.57 to 8.70 mm, thickness ranged from 4.63 to 4.97 mm, geometric mean diameter (GMD) increased from 7.34 to 7.67 mm, sphericity increased from 0.72 to 0.73, thousand kernel weight (TKW) increased from 258.1 to 287.9 g, bulk density decreased from 591.6 to 554.2 kg m^{-3}, true density increased from 1194.9 to 1267.2 kg m^{-3}, porosity increased from 52.61 to 56.27%, hardness decreased from 293.75 to 228.04 N, initial cracking force decreased from 190.11 to 137.35 N and area ranges from 55.09 to 36.58 Nmm. In the same moisture range the angle of repose varied from 23.36 to 28.55 for grain. Lightness (L) of grain ranges from 62.82 to 59.26, a value (red-green axis) ranges from 13.97 to 8.96, b value (yellow-blue axis) ranges from 31.05 to 26.19 and hue angle (z%) decreased from 14.59 to 14.06 with increase in moisture content of grain from 10 to 18% w.b.

Keywords: maize, moisture, physical property, porosity

Maize is the most widely grown grain crop in the Punjab, India. The kernel of maize has a pericarp of the fruit fused with the seed coat referred to as “caryopsis”, typical of the grasses, and the entire kernel is often referred to as the “seed”. The cob is close to a multiple fruit in structure, except that the individual fruits (the kernels) never fuse into a single mass. The grains are about the size of peas, and adhere in regular rows round a white, pithy substance, which forms the ear. An ear can commonly hold 600 kernels and be 7 in (178 mm) in length. They are of various colours: blackish, bluish-gray, purple, green, red, white and yellow. When ground into flour, maize yields more flour with much less bran than wheat does. It lacks the protein gluten of wheat and, therefore, makes baked goods with poor rising capability.

Measuring some physical properties of this grain and their comparison with other grains are considered to be necessary for the proper design of equipment for handling, conveying, separation, drying, milling, storage and other processes (KACHRU et al., 1994). Despite an extensive search, no published literature was found on the detailed physical properties of maize and their dependency on operational parameters, which would be useful for the design of dehulling and storage systems. The properties of different types of grains have been determined by other researchers such as OUGT (1998) for white lupin; BARYEH (2002) for millet; CETIN (2007) for barbunia bean; OGUNJIMI and co-workers (2002) for locust bean grain and COSKUN and co-workers (2006) for sweet corn grain. Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities. Coefficients of static

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friction on different surfaces were measured. They can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans.

In this study, some physical properties of maize were determined, namely size and shape, GMD, sphericity, TKW, bulk and true densities, porosity, coefficients of static friction, angle of repose, hardness, initial cracking force and colour measured at various moisture contents in the range of 10–18% w.b. Although moisture content has been reported to influence several physical properties, Gupta and Prakash (1992) reported non-significant variations of sphericity for a wide range of moisture contents in safflower grain. An increase in grain moisture content was found to increase the angle of repose in faba bean (Fraser et al., 1978) as well as the coefficient of static friction in safflower grains (Gupta & Prakash, 1992). Thus, various physical properties of grains and their fractions are dependent on moisture content and appear to be important in the design of handling and processing equipment.

1. Materials and methods

For this study, the short duration modern var. PMH 1 of maize maturing within 95 days and widely grown in Punjab, India was selected. Bulk sample consisting of 16 kg of grains was procured from the Punjab Agricultural University, Ludhiana during July 2012. Grains were packed in double layered low density polyethylene bags of 90 mm thickness, sealed and stored at low temperature (4±1 °C). The required quantity of grain was taken out and allowed to warm up for approximately 2 h. The method of random sampling was used for sample preparation (Dutta et al., 1988). For each individual grain three principal dimensions, namely length, width and thickness, were measured using a digital vernier calliper (accuracy 0.1 mm). Because of the irregular shape of the maize, only the highest values of both width and thickness have been taken. To obtain the mass, each grain was weighed on a precision electronic balance reading to 0.0001 g. The geometric mean diameter (GMD) and sphericity (Ø) of grains were determined using the following methods.

