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ENGINEERING PROPERTIES OF MAIZE COBS AND GRAIN FOR POWER-OPERATED DEHUSKER-CUM-SHELLER DESIGN

Akshay Kinge[1,2]*, T.B. Bastewad[1], S.C. Bhangare[1], Rohit Gaddamwar[2], Pavan Panzade[3], Anjani Kumar[2] and Utkarsh Dwivedi[2]

[1]Department of Farm Machinery and Power Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering and Technology, Mahatma Phule Krishi Vidyapeeth, Rahuri - 413 722, Maharashtra, India.

[2]Division of Agricultural Engineering, ICAR-Indian Agricultural Research Institute, New Delhi - 110 012, India.

[3]Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi – 110 012, India.

*Corresponding author E-mail: akshaykinge72@gmail.com

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ABSTRACT

Engineering properties of cobs and grain govern the design of the hopper, concave, blower, and outlets of a maize dehusker cum sheller. The properties of two maize varieties, Rajarshi and Phule Maharshi, were measured at about 15–16% moisture content (w.b.) in five replications each. Undehusked cobs of Rajarshi and Phule Maharshi averaged 189.1 and 191.8 mm long and 53.2 and 53.1 mm in diameter, while shelled cobs averaged 25.4 and 25.3 mm in diameter. Grains measured 10.34 × 7.90 × 5.24 mm and 10.31 × 7.61 × 5.17 mm, with geometric mean diameters of 7.53 and 7.39 mm and sphericity of 0.73 and 0.72. Bulk density was 0.743–0.744 g cm^{-3}, true density 1.082 and 1.095 g cm^{-3}, grain terminal velocity 15.28 and 15.75 m s^{-1} (compared with 1.22–1.23 m s^{-1} for husk), and grain angle of repose 30.5° and 31.6°. Welch's t-test showed no significant differences among the varieties for any property ($p > 0.05$), but Phule Maharshi was more variable across all properties, significantly so for bulk density and porosity (Brown–Forsythe test, $p < 0.05$). These values fixed the concave clearance, concave bar spacing, blower air velocity, and outlet slope of a 2 hp dehusker cum sheller, which shelled 99.2–99.3% of Rajarshi grain at 300–400 kg h^{-1} feed rates.

***Key words*:** Maize, physical properties, terminal velocity, angle of repose, dehusker cum sheller.

Introduction

Maize (*Zea mays* L.) is the world's leading cereal, accounting for about 38% of total grain production. India ranks seventh in world maize output, with about 2.4% of production from 5% of the world maize area (Chaudhary, 2016; Anonymous, 2022). Maharashtra ranks fourth among Indian states, and national productivity averages about 2.43 t ha^{-1}. Nearly half of Indian maize goes to poultry feed, with the rest used for livestock feed, starch, food and processed products (Anonymous, 2022).

Tillage, sowing and weeding in Indian maize are 80–90% mechanised, but threshing and harvesting remain below 20% (Chaudhary, 2016). Manual dehusking and shelling are slow and tiring. Large maize shellers and whole-crop threshers exist, but they are too costly for the small and marginal farmers who make up over 75% of Indian holdings. A compact, low-power dehusker cum sheller fills this gap, and its design depends on the properties of the cobs and grain it handles.

Cob length and diameter decide hopper size and concave clearance. Grain dimensions decide concave bar spacing and sieve openings. Terminal velocities of grain and husk set the cleaning air velocity, and angle of repose sets hopper and outlet slopes (Chilur and Sushilendra, 2016; Varshney *et al.*, 2004). These properties vary with variety and moisture content (Tarighi *et al.*, 2011; Kumar *et al.*, 2017), so published values for other hybrids cannot be assumed for local varieties.

The objectives of this study were to:

(i) Measure the dimensional, gravimetric, frictional, and aerodynamic properties of cobs and grain of two maize varieties, Rajarshi and Phule Maharshi;

(ii) Compare the varieties statistically;

(iii) Show how these values were used to size the working parts of a 2 hp power-operated maize dehusker cum sheller.

