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Research Article

INVESTIGATION ON ENGINEERING PROPERTIES OF MAIZE FOR DEVELOPMENT OF MAIZE DEHUSKER CUM SHELLER

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Abstract- The study has been conducted to investigate the engineering properties of popular varieties of maize grown in Karnataka *viz.*; Mahyco [Hero 550], Hema variety, Ganga Kaveri [GK 3090] and CP 818 were selected in Karnataka. The engineering properties such as mean linear dimensions such as length, width and thickness of maize grain were found as 10.99 mm, 8.18 mm and 5.15 mm, respectively. The mean length, diameter and weight of un-dehusked cob were 179.36 mm, 53.88 mm and 212.76 g, respectively, with a Standard Deviation [SD] of 29.56 mm, 4.37 mm and 13.56 mm, respectively. The Physical properties *viz.*, roundness, arithmetic mean diameter, geometric mean diameter, sphericity, surface area, bulk density, true density, bulk density, true density, moisture content, test weight of grains [W_{1000}] and grain to straw [husk and grainfree cob] ratio were observed as 0.28, 8.15 mm, 7.69 mm, 0.69, 209.17 mm^2, 0.74 g cc^{-1}, 1.03 g cc^{-1}, 276.58 g and 3.30, respectively. The aerodynamic property, i.e. terminal velocity of grain varied from 14.56 to 15.6 m s^{-1} with 0.43 m s^{-1} SD, whereas the mean terminal velocity of husk was 1.2 m s^{-1}. The frictional properties such as angle of repose was found 22.76˚ and coefficient of friction was 0.31 [grain-grain], 0.35 [grain-fly wood], 0.44 [grain-MS sheet] and 0.50 [grain to wood].

Keywords- Maize properties, Maize de-husking, Maize shelling

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Introduction

Maize [*Zea mays* L.] positions as the third most leading cereal grain in the world. Identifying the engineering properties are useful and necessary in the design and successful operation of numerous equipment employed in agricultural operations [1-3]. The present investigation helps in the development of post-harvest process, i.e. maize dehusking, shelling and cleaning of grain. The engineering properties of four maize varieties [*viz.*, Mahyco [Hero 550], Hema hybrid variety, Ganga Kaveri [GK-3090] and CP818] selected. The development of dehusker cum sheller for maize cobs requires the knowledge of engineering properties such as physical [shape and size, roundness, arithmetic and geometric mean diameter, sphericity, surface area, bulk density and true density], moisture content, test weight of grains and grain to dry matter [husk and grain free cob] ratio], aerodynamic [terminal velocity] and frictional [angle of repose and coefficient of friction] properties of maize grains.

Materials and Methods

All the four varieties of maize were chosen a random sampling of 20 kg taken from farmers' fields immediately after harvesting in different districts of Karnataka and used to determine the optimum engineering [physical, aerodynamic and mechanical] properties.

Physical properties of the maize

Dimensions of the maize cob and grains

For all the four varieties of the maize cobs, 20 randomly picked cobs were selected for the study. Since the linear dimensions of maize grains affected by moisture content, the measurements were carried when moisture content at 11-13.5% [w. b.] in all four varieties to avoid bias. The weight related properties were measured for all varieties after the 10th day of harvested. The similar method followed in case of weight and dimensions measurement found in study of Jayan and Kumar [4] for maize crop.

The length of un-dehusked cob [mm], stalk length [mm], weight of un-dehusked cob [g], linear dimensions of maize grains [at wet bulb [w.b.] moisture content of 11 to 13.5%] [mm], number of grain lines in cob, number of grains in one line of the cob, minimum diameter of cob without grains [mm], maximum diameter of cob without grains [mm], average length of shelled cob [mm], diameter of un-dehusked cob [mm] and shape were determined using digital vernier calliper and weighing balance with an accuracy of 0.01 mm and 0.01 g, respectively. The similar studied conducted by Tarighi et al. [5] and Singh and Singh [2010][6] for development maize threshing systems.