1.1. Moisture content

The moisture content of grain was determined by an oven drying method (ISI, 1966). To study the effect of moisture content of the sample on some of its physical properties, samples of grain at desired moisture levels were prepared by adding calculated amounts of distilled water according to relation (Eq. 1) given by Sacilik and co-workers (2003) and sealed in separate polyethylene bags. The initial moisture content of the grains was 8.5% w.b.

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

where W_i is the initial mass of the sample in kg; M_i is the initial moisture content of the sample in % w.b.; and M_f is the final moisture content of sample in % w.b. The samples were then poured into separate polyethylene bags and the bags were sealed tightly. The samples were kept at 4±1 °C in a refrigerator for a week to enable the moisture to be distributed uniformly throughout the samples. Before starting a test, the required quantity of the grains were taken out of the refrigerator and allowed to equilibrate to the room temperature for about 2 h (SINGH & GOSWAMI, 1996). All the physical properties of the grains were determined at five moisture contents in the range of 10 to 18% w.b. with 15 replications at each moisture contents.

1.2. Geometric mean diameter and sphericity

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

$$\text{Sphericity} = \frac{(LWT)^{1/3}}{L} \tag{3}$$

where L, W and T are length, width and thickness, respectively.

1.3. Bulk density and true density

The bulk and true density for grain at different moisture levels were determined. The bulk density (ρ_b) is the ratio of the mass sample of the grain to its total volume. It was determined by filling a 1000 ml container with grain from a height of 15 cm, striking the top level and then weighing the contents (MOHSENIN, 1970). Bulk density for each replication was calculated from the following relation:

$$\rho_b = \frac{W_s}{V_s} \tag{4}$$

where the ρ_b is the bulk density in kg m^{-3}; W_s is the weight of the sample in kg; and V_s is the volume occupied by the sample in m^3.

1.4. True density

The true density (ρ_t) was defined as the ratio between the mass of maize and the true volume of the grains, and was determined using the toluene (C_7H_8) displacement method. Toluene was used instead of water because it is absorbed by grains to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of fennel grains in the measured toluene (TAVAKKOLI et al., 2009).

1.5. Porosity

The porosity was calculated from the values of bulk and true densities using the following relationship (MOHSENIN, 1970):

$$\text{Porosity} = \frac{(\text{True density} - \text{Bulk density}) \times 10}{\text{True density}} \tag{5}$$

1.6. Angle of repose

The emptying or dynamic angle of repose was measured for five moisture contents. For such measurement, a plywood box with a removable front panel was filled with grains. The front panel was quickly removed, allowing the seeds to flow and assume a natural slope (DUTTA et al., 1988). The angle of repose was calculated from the measurements of the vertical depth and radius of spread of the sample.

1.7. Static coefficient of friction

The static coefficient of friction for maize was measured against two structural materials, namely mild steel and galvanized iron. A galvanized iron cylinder of 100 mm diameter and 50 mm height was placed on an adjustable tilting plate, faced with the test surface, and filled with the sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the box resting on it was inclined gradually with a screw device until the box just started to slide down and the angle of tilt was read from a graduated scale (Joshi et al., 1993).

1.8. Texture analysis

Texture of the maize was evaluated on texture analyser (TA-XT2i) (Bourne, 1982). Maize subjected to compression test to measure hardness (N), initial cracking force (N) and area (Nmm) at different moisture content.

1.9. Colour analysis

Colour value L, a, b values and hue angle of maize measured using Hunter Lab Colorimeter (Kimura et al., 1993).

2. Results and discussion

2.1. Grain dimensions

In the moisture range from 10–18% w.b., the length of the rewetted grain increased from 10.01 to 10.65 mm, width ranges from 8.57 to 8.70 mm and thickness ranges from 4.63 to 4.97 mm as shown in Table 1.