Materials and Methods

Sample

Cobs of maize varieties Rajarshi and Phule Maharshi were picked at random and tested at the AICRP on Farm Implements and Machinery, Dr. A.S. College of Agricultural Engineering and Technology, MPKV, Rahuri. Mean moisture content was 15.5–15.7% (w.b.) for Rajarshi and 15.0–15.7% (w.b.) for Phule Maharshi. Each property was measured in five replications (R_1–R_5) per variety.

Cob properties

Length and diameter of undehusked cobs (with husk), length and diameter of shelled cobs, number of grain rows per cob, and number of grains per row were recorded. Lengths and diameters were measured with a digital vernier caliper of least count 0.01 mm (Fig. 1). Grains per cob were taken as the product of rows per cob and grains per row.

Grain dimensions and shape

Length (l), breadth (b), and thickness (t) of grains were measured with the digital vernier caliper (Fig. 2), and mass with a balance of 0.01 g accuracy (Tarighi *et al.*, 2011). Roundness (R), arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (φ), and surface area (S) were calculated as (Sahay and Singh, 1994; Mohsenin, 1970):

$$R = \frac{A_p}{A_c} \qquad ...(1)$$

$$D_a = \frac{l + b + t}{3} \qquad ...(2)$$



Fig. 1: Measurement of length of unhusked maize cob with a digital vernier caliper.

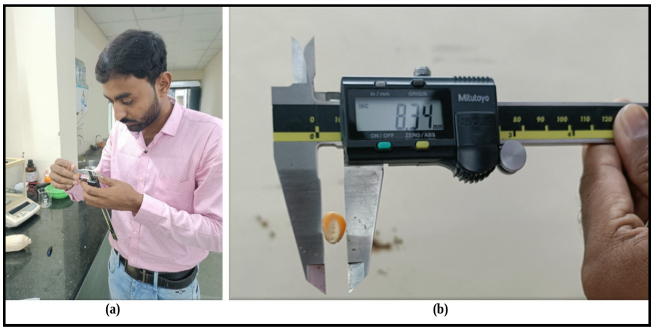


Fig. 2: (a) Measurement of maize grain dimensions and (b) digital vernier caliper reading of a single grain.

$$D_g = (l \times b \times t)^{1/3} \qquad ...(3)$$

$$\varphi = \frac{(l \times b \times t)^{1/3}}{l} \qquad ...(4)$$

$$S = \pi D_g^2 \qquad ...(5)$$

Where,

A_p = largest projected area of the grain in natural rest position, mm^2;

A_c = area of the smallest circumscribing circle, mm^2;

l, b, t = length, breadth and thickness of grain, mm.

Bulk density, true density and porosity

A 500 ml container was filled with grain to a height of 150 mm at a constant rate and weighed; bulk density (ρ_b) is the sample mass divided by container volume (Chaudhary, 2016). For true density (ρ_t), a known mass of grain was dropped into 50 mL of toluene in a 100 mL measuring cylinder, and the rise in toluene level gave the grain volume excluding voids (Mohsenin, 1970). Porosity (ε) was calculated as:

$$\varepsilon = (1 - \rho_b / \rho_t) \times 100 \qquad ...(6)$$

Moisture content

Samples were weighed on a precision balance (Fig. 3a), dried in a hot-air oven at 105 °C for 24 h (Fig. 3b), and weighed again. Moisture content was calculated on a wet basis (Sahay and Singh, 1994):