Roundness

The roundness is a measure of the sharpness of the corners of the solid. Several methods have been proposed for estimating the roundness. The maize grains [10 numbers] were projected on a graph paper and traced. The roundness was calculated using the following formula [4].

$$\text{Roundness} = \frac{A_p}{A_c} \quad \ldots [1]$$

Where,

A_p = Largest projected area of maize grains in natural rest position, mm^2

A_c = Area of the smallest circumscribing circle, mm^2

Arithmetic and geometric mean diameter

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 calliper with an accuracy of 0.01 mm. The arithmetic mean and geometric mean diameter were calculated from the three axial dimensions. The arithmetic mean diameter [D_a] and geometric mean diameter [D_g] of the grains were calculated by using the following equations [7].

$$D_a = \frac{(L+W+T)}{3},\ mm \quad \ldots [2]$$

$$D_g = (L+W+T)^{1/3},\ mm \quad \ldots [3]$$

Where,

L = Length of maize grain, mm

W = Width of maize grain, mm

T = Thickness of maize grain, mm

Sphericity

The sphericity [ϕ] is defined as the ratio of the surface area of a sphere with the same volume as the grain to the surface area of the grain. This measurement was determined using the following equation [7 & 3].

$$\phi = \frac{(L \times W \times T)^{1/3}}{L} \quad \ldots [4]$$

Surface area

The surface area [S] of an agricultural product is generally indicative of its pattern of behaviour in a flowing fluid such as air, as well as the ease of separating extraneous materials from the product during cleaning by pneumatic means. The surface area of grains was found by analogy with a sphere of the same geometric mean diameter. The surface area of grains was calculated by using the following formula [7 &4].

$$S = \pi [D_g]^2,\ mm^2 \quad \ldots [5]$$

Bulk density

The bulk density [ρ_b] of maize grains was determined using the standard test procedure reported by Singh and Goswami [18]. The standard procedure involves filling a container of 500 ml with the grain to a height of 150 mm at a constant rate and then weighing the content.

$$\rho_b = \frac{M}{V},\ g\ cm^{-3}$$

$$\rho_b = \frac{4M}{\pi D^2 h} \quad \ldots [6]$$

Where,

M = Mass of the grain sample, g

V = Volume of glass jar sampler, cm^3

D = Diameter of glass jar sampler, cm

h = Height of glass jar sampler, cm

True density

True density [ρ_t] is used in the design of hoppers, storage bins, and separation of desirable materials from impurities. The apparatus used for measuring the true density of grains consists of a 100 ml measuring jar and a weighing balance. A 50 ml of toluene was taken in a measuring jar and the known weight of grain sample was poured into the measuring jar. The rise in the toluene level was recorded as the true volume of the grains without void space. The true density of the grain was calculated by using the following formula [7 & 3].

$$\rho_t = \frac{W}{V},\ g\,cm^{-3} \quad \ldots [7]$$

W =Weight of grains, g

V =Volume of grains excluding void space, cm^3

Moisture content of grains

The moisture content of maize grains was determined by oven drying method. The grain samples were kept for 24 hours at 105 ˚C temperature in oven according to IS 7051-1973 [9] and moisture content was calculated accordingly. Moisture content of grains:

$$= \frac{(W1-W2)}{(W1-W3)} \times 100,\ \% \quad \ldots [8]$$

Where,

W_1 = Weight of the wet sample, g

W_2 = Weight of the dry sample, g

W_3 = Weight of the tray, g

Test weight of grains

For measuring the weight of the grains, digital electronic weigh balance having the accuracy of 0.01 g was used. In order to determine the one thousand grains weight [W_{1000}], one thousand randomly picked maize grains by manually and weighed by an electronic balance [7 & 4].

Grain to dry matter ratio

The five samples of the cob with grains were selected each weighing about one kg and separated the grains from stalks and husk manually for each sample. The mass of the grain and dry matter were measured separately for each sample and expressed it as the percentage of the mass of the grain to dry matter ratio.

$$\text{Grain to dry matter} = \frac{W_g}{W_t - W_g} \quad \ldots [9]$$

Where,

W_g = Weight of grain from the sample, g

W_t = Weight of total maize cob sample, g

Aerodynamic properties

Aerodynamic properties of agricultural products are important and required for design of air conveying systems and the separation equipment [2].

Terminal velocity

In order separate grains from chaffed straw and dust, the significant quantifying parameter is terminal velocity. Terminal velocity is to decide the winnowing velocity of air blower for separation of lighter materials [2&10]. The terminal velocity was measured using an air column. For each test, a sample was dropped to the air stream from the top of the air column, and air was blown up the column to suspend the material in the air stream [3]. The air velocity near the location of the sample suspension was measured by digital anemometer having a least count of 0.1 m s^{-1}. The husk and chaffed straw coming to separation and cleaning unit after passing through threshing drum was taken for study.

