The Pharma Innovation Journal 2021; SP-10(12): 332-337

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(12): 332-337

www.thepharmajournal.com
Received: 15-10-2021
Accepted: 20-11-2021

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Moisture dependent physical properties of maize cobs and kernels

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Abstract
The physical property of maize cob and grains plays a significant role in designing of various components of maize sheller machine. The physical properties of maize grain were investigated for three variety of maize i.e. NK30, JKMH4222 and Bio 9544 at three moisture level of 12, 14 and 16 per cent (db). Area of the woody ring was found to be highest (206.47 mm2) followed by area of glume, area of pith. Maize cob is composed of three tissue fractions, chaff, woody ring, and pith, with dry weight percentages of 22.1%, 76.5%, and 1.4%, respectively. The mean value of top diameter (D_t), upper diameter (D_u), middle diameter (D_m), lower diameter (D_l) and bottom diameter (D_b) 97 of the maize cob were 44.4, 48.1, 52.5, 53.5and 55.4 cm respectively. The linear dimensions i.e. length, width, thickness and geometric mean diameter (GMD) of maize grains increased with increase in moisture content for all three varieties. The highest length, width and thickness were observed for the NK 30 of maize as 11.40, 8.56 and 4.50 mm, respectively. Furthermore, the highest surface area, 1000 grain weight and roundness were observed for the NK 30 of maize as 180.71 mm^2, 252.85 g and 4.67 mm, respectively at moisture content of 16%.

Keywords: moisture dependent physical, maize cobs, kernels

Introduction
Maize (*Zea mays*) is the second most-sought crop after paddy preferred by farmers in Chhattisgarh. In Chhattisgarh maize is mainly produced in Bastar district and Surguja's hilly terrain during the Kharif season. At present in Chhattisgarh total area, production, productivity was 119.6 thousand ha, 306.98 metric tonnes and 2.566 t/ha, respectively (Annon, 2020) [1]. Maize grain starch is used as a substitute for talc in bath powder and is also used for starching clothes. Maize grains provide one of the cheapest and best materials for the production of fermented liquors (Kochar and Kenneth, 1988). After maturity the maize cobs are harvested manually by hand plucking. The outer husks are peeled from the whole cobs. Maize shelling manually is a very exhausting and time-consuming task. Many machines are available which can shell maize, but these are usually costly for rural farmers and therefore, necessitated the design of a low-cost system that will be affordable. The physical properties are important in designing particular machine or determining the behaviour of the product for its handling. The size and shape of maize grains are essential properties in designing of the threshing sieve and cleaning sieve in maize sheller. Bulk density and porosity have an effect on the structural loads and are important to decide the size of hopper and capacity of the machine. The angle of repose is useful in designing of the hopper, storage and transport. Terminal velocity of grains, kernel and husk are useful in the design of pneumatic conveying and cleaning system of grains. The coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting and storing structures (Subramanian and Viswanathan, 2007). Hence study was undertaken to find out moisture dependent physical properties of maize cob and kernel in 12, 14 and 16% moisture content.

Materials and Methods
Maize cobs and grains for the present study were procured from the department of Agronomy, IGKV, Raipur. The sample was cleaned manually to remove all foreign materials such as dust, husk, small branches and immature seeds. Hundred grams of each sample were placed in a hot air oven at 105 ^{0}C for 24 h to determine the initial moisture content of the grain using the following formula (AACC, 1995) [2].

$$MC\ (\%) = \frac{(W1-W2)}{(W1-W3)} \times 100$$

Where, MC= Moisture content on dry basis, %; W1= Initial weight of the bowl, g; W2 = sample weight before drying + bowl weight, g; W3 = sample weight after drying + bowl weight, g.

Seed sample of desired moisture content levels were prepared by adding calculated amount of distilled water by using following equation and mixed thoroughly (Sacilink *et al.*, 2002)

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

Where, Q = Weight of water to be added, g; Wi = Initial weight of seed sample, g; mi = Initial moisture content of seed sample (% db); and mf = Final moisture content of seed sample (% db).