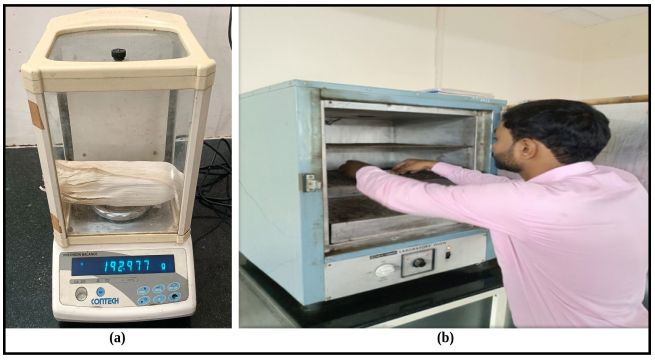


Fig. 3: (a) Weighing of a cob sample on a precision balance and (b) oven drying for determination of moisture content.

Table 1: Engineering properties of maize cobs of two varieties (n = 5).

Property	Rajarshi (Mean ± SD)	CV (%)	Phule Maharshi (Mean ± SD)	CV (%)
Length of undehusked cob (mm)	189.1 ± 13.0	6.9	191.8 ± 26.2	13.7
Diameter of undehusked cob (mm)	53.2 ± 3.2	6.0	53.1 ± 6.1	11.5
Length of shelled cob (mm)	156.9 ± 7.9	5.0	159.0 ± 18.6	11.7
Diameter of shelled cob (mm)	25.4 ± 2.8	11.2	25.3 ± 3.9	15.4
Grain rows per cob	14.2 ± 0.8	5.9	14.4 ± 2.1	14.2
Grains per row	40.4 ± 2.1	5.1	40.3 ± 4.2	10.4
Grains per cob[a]	574 ± 54	9.4	577 ± 58	10.1
Angle of repose (°)	36.0 ± 1.6	4.4	36.4 ± 3.6	10.0
Moisture content (% w.b.)	15.7 ± 0.3	1.7	15.7 ± 1.5	9.4
[a]Derived as rows per cob × grains per row.				

$$MC_{wb} = \frac{w_1 - w_2}{w_1} \times 100 \quad \ldots(7)$$

Where,

w_1 = mass of sample before drying, g;

w_2 = mass of sample after drying, g.

Terminal velocity

Grain and husk were dropped into a vertical air column, and the air velocity that held them in suspension was read with a digital anemometer of least count 0.1 m s^{-1}.

Angle of repose

Grain (or cobs) was filled into a hollow cylinder resting on a circular wooden platform (Fig. 4a). The cylinder was lifted slowly so that the material flowed out and formed a heap on the platform. Heap height (h) and base radius (r) were measured (Fig. 4b), and the angle of repose (θ) was calculated as (Sahay and Singh, 1994):

$$\theta = \tan^{-1}(h / r) \quad \ldots(8)$$

Arithmetic and geometric mean diameter, sphericity, surface area and porosity were calculated from the replicate measurements with equations (2)-(6); all other properties were measured directly.

Statistical analysis

Each property was summarised as mean, standard deviation (SD) and coefficient of variation (CV = SD/ mean × 100). Means of the two varieties were compared with Welch's two-sample t-test, which does not assume equal variances (Welch, 1947), and the 95% confidence interval (CI) of the difference was calculated. Normality was checked with the Shapiro–Wilk test (Shapiro and Wilk, 1965); where it failed, the Mann–Whitney U test was used as a check (Mann and Whitney, 1947). Equality of variances was tested with the Brown–Forsythe test (Brown and Forsythe, 1974). Differences were taken as significant at $p < 0.05$. Analysis was done in Python with SciPy (Virtanen *et al.*, 2020).



Fig. 4: (a) Cylinder and circular platform used for angle of repose and (b) measurement of heap height of maize grain.

Results and Discussion

Cob properties

Cobs of the two varieties had nearly equal mean dimensions (Table 1, Fig. 5). Undehusked cobs averaged 189.1 mm (Rajarshi) and 191.8 mm (Phule Maharshi) long, with diameters of 53.2 and 53.1 mm. After shelling, cobs averaged 156.9 and 159.0 mm long and 25.4 and 25.3 mm in diameter. In both varieties, the husked cob was about 1.2 times the length of the shelled cob, and each cob carried about 575 grains.