Frictional properties

The frictional properties such as angle of repose and coefficient of friction are important in designing of hoppers, chutes, pneumatic conveying systems, screw conveyors, forage harvesters, storage bins etc.

Angle of repose

For measuring the angle of repose, a rectangular box filled with grains was kept horizontal. The grains were then allowed to fall on a horizontal circular disc kept below the box. The flow of grains was stopped after the grains were fully heaped on the disc. The radius of the base of the heap and height of the heap were measured and angle of repose was calculated using the following expression [2].

$$\theta = \tan^{-1}\left(\frac{h_0}{r}\right) \quad \ldots [10]$$

Where,

θ = Angle of repose, degree

h_0 = Height of heap, m

r = Radius of heap, m

Coefficient of friction

It is the friction experienced between the grain mass and the container. The coefficient of friction is used to determine the angle at which hopper, collecting tray and chutes must be positioned in order to achieve consistent flow of materials through the chute [2 & 3].

The coefficient of friction apparatus consists of a horizontal plane and a bottomless open container and a pan. Known weights of grains were taken in the container. The weights were added to the pan and at the instant at which the pan weight exceeds the grain weight and friction; the container starts to slide on selected surfaces. Using the equation 11 [2], the coefficient of friction of grains was determined on four different material surfaces *viz*., grain surface, plywood, MS sheet and wood by the inclined surface method.

$$\mu = \frac{F}{N} \quad \ldots [11]$$

Where,

μ = Coefficient of friction

F = Frictional force [force applied]

N = Normal force [weight of the grain]

Results

Engineering properties of maize

The dimensions of cob and grain, physical, aerodynamic and frictional parameters of all four varieties results are explained below.

Physical properties

The dimensions and other related parameters for all the selected four maize verities are given in [Table-1]. The mean length of un-dehusked cob was maximum [183.25 mm] in case of CP 818 variety and minimum [174.05 mm] in case of GK 3090 variety. The mean length from all the varieties of maize was found to be 179.36 mm with a deviation of 29.56 mm. The diameter of un-dehusked maize cob was maximum [54.98 mm] in case of GK 3090 variety followed by CP 818 [54.21 mm], Hema variety [51.82 mm] while it was minimum in Hero 550 variety [50.21 mm]. The mean value found to be 53.88 mm with 4.37 mm deviation. Among all the four varieties, the maximum stalk length was observed in GK 3090 [32.78 mm] and a minimum of 29.09 mm was observed in Hema variety, whereas the mean value was found to be 30.94 mm with a deviation of 13.41 mm. The weight of un-dehusked cob was found maximum [228.23 g] in CP 818, while it was minimum [193.32 g] in Hero 550. The mean linear dimensions involved length, breadth and thickness of maize grains. The maximum ear length of 11.96 mm was obtained in Hema variety while it was minimum [10.28 mm] in CP 818. The maximum value of the was found in GK 3090 [9.34 mm] and minimum in CP 818 variety [7.55 mm]. The mean thickness was found to be 5.15 mm with deviation of 0.75. The number of grain lines in cob ranged from 14.56 to 15.63 for all the four varieties of maize with a mean of 15.27. Among the four varieties, the number of grains in one line of cob was maximum in CP 818 [41] while it was minimum [36.25] in Hero 550 and the mean value was found to be 38.95 with deviation of 4.85. The highest minimum diameter of cob without grains was found in Hema variety [23.65 mm] and it was minimum [20.52 mm] for Hero 550 variety. The maximum diameter of cob without grains was found to be varied from 25.09 to 29.53 mm for all the four varieties of the maize. The maximum diameter [29.53 mm] of the cob was found for CP 818 variety and a minimum [25.09 mm] of was found for Hero 550. The maximum length of the shelled maize cob of 159.62 mm was noticed in the case of CP 818 and a minimum of 140.98 mm for Hema variety. The mean value was found to be 141.53. The shape of maize grains for all the varieties was found as oval flattened. The [Table-2] shows that, different physical properties of maize. The roundness of maize grain varied from 0.24 to 0.32 for Hema and Hero 550 varieties of the maize. The maximum arithmetic mean diameter was recorded in CP 818 variety [8.55] while it was minimum [7.61 mm] in Hema variety. The geometric mean diameter and SD among all the varieties of maize grains was in the range of 7.1 to 8.04 mm and 0.43 mm, respectively. The sphericity of maize grain was maximum [0.73] in case of GK 3090 variety followed by CP 818 [0.71], Hema variety [0.68] while it was minimum [0.64] in Hero 550 variety. The maximum surface area of 229.67 mm^2 was observed in CP 818 variety while it was minimum [182.04 mm^2] in Hema variety. The CP 818 maximum due to the highest geometric diameter compares to others. The mean bulk density of all the maize varieties was found to be 0.74 g cm^{-3}. The maximum [0.78 g cm^{-3}] bulk density was found in Hero 550 and the minimum bulk density [0.69 g cm^{-3}] was recorded in CP 818. The true densities for all the four varieties of maize grains were in the range of 0.98 to 1.11 g cm^{-3} and with a mean value of 1.03 g cm^{-3}. The maximum test weight of the maize grain was noticed in case of Hero 550 [317.60 g] and a minimum of 224.13 g for GK 3090 variety. The mean value of the four verities was found to be 276.58 g with a deviation of 46.96 g..