Macro morphology characteristics of maize

The macrostructure of the maize cob consists of the pith, the woody ring, and the glume. The cross-section of the pith is an irregular circle, and its outer side is an annular woody ring and an annular glume. A single glume is S-shaped, divided into outer glume and inner glume. The macro morphology of the cross-section was observed. The areas of the pith, woody ring and glume were calculated by Equations (3.1), (3.2) and (3.3), respectively.

$$Ap = \pi(r_1)^2 \quad (3.1)$$

Where,
Ap= Area of pith, mm^2;
r_1= radius of pith

$$Awr = \pi((r_2)^2 - (r_1)^2) \quad (3.2)$$

Where,
Awr = Area of woody ring, mm^2;
r_2= radius of woody ring

$$Ag = \pi((r_3)^2 - (r_2)^2) \quad (3.3)$$

Where,
Ag= Area of glume, mm^2;
r_3= radius of glume, mm

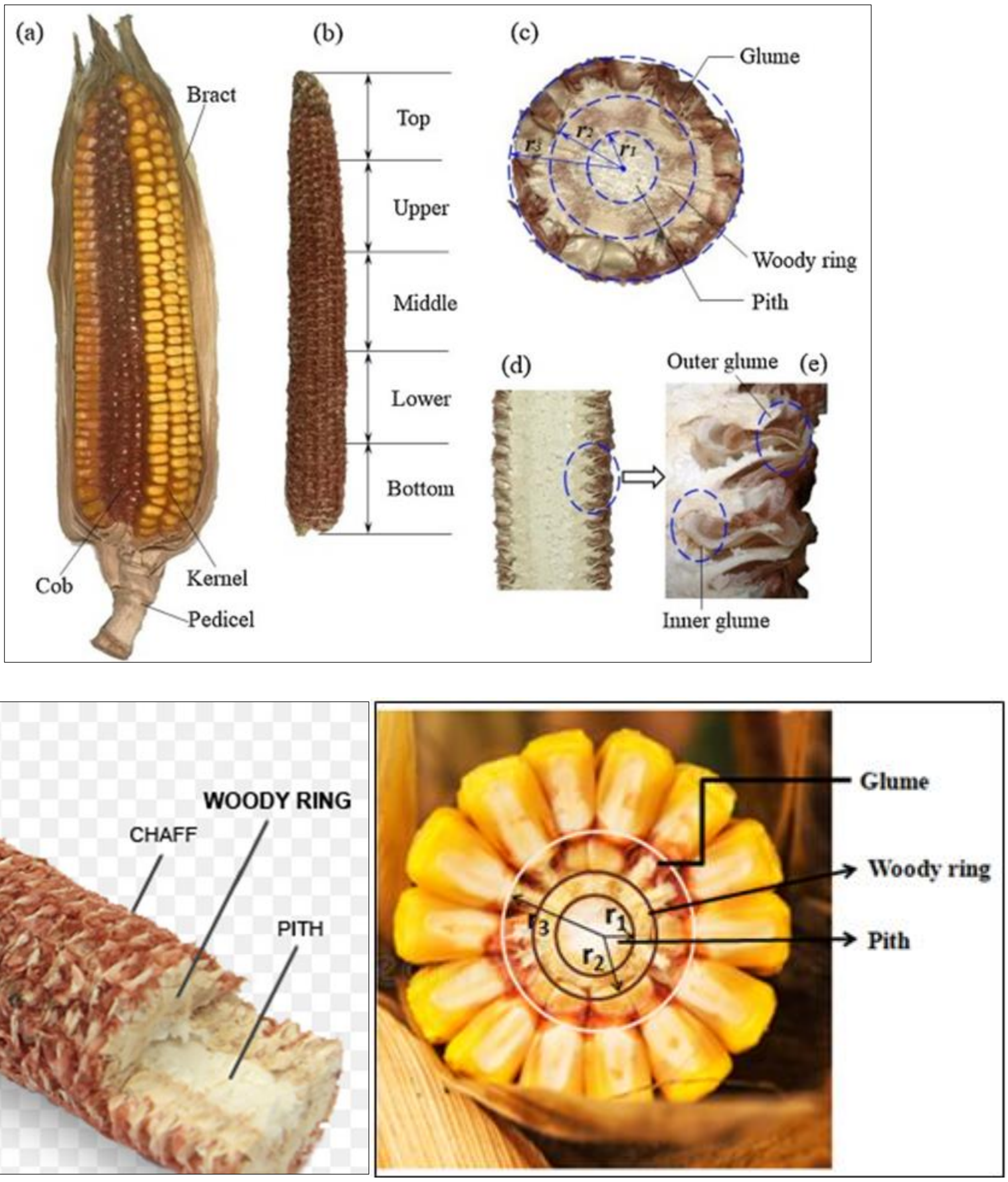

Fig 1: Macro morphology of the cross-section of maize cob

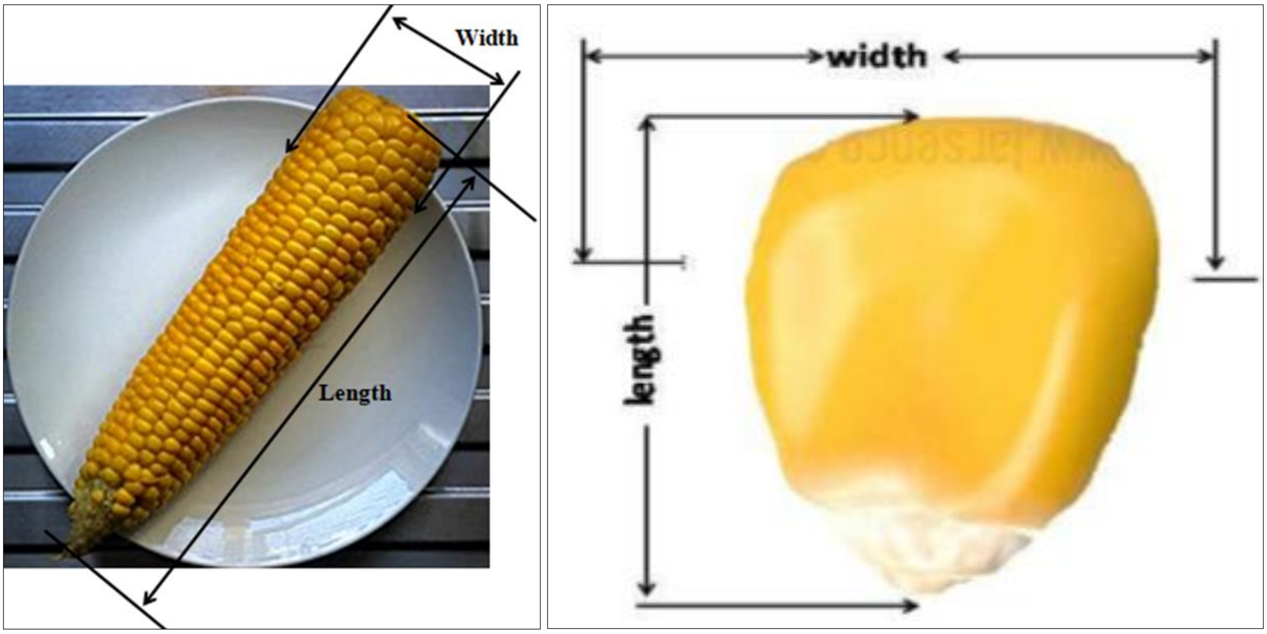

Fig 2: Physical properties of maize cob and maize grains

Fig 3: Linear dimensions

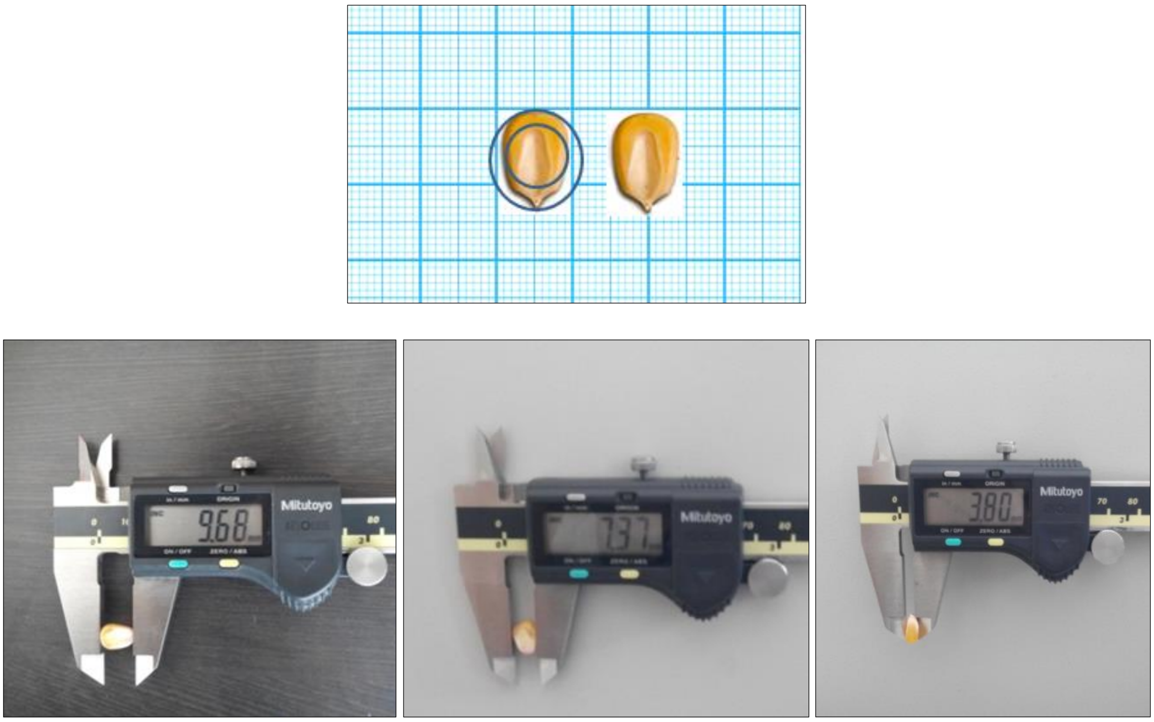

Fig 4: Measurement of length, width and thickness of maize seed

From each variety, twenty-five numbers of maize cobs drawn randomly and each variety consists of at least 16 to 19 columns, from each column one number of kernels drawn spirally over the cobs and their linear dimensions were measured using a vernier caliper with an accuracy of ±0.01 mm. Linear dimensions of cob and kernel measured were: length (l), breadth (b) and thickness (t). Breadth (b) is the randomly measured diameter at three sections of cob from top to bottom. Thickness (t) is the smallest intercept diameter at three sections for cobs. (Ghaffari *et al.*, 2013 and Karthik *et al.*, 2016) [8].