Phule Maharshi cobs were about twice as variable as Rajarshi cobs; the CV of undehusked cob length was 13.7% against 6.9%. Shelled cob diameter was the most variable dimension in both varieties (CV 11.2% and

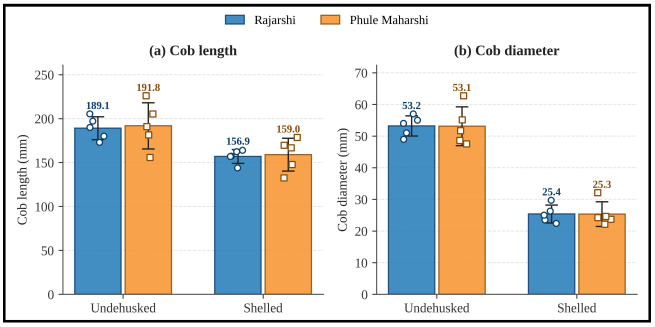


Fig. 5: Length (a) and diameter (b) of undehusked and shelled cobs of the two varieties. Bars show means (values above bars), error bars ± SD, and open symbols show the five replicate values.

Table 2: Engineering properties of maize grain of two varieties (n = 5).

Property	Rajarshi (Mean ± SD)	CV (%)	Phule Maharshi (Mean ± SD)	CV (%)
Length, *l* (mm)	10.34 ± 0.62	6.0	10.31 ± 1.10	10.6
Breadth, *b* (mm)	7.90 ± 0.22	2.8	7.61 ± 0.67	8.8
Thickness, *t* (mm)	5.24 ± 0.30	5.7	5.17 ± 0.38	7.4
Roundness	0.29 ± 0.01	4.1	0.29 ± 0.01	4.9
Arithmetic mean diameter (mm)	7.83 ± 0.17	2.1	7.70 ± 0.39	5.0
Geometric mean diameter (mm)	7.53 ± 0.16	2.2	7.39 ± 0.38	5.2
Sphericity	0.73 ± 0.05	6.4	0.72 ± 0.07	10.1
Surface area (mm^2)	178.2 ± 7.7	4.3	171.8 ± 18.2	10.6
Bulk density (g cm^{-3})	0.744 ± 0.002	0.3	0.743 ± 0.035	4.7
True density (g cm^{-3})	1.082 ± 0.008	0.8	1.095 ± 0.072	6.6
Porosity (%)	31.2 ± 0.4	1.3	31.8 ± 6.8	21.4
Moisture content (% w.b.)	15.5 ± 0.2	1.4	15.0 ± 1.2	7.9
Terminal velocity, grain (m s^{-1})	15.28 ± 0.35	2.3	15.75 ± 1.32	8.4
Terminal velocity, husk (m s^{-1})	1.22 ± 0.02	1.3	1.23 ± 0.04	3.5
Angle of repose (°)	30.5 ± 0.6	2.0	31.6 ± 1.5	4.7

Table 3: Comparison with published values for maize grain.

Source	l × b × t (mm)	D_g (mm)	Spheri-city	ρ_b (g cm^{-3})	ρ_t (g cm^{-3})	Angle of repose (°)
Present study, Rajarshi	10.34 × 7.90 × 5.24	7.53	0.73	0.744	1.082	30.5
Present study, Phule Maharshi	10.31 × 7.61 × 5.17	7.39	0.72	0.743	1.095	31.6
Chilur and Sushilendra (2016)	10.99 × 8.18 × 5.15	7.69	0.69	0.74	1.03	22.8
Brar *et al.* (2017), three hybrids	—	7.06–7.68	0.75–0.79	0.734–0.750	—	27.1–28.7
Varshney *et al.*, (2004)	9.52 × 8.44 × 4.35	7.04[b]	0.74	—	—	—
Tarighi *et al.*, (2011), 5–22% d.b.	—	—	—	0.632–0.679	0.999–1.170	42–57

[b]Reported as equivalent diameter.