2.1.1. Geometric mean diameter and sphericity. The geometric mean diameter of maize was higher than those reported for pigeonpea, muskmelon and longmelon grain (Ramakrishana, 1986) and was found close to safflower. Sphericity of maize was higher than those reported for pigeonpea (Shepherd & Bhardwaj, 1986). GMD of maize increased from 7.34 to 7.67 mm and sphericity ranges from 0.72 to 0.73 as the moisture content increased from 10 to 18% w.b. (Table 1)

2.2. Thousand kernel weight

The thousand kernel weight of grains was measured in the moisture range between 10 and 18% w.b. (Table 1). The thousand kernel weight increased with the increase in moisture content of grain from 258.12 g to 287.85 g. The results showed that the mass of 1000 grains was higher than millet (Baryeh, 2002) and karingda grains (Suthar & Das, 1996).

2.3. Bulk density

The bulk density of grains was measured in the moisture range between 10 and 18% w.b. The bulk density decreased with the increase in moisture content of grain (Table 1). Thus, it

Table 1. Variation in physical properties of maize at different moisture contents

Dimensions	Moisture content, % w.b.									
	10		12		14		16		18	
	Mean*	± SD	Mean*	± SD	Mean*	± SD	Mean*	± SD	Mean*	± SD
Length (mm)	10.01	0.60	10.23	0.83	10.35	0.63	10.53	0.31	10.65	0.61
Width (mm)	8.57	0.4	8.69	0.63	8.85	0.40	8.80	0.56	8.70	0.39
Thickness (mm)	4.63	0.39	4.76	0.21	4.69	0.34	4.93	0.52	4.97	0.36
GMD (mm)	7.34	0.22	7.50	0.30	7.54	0.25	7.64	0.15	7.67	0.26
Sphericity	0.72	0.05	0.734	0.039	0.728	0.04	0.726	0.027	0.733	0.034
TKW (g)	258.12	7.70	270.68	6.19	272.60	5.04	282.8	5.8	287.9	8.6
Bulk density (kg m^{-3})	591.63	0.02	585.76	0.01	551.40	0.02	546.8	0.01	554.2	0.02
True density (kg m^{-3})	1194.9	0.1	1204.60	0.04	1244.40	0.06	1248.5	0.05	1267.1	0.05
Porosity (%)	52.61	0.62	52.93	0.47	53.85	0.21	54.61	0.38	56.27	0.52
Coefficient of friction (N)	23.36	3.86	24.31	2.05	24.78	1.81	26.56	2.27	28.55	2.07
Angle of repose (°)	0.59	0.04	0.63	0.03	0.640	0.018	0.680	0.07	0.690	0.060
Hardness (N)	293.75	4.64	277.52	14.36	261.16	5.95	238.93	10.25	228.04	9.20
Initial cracking force (N)	190.11	7.07	167.35	19.54	164.31	6.23	143.59	10.30	137.4	14.9
Area (Nmm)	55.09	2.78	56.69	1.95	47.37	9.49	47.84	8.00	36.58	2.40
Colour L	62.82	3.23	64.23	1.24	63.03	2.59	60.89	2.56	59.26	2.32
a	13.97	2.53	12.61	0.34	10.71	1.73	11.76	1.00	8.96	1.50
b	31.05	4.16	32.10	2.63	27.54	3.05	28.15	2.30	26.19	1.86
z%	14.59	3.74	15.22	1.48	16.24	3.40	14.38	2.32	14.06	1.57

*: Each value is mean of 15 replications; SD: standard deviation

appears that the increase in volume was more than proportional to the increase in mass of the bulk grain. The bulk density of maize decreased from 591.630 to 554.190 kg m^{-3} and at given moisture levels the values were higher than those of safflower (GUPTA & PRAKASH, 1992).

2.4. True density

The true density of grain was found to vary from 1194.9–1267.1 kg m^{-3}, when the moisture level increased from about 10 to 18% w.b. (Table 1). The true density of maize varies linearly with moisture content similar to other grains such as corn and hard red winter wheat and the values were found to be higher than those of safflower (GUPTA & PRAKASH, 1992) and pumpkin grains (JOSHI et al., 1993).