Table-1 *Parameters and properties of maize variety selected for the study*

Particulars		Average values of varieties				SD	Mean
Name of the varieties		Hero 550	Hema variety	GK 3090	CP 818		
Length of un-dehusked cob, mm		181.19	178.94	174.05	183.25	29.56	179.36
Diameter of un-dehusked cob		50.21	51.82	54.98	54.21	4.37	53.88
Stalk length, mm		30.64	29.09	32.78	31.26	13.46	30.94
Weight of un-dehusked cob, g		207.17	222.33	193.32	228.23	36.12	212.76
Linear dimensions of maize grains	Length	10.96	11.96	10.76	10.28	0.82	10.99
	Width	8.11	7.71	9.34	7.55	0.76	8.18
	Thickness	4.45	4.09	5.20	6.85	0.75	5.15
No. of grain lines in cobs		14.56	14.88	15.63	15.29	1.15	15.27
No. of grains in one line of cob		36.25	37.99	40.56	41.00	4.85	38.95
Min. diameter of cob without grains, mm		20.52	23.65	21.09	23.11	2.17	21.53
Max. diameter of cob without grains, mm		25.09	25.21	27.90	29.53	2.86	27.64
Avg. length of shelled cob, mm		145.26	140.98	155.98	159.62	15.43	141.53
Shape		Oval flattened					

Table-2 *Physical properties of the maize grains*

Properties	Average values of varieties				SD	Mean
	Hero 550	Hema variety	GK 3090	CP 818		
Roundness	0.24	0.32	0.30	0.28	0.03	0.28
Arithmetic mean diameter, mm	7.96	7.61	8.48	8.55	0.45	8.15
Geometric mean diameter, mm	7.64	7.10	8.04	8.00	0.43	7.69
Sphericity	0.64	0.68	0.73	0.71	0.04	0.69
Surface area, mm^2	198.89	182.04	226.06	229.67	22.71	209.17
Bulk density, g cm^{-3}	0.78	0.77	0.73	0.69	0.04	0.74
True density, g cm^{-3}	1.11	1.04	0.98	0.99	0.06	1.03
Test weight, g	317.60	314.83	224.13	249.77	46.96	276.58
Grain straw ratio	3.16	2.88	3.85	3.29	0.41	3.30

Aerodynamic property

The data pertaining to the aerodynamic properties of all the four varieties of maize are presented in [Table-3]. The mean terminal velocity of maize husk was found to be 1.20 m s^{-1} whereas it was 15.12 m s^{-1} for maize grains. About 15 times more terminal velocity of grain from husk was observed from the study.

Frictional properties

The data pertaining to the frictional properties of maize grains of four different varieties *viz.*, Hero 550, Hema variety, GK 3090 and CP 818 are presented in [Table-4]. The maximum angle of repose for maize grains was found in CP 818 [23.7°] and was minimum in Hero 550 variety 21.16°. The maximum coefficient of friction of maize grain on Mild Steel [MS] sheet was found in Hema variety [0.46°] and the minimum coefficient of friction was recorded in Hero 550 [0.42°] with a deviation of 0.02°.