15.4%) and ranged from 22.1 to 32.1 mm across the two. A fixed concave clearance would therefore suit only part of the crop. The undehusked cob dimensions of both varieties agree closely with the 179.4 mm and 53.9 mm reported by Chilur and Sushilendra (2016).

Grain properties

Grain length was almost the same in the two varieties, 10.34 mm in Rajarshi and 10.31 mm in Phule Maharshi (Table 2, Fig. 6). Phule Maharshi grains were slightly narrower (7.61 against 7.90 mm) and thinner (5.17 against 5.24 mm), giving a smaller geometric mean diameter (7.39 against 7.53 mm). Sphericity was 0.73 and 0.72, and roundness was 0.29 in both, describing a flat, angular kernel.

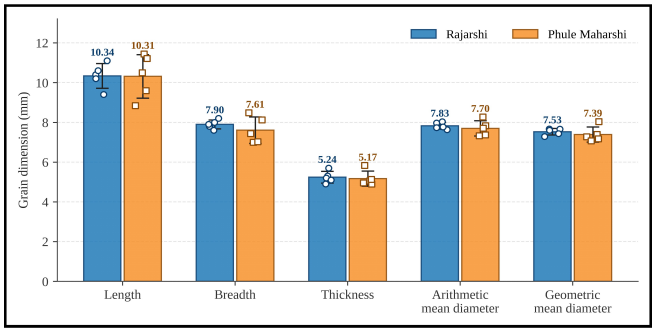


Fig. 6: Grain dimensions of the two varieties. Bars show means (values above bars), error bars ± SD, and open symbols show the five replicate values.

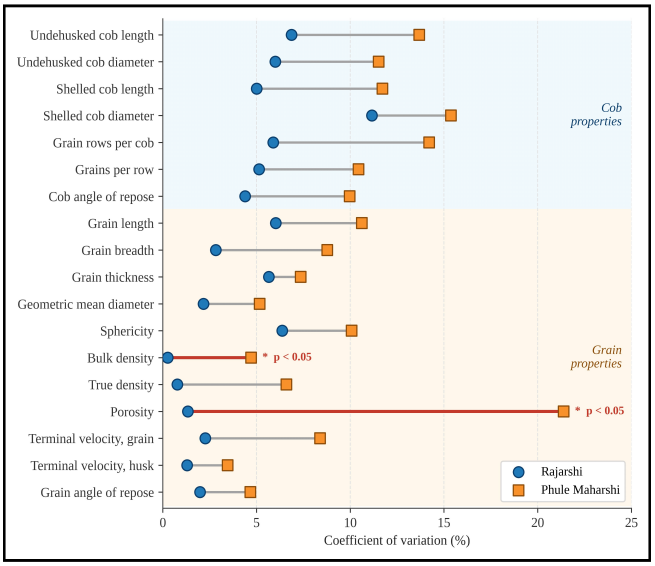


Fig. 7: Coefficient of variation of cob and grain properties of the two varieties. Each line joins the two varieties for one property; red lines mark properties whose variances differ significantly (Brown–Forsythe test, $p < 0.05$).

Table 4: Statistical comparison of engineering properties of Phule Maharshi (PM) and Rajarshi (RJ) (n = 5 per variety).