Geometric mean diameter (GMD)

The geometric mean diameter (D_p) of maize seed as well as cob was calculated by using the following relationship (Mohsenin, 1986) [4]:

$$D_g = (LWT)^{1/3} \quad (3.4)$$

Where,
L = largest intercept (length), mm;
W= width, mm; and
T = Thickness, mm.

Arithmetic mean diameter (AMD)

For each variety of maize, the length, width, thickness and mass of maize grains were measured on randomly selected 100 maize grains. The length, width and thickness of grains were measured using a digital caliper with an accuracy of ±0.01 mm. The arithmetic mean diameter (D_a) of the grains were calculated by using the following equations

$$Da=(L \times W \times T)/3 \quad (3.5)$$

Thousand grain weight (TGW)

Thousand grain and kernel weight 'M' was determined by counting 1000 seeds and weighing with an electronic balance. Electronic balance with least count 0.001g was used for measurement.

Sphericity

Sphericity defines the ratio of the diameter of a sphere of the same volume as that of the particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle (Sahay and Singh, 1994) [5]. This parameter shows the shape character of seeds relative to the sphere having the same volume.

$$\text{Sphericity } \frac{(LWT)^{1/3}}{L} \quad (3.6)$$

Where,
L = largest intercept (length), mm;
W= width, mm and
T = Thickness, mm.

Roundness

It is measurement of sharpness of solid materials. The maize grains (10 numbers) were projected on a graph paper and traced. Roundness was estimated by using the formula as given below:

$$\text{Roundness}=Ap/ Ac \quad (3.7)$$