2.5. Porosity

The porosity was evaluated for maize using Eqn 5. It increased from 52.61 to 56.27% for grains when the moisture content changed from 10 to 18% w.b. (1). Higher porosity provides better aeration and water vapour diffusion during deep bed drying. Similar trend was reported for gram (DUTTA et al., 1988) and sunflower (GUPTA & DAS, 1997).

2.6. Static coefficient of friction

The experimental results showing the effect of moisture content and structural surfaces on the static coefficient of friction are given in Table 1 for maize, friction increased with moisture content against both mild steel and galvanized iron. Further, these values were slightly higher for mild steel than for galvanized iron. This may be due to the smoother surface of galvanized iron compared with mild steel. The difference in coefficients for maize on both surfaces was found to be significant at the 1% level at moisture contents between 10 and 18% w.b. Similar findings were reported for millet (BARYEH, 2002), pumpkin seeds (JOSHI et al., 1993), karingda seeds (SUTHAR & DAS, 1996), and corn seed (SEIFI & ALIMARDANI, 2010).

2.7. Angle of repose

The angle of repose of maize at different moisture contents are shown in Table 1. It increased from 23.36 to 28.55 in the moisture range of 10 to 18% w.b. This may be due to the rough surface or shape factor of maize that imposes resistance to the maize in sliding on one another. The surfaces of the pigeonpea, faba bean, safflower and oilbean seed may be comparatively smoother or have a greater sphericity, thus enabling them to slide more easily on one another, resulting in a lower value of angle of repose. A linear increasing angle of repose as the seed moisture content increases has also been noted by OJE and UGBOR (1991) for oilbean seeds and by JOSHI and co-workers (1993) for pumpkin seeds.

2.8. Hardness and initial cracking force

The hardness and initial cracking force of maize at different moisture contents are shown in Table 1. Both hardness and initial cracking force decreased from 293.75 to 228.04 N and 190.11 to 137.35, respectively, for maize in the moisture range of 10 to 18% w.b. A linear decreasing in hardness and initial cracking force as the maize moisture content increases has not yet been reported in the literature. The area of maize decreased from 55.09 to 36.58 Nmm with increase in moisture content.

2.9. Colour

The colour of maize at different moisture contents in terms of L, a, b and z% value were measured (Table 1). Lightness (L) of maize ranged from 62.82 to 59.26, a value (red-green axis) decreased from 13.97 to 8.96, b value (yellow-blue axis) decreased from 31.05 to 26.19 and hue angle (z%) decreased from 14.59 to 14.06 with increase in moisture content from 10 to 18%, w.b. A linear decrease in L, a, b and hue angle was found as the moisture content of maize increased. Similar findings have not been reported in literature.

3. Conclusions

The average length, width and thickness of maize were 10.117 mm, 8.567 mm, 4.625 mm respectively. The length of the maize was found to be closely related to its width but less associated with its thickness and mass. The mean geometric mean diameter and sphericity of maize were 7.38 mm and 0.73, respectively. In the moisture range from 10–18% w.b., the length of the rewetted maize increased from 10.01 to 10.65 mm, width ranged from 8.57 to 8.70 mm, thickness ranged from 4.63 to 4.97 mm, geometric mean diameter (GMD) ranged from 7.34 to 7.67 mm, sphericity ranged from 0.72 to 0.73, thousand kernel weight (TKW) increased from 258.12 to 287.85 g, bulk density decreased from 591.63 to 554.19 kg m^{-3}, true density increased from 1194.92 to 1267.15 kg m^{-3}, porosity increased from 52.61 to 56.27%, hardness decreased from 293.75 to 228.04 N, initial cracking force decreased from 190.11 to 137.35 N and area decreased from 55.09 to 36.58 Nmm. The static coefficient of friction of maize varied from 0.590 to 0.690 with the increase in moisture content from 10–18% w.b. The angle of repose increased from 23.36 to 28.55 for maize in the moisture range of 10–18% w.b. A linear decrease in L, a, b and hue angle (z%) as the maize moisture content increased has been found.

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