Property	Difference, PM - RJ) (95 % CI)	Welch t	df	p (t-test)	p (Brown–Forsythe)
Undehusked cob length (mm)	2.7 (-29.6, 34.9)	0.20	5.8	0.845	0.281
Undehusked cob diameter (mm)	-0.1 (-7.6, 7.5)	-0.03	6.0	0.980	0.363
Shelled cob length (mm)	2.1 (-20.7, 24.8)	0.23	5.4	0.828	0.233
Shelled cob diameter (mm)	-0.04 (-5.09, 5.01)	-0.02	7.3	0.986	0.926
Grain rows per cob	0.2 (-2.3, 2.7)	0.22	5.3	0.832	0.090
Grains per row	-0.1 (-5.3, 5.1)	-0.04	5.8	0.971	0.482
Grains per cob	2 (-80, 84)	0.06	8.0	0.951	0.853
Cob angle of repose (°)	0.4 (-4.0, 4.9)	0.24	5.5	0.821	0.084
Cob moisture content (% w.b.)	-0.02 (-1.84, 1.80)	-0.03	4.3	0.978	0.136
Grain length (mm)	-0.03 (-1.39, 1.34)	-0.05	6.3	0.965	0.225
Grain breadth (mm)	-0.29 (-1.11, 0.52)	-0.93	4.9	0.397	0.086
Grain thickness (mm)	-0.07 (-0.57, 0.43)	-0.32	7.6	0.754	0.889
Roundness	0.000 (-0.019, 0.020)	0.02	7.8	0.982	0.618
Arithmetic mean diameter (mm)	-0.13 (-0.60, 0.34)	-0.69	5.5	0.519	0.201
Geometric mean diameter (mm)	-0.14 (-0.61, 0.32)	-0.77	5.4	0.472	0.439
Sphericity	-0.01 (-0.10, 0.08)	-0.22	6.8	0.829	0.283
Surface area (mm^2)	-6.4 (-28.7, 15.8)	-0.73	5.4	0.497	0.448
Bulk density (g cm^{-3})	-0.001 (-0.045, 0.042)	-0.09	4.0	0.933	**0.019**
True density (g cm^{-3})	0.013 (-0.077, 0.102)	0.39	4.1	0.713	0.081
Porosity (%)	0.6 (-7.8, 9.1)	0.20	4.0	0.851	**0.016**
Grain moisture content (% w.b.)	-0.52 (-1.99, 0.94)	-0.96	4.3	0.386	0.282
Terminal velocity, grain (m s^{-1})	0.47 (-1.15, 2.08)	0.76	4.5	0.483	0.170
Terminal velocity, husk (m s^{-1})	0.012 (-0.040, 0.064)	0.58	5.1	0.587	0.176
Grain angle of repose (°)	1.0 (-0.8, 2.8)	1.43	5.3	0.210	0.192
Values in bold are significant at $p < 0.05$.					

Grain dimensions of both varieties lie within the range reported for Indian maize (Table 3). Length and breadth are close to the 10.99 × 8.18 mm of Chilur and Sushilendra (2016) and the 9.52 × 8.44 mm of Varshney *et al.,* (2004). Geometric mean diameters of 7.39 and 7.53 mm fall within the 7.06–7.68 mm reported for three Punjab hybrids (Brar *et al.*, 2017).

Bulk density was almost identical in the two varieties (0.743–0.744 g cm^{-3}) and matches the 0.734–0.750 g cm^{-3} of Brar *et al.,* (2017). True densities of 1.082 and 1.095 g cm^{-3} lie inside the 1.00–1.17 g cm^{-3} range observed by Tarighi *et al.,* (2011) across 5–22% moisture (d.b.). Mean porosity was about 31–32% in both varieties, but Phule Maharshi porosity varied widely between replications (22.5–38.4%).

Grain terminal velocity was 15.28 m s^{-1} in Rajarshi and 15.75 m s^{-1} in Phule Maharshi, about 12.5–12.8 times that of husk (1.22–1.23 m s^{-1}). Both varieties therefore separate easily by air, in line with the 14.56–15.6 m s^{-1} for grain and 1.2 m s^{-1} for husk reported by Chilur and Sushilendra (2016). The grain angle of repose (30.5° and 31.6°) is close to the 27.1–28.7° reported by Brar *et al.,* (2017) and below the 36.0–36.4° of whole cobs.