Where,
Ap = Largest projected area of maize grains in natural rest position, mm^2
Ac = Area of the smallest circumscribing circle, mm^2

Surface area

Surface area is generally indicative of its pattern of behavior in a flowing fluid such as air, as well as the ease of separating extraneous materials from the product during cleaning by pneumatic means. Surface area was calculated by following formula

$$S =\pi (D_g)^2 \quad (3.8)$$

Where,
Dg= Geometric mean diameter, mm.

Cross sectional area

The cross-sectional area of the cob was determined by the formula given by (Mohsenin, 1986) [4].

$$ACS=\frac{\pi}{4}\{\frac{(L+B+T)^2}{3}\} \quad (3.9)$$

Results and Discussions

Different macro morphological characteristics of the maize cob were measured and are presented in Table 1. The mean value of the width, length, area of the pith, area of woody ring, and area of glume and shape index of the maize con without grain was found to be 39.59 mm, 167.80mm, 49.95 mm^2, 206.47 mm^2, 190.97 mm^2 and 1.69, respectively. The data showed that the grain was attached to the woody ring very firmly by glume. The variation in area of pith was found to be highest whereas the shape index was found to be lowest. Area of the woody ring was found to be highest (206.47 mm^2) followed by area of glume, area of pith. It may be due to the fertilizer absorption of the woody ring in central position of the maize cob. It was also observed that maize cob is composed of three tissue fractions, chaff, woody ring, and pith, with dry weight percentages of 22.1%, 76.5%, and 1.4%, respectively. The similar type of observation was also reported by Takada *et al.* (2018).