Table-3 *Aerodynamic properties of the grains and husk of maize cob*

Properties		Average values of varieties				SD	Mean
		Hero 550	Hema variety	GK 3090	CP 818		
Terminal velocity, m s^{-1}	Husk*	1.26	1.18	1.12	1.22	0.06	1.20
	Grain**	14.56	15.08	15.22	15.60	0.43	15.12

*The husk and chaffed straw coming to separation and cleaning unit after passing through threshing drum was took for study.
**The grains moisture content during study was 11-13.5% (w. b.).

Table-4 *Frictional properties of maize grain*

Properties		Average values of varieties				SD	Mean
		Hero 550	Hema variety	GK 3090	CP 818		
Angle of repose, degree		21.16	23.24	22.89	23.73	1.12	22.76
Coefficient of friction of grains with	Grains	0.29	0.31	0.32	0.33	0.02	0.31
	Plywood	0.36	0.33	0.39	0.32	0.03	0.35
	MS sheet	0.42	0.46	0.44	0.45	0.02	0.44
	Wood	0.49	0.48	0.53	0.51	0.02	0.50

Discussion

The measurement of dimensions of materials [maize cob and grain] plays a key role in deciding the volumetric capacity of hopper, hopper opening section dimensions, clearances in concave, concave and sieve opening size. Whereas weight related properties are important in case of hopper load bearing strength, inertia force, strokes of sieve and terminal velocity. The frictional property i. e. angle of repose is an essential property for deciding the tilt of sides in the hopper and sieve inclination. The analogous recommendations were observed in the Data Book of Agricultural Machinery Design by Anon., [10]. The different recommendations made for components of maize dehusker cum sheller based on study conducted are shown below.

- Since the SD of length of un-dehusked maize varies 29.56 mm with a maximum mean of 183.25 mm [Table-1], the minimum bottom opening [axially and laterally] of the hopper section for maize entry to threshing section must be more than 25% higher value of sum of SD and 183.25 mm. The upper boundary value is recommended for entry all possible cob sizes.
- The diameter of un-dehusked cob is useful for deciding the clearance at feed end of the threshing drum in case of axial flow shelles. The feed-chute or hopper opening must be placed away from the rotational axis of drum, which helps to self-suctioning of cobs without any assistance. It's recommended to have 15 to 20 % higher than average diameter to give clearance from threshing drum surface [not from lugs/beaters tip] to sieve or louvers around the drum.
- The maximum diameter of cob without grains was found to be 27.64 mm is recommended to design dimension of concave clearance [radial distance between the extreme tip of the drum to outer sieve/louver surface] at chaff outlet opening side of threshing drum.
- The linear dimensions of maize grains [l x b x t] were preferred to use in finding roundness and other properties, which were found to be 10.99 x 8.18 x 5.15 mm [Table-1], respectively. The 20 to 25% higher value of maximum dimension is recommended for sieve opening size. The number of grain lines in the cobs and the number of grains in one line of cob was observed at 15 and 38.95, respectively. The shape of grains was oval flattened [Table-1], which have more friction compare to round shaped.
- The roundness was 0.28, arithmetic mean diameter was 8.15 mm, geometric mean diameter was 7.69 mm, sphericity was 0.69, surface area was 209.17 mm^2, bulk density was 0.74 g cc^{-1}, true density was 1.03 g cc^{-1} and grain to dry matter ratio was 3.3 [Table-2]. The lower density value of grains than stones is helpful cleaning and separation unit.
- The significant amount of difference among the maize grain and Material Other than Grain [MOG] is advantageous for effective separation and cleaning of grains. The blower air velocity must be kept 10-15% less that lowest terminal velocity of the grains, in the present study i. e. about 14.56 m s^{-1} [Table-3]. Since the grains have 15 times higher value of terminal velocity than MOG [prior to cleaning and separation unit], it's recommended to keep two times the maximum terminal velocity of MOG.
- Due to maximum proportion [weight basis] of grains present compared to MOG, the angle of repose of the grains is deciding factor for the slope of sieve. The sieve slope must be 1.25 times the angle of repose of highest valve found in study i.e. 23.73° [Table-4].

- For easy flow of grains over the surface, the plywood is recommended, followed by MS sheet and wood. However, MS sheet was most commonly used surface and most of sieves availability is in MS sheet only, i.e. having 0.44 coefficient of friction [Table-4].

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