Table 1: Different macro morphology of the cross-section of maize cob

S. No.	Width of maize, mm	Length of maize, mm	Area of pith A_p, mm^2	Area of woody ring A_{wr}, mm^2	Area of glume A_g , mm^2
Mean	39.59	167.80	49.95	206.47	190.97
Range	37.68-41.89	148-188	39.81-59.44	190-246	164-232
CV	4.07	9.10	15.55	11.07	12.94
SD	1.61	15.27	7.77	22.85	24.72

Table 2: Diameter of the maize cob at different position from the stalk (bottom position)

S. No.	Top diameter (D_t)	Upper diameter (D_u)	Middle diameter (D_m)	Lower diameter (D_l)	Bottom diameter (D_b)	Total Length (L_t)
Mean	44.4	48.1	52.5	53.5	55.4	191.4
Range	35.2-50.6	42.5-52.4	50.7-55.2	50.8-55.9	51.0-55.8	186-202
CV	7.68	12.96	26.64	26.18	20.29	21.10
SD	0.58	0.37	0.20	0.20	0.27	0.91

The diameter at five points of the maize cob were measured and presented in Table 2. It was observed that the mean value of top diameter (Dt), upper diameter (Du), middle diameter (Dm), lower diameter (Dl) and bottom diameter (Db) of the maize cob were 44.4, 48.1, 52.5, 53.5 and 55.4 cm, respectively. Further, it was found that the total length of the maize cob was observed to be 191.4 mm.

Effect of moisture content and variety on length, breadth, thickness

The mean values of length were found to be 9.76, 10.01 and 10.27 mm at 12, 14 and 16% moisture content and were found significantly different. It was found highest (11.14 mm) for variety NK 30 and lowest in case of variety Bio 9544. It was also observed that moisture content also plays a vital role on length of grains. It was observed 10.27 mm in case of moisture content 16% which was significantly highest.

The values of breadth were found to be 8.00, 8.11 and 8.23 mm for NK 30, JKMH 4222 and Bio 9544 respectively and were statistically different (CD =0.05) at 1% level of significance. The mean values of thickness were found to be 3.90, 4.16 and 4.36 mm at 12, 14 and 16% moisture content and were found significantly different (CD = 0.05) at α = 0.01 level of significance. It was found highest (4.23 mm) for variety NK 30 and lowest in case of variety Bio 9544.

Table 3: Effect of moisture content and variety on length, breadth, thickness

Moisture content (%)	Length (mm)			Breadth (mm)			Thickness (mm)		
	V1	V2	V3	V1	V2	V3	V1	V2	V3
M1(12.00)	10.90	9.46	8.93	7.64	7.91	7.91	3.92	3.92	3.86
M2 (14.00)	11.12	9.62	9.29	7.80	8.04	8.32	4.26	4.21	4.03
M3 (16.00)	11.40	9.81	9.60	8.56	8.39	8.47	4.50	4.35	4.22
Mean	11.14	9.63	9.27	8.00	8.11	8.23	4.23	4.16	4.04

Effect of moisture content and variety on geometric mean diameter (GMD), and arithmetic mean diameter (AMD) and thousand grain weight. The mean values of geometric mean diameter of maize grains varied from 6.47 to 7.59 mm among all the treatments and were significantly different at 1% level of significance. The values of GMD were found to be 6.66, 6.93 and 7.22 mm at 12, 14 and 16% moisture content and were found significantly different with CD = 0.04 at 1% level of significance. It was found highest (7.21 mm) for variety NK 30 and lowest in case of variety Bio 9544.

The observed values of geometric mean diameter were found to be 7.79, 7.30 and 7.18 mm for NK 30, JKMH 4222 and Bio 9544 respectively and were statistically different. Interaction between the variety and moisture content is depicted that there is significant difference at 1% level in between the varieties on arithmetic mean diameter. It was found highest (7.79 mm) for variety NK 30 and lowest (7.18) in case of variety Bio 9544. The values of 1000 grain weight were found to be 228.63, 234.52 and 242.84 g at 12 ,14 and 16% moisture content and were found significantly different with CD = 2.43 at 1% level of significance. The interaction between the variety and moisture content. Similar results were also reported by Chilur *et al.* (2016) [3], Sangamithra *et al.* (2016), Ashwin *et al.* (2017), Barnwal *et al.* (2012).

Table 4: Effect of moisture content and variety on geometric mean diameter (GMD), and arithmetic mean diameter (AMD) and thousand grain weight

Moisture content (%)	Geometric mean diameter (mm)			Arithmetic mean diameter (mm)			Thousand grain weight (gm)		
	V1	V2	V3	V1	V2	V3	V1	V2	V3
M1(12%)	6.87	6.63	6.47	7.49	7.09	6.90	237.15	217.08	231.68
M2 (14%)	7.16	6.86	6.76	7.73	7.29	7.21	240.53	225.60	237.43
M3 (16%)	7.59	7.08	6.98	8.15	7.51	7.43	252.85	233.10	242.58
Mean	7.21	6.86	6.74	7.79	7.30	7.18	243.51	225.26	237.23

Table 5: Effect of moisture content and variety on sphericity, roundness, surface area and cross sectional area

Moisture content (%)	Sphericity			Roundness			Surface area			Cross sectional area		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
M1(12%)	0.63	0.70	0.73	3.25	2.63	2.0	148.27	137.98	131.49	132.06	118.52	112.04
M2 (14%)	0.64	0.71	0.73	3.69	3.63	2.48	161.02	147.95	143.66	140.60	125.13	122.51
M3 (16%)	0.67	0.72	0.73	4.67	4.01	3.325	180.71	157.58	153.15	156.56	133.00	129.92
Mean	0.65	0.71	0.73	3.87	3.42	2.60	163.33	147.84	142.77	143.07	125.55	121.49

It was observed from the Table 5 that the mean values of sphericity of maize grains varied from 0.63 to 0.73 mm among all the treatments and were significantly different at 1% level of significance. The observed values of sphericity were found to be 0.65, 0.71 and 0.73 mm for NK 30, JKMH 4222 and Bio 9544 respectively and were statistically different (CD =0.01) at ∝ =0.01 level of significance. It was found highest (0.73 mm) for variety Bio 9544 and lowest in case of variety NK 30. It was observed 0.71 mm in case of moisture content 16% which was significantly highest (∝ =0.01). The mean values of roundness of maize grains varied from 2.003 to 4.678 mm among all the treatments and were significantly different at 1% level of significance. It was found highest (0.73 mm) for variety Bio 9544 and lowest in case of variety NK 30. It was observed 0.71 mm in case of moisture content 16% which was significantly highest

It was observed from the Table 5 that the mean values of surface area of maize grains varied from 131.49 to 180.71 mm^2 among all the treatments and were significantly different at 1% level of significance. The observed values of surface area were found to be 163.33, 147.83 and 142.77 mm^2 for NK 30, JKMH 4222 and Bio 9544 respectively and were statistically different (CD = 1.92) at α =0.01 level of significance. It was found highest (163.33 mm^2) for variety

NK 30 and lowest (142.77 mm^2) in case of variety Bio 9544.
cross-sectional area of maize grains varied from 112.04 to 156.56 mm2 among all the treatments and were significantly different. The observed values of cross-sectional area were found to be 143.07, 125.55 and 121.49 mm2 for NK 30, JKMH 4222 and Bio 9544, respectively.

Conclusions
The physical parameters play vital role in the determination of the dimensions of the machine parts like sieve size, hanging distance of the chain flail from the concave, cleaning system, hopper, cylinder diameter as well as its length.
The physical properties of maize were significantly affected by moisture content and variety.
The mean value of the width, length, area of the pith, area woody ring, and area of glume and shape index of the maize con without grain was found to be 39.59 mm, 167.80mm, 49.95 mm2, 206.47 mm2, 190.97 mm2 and 1.69 respectively.
It was observed that the mean value of top diameter (Dt), upper diameter (Du), middle diameter (Dm), lower diameter (Dl) and bottom diameter (Db) of the maize cob were 44.4, 48.1, 52.5, 53.5 and 55.4 mm respectively with mean total length of 191.4 mm.
It was concluded that the mean value of linear dimensions like length, width, thickness, AMD, GMD, sphericity, roundness, surface area and cross-sectional area of maize seed increased with increase in moisture content.

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