Statistical comparison of the varieties

None of the 24 properties differed significantly between Rajarshi and Phule Maharshi (Welch's t-test, p = 0.21–0.99; Table 4). The largest differences were in grain angle of repose (1.0° higher in Phule Maharshi, p = 0.21) and grain breadth (0.29 mm lower, p = 0.40). Terminal velocity of Rajarshi grain failed the normality test because of one high value (15.90 m s^{-1}), but the Mann–Whitney U test gave the same result (p = 0.22).

The wide confidence intervals show that five replications can detect only large differences. For example, the true difference in undehusked cob length could lie anywhere between -30 and +35 mm. The absence of significant differences therefore means the varieties could not be told apart with this sample, not that they are proven identical.

The clearer result concerns variability. Phule Maharshi had a higher CV than Rajarshi for all 18 properties compared (Fig. 7), often about twice as high. The difference in spread was significant for bulk density (p = 0.019) and porosity (p = 0.016), whose CVs rose from 0.3% to 4.7% and from 1.3% to 21.4%. For machine

Table 5: Engineering properties used to size machine components (range across both varieties).

Component	Governing property	Measured value	Design choice
Hopper	Undehusked cob length and diameter	155.7–225.9 mm; 47.5–62.7 mm	390 × 365 × 270 mm hopper feeding one cob at a time
Concave clearance	Shelled cob diameter	22.1–32.1 mm (mean 25.3–25.4)	Spring-loaded concave adjustable within 20–30 mm
Concave bars	Grain arithmetic and geometric mean diameter	7.39–7.83 mm	7 mm round MS rods, spacing set from grain mean diameter
Blower	Terminal velocity of husk and grain	1.17–1.27 m s^{-1}; 13.62–17.17 m s^{-1}	Air velocity above husk and below grain terminal velocity; 1.77 m s^{-1} at chaff outlet
Grain outlet	Grain angle of repose	29.8–33.4°	Outlet inclined at 45° for free flow

design, this matters more than the small differences in means, because settings must cover the full range of cobs and grain fed to the machine.

Application to dehusker cum sheller design

The measured properties fixed the main working dimensions of a 2 hp power-operated maize dehusker cum sheller (Table 5). The axial-flow unit uses a 154 mm cylinder running at 1366 rpm, a peripheral speed of about 11 m s^{-1}, within the 9–12 m s^{-1} recommended for maize (Jain and Philips, 2003).

The spread in shelled cob diameter justified the spring-loaded concave. A fixed gap sized for the mean cob would leave grain on thin cobs and crush thick ones. The largest Phule Maharshi cob (32.1 mm) was slightly above the 20–30 mm clearance range, so the concave spring must allow some extra travel for this variety. Even the lowest grain terminal velocity (13.62 m s^{-1}) was over ten times the highest husk value, which gives the blower a wide operating window for both varieties.

The machine was tested with Rajarshi cobs. At feed rates of 300, 350, and 400 kg h^{-1}, it gave 100% dehusking and 99.19–99.33% shelling efficiency. Cleaning efficiency was 98.26–98.63%, broken grain 0.28–0.38%, and total losses 2.58–3.09%. Output rose from 212 to 277 kg h^{-1} of grain across that feed range. Since the mean properties of Phule Maharshi are close to those of Rajarshi, similar performance can be expected, but this needs confirming in trials.

Conclusion

Cobs of Rajarshi and Phule Maharshi at about 15–16% moisture (w.b.) averaged 189.1 × 53.2 mm and 191.8 × 53.1 mm with husk, and 156.9 × 25.4 mm and 159.0 × 25.3 mm after shelling, each carrying about 575 grains. Grains measured 10.34 × 7.90 × 5.24 mm and 10.31 × 7.61 × 5.17 mm, with geometric mean diameters of 7.53 and 7.39 mm and sphericity of 0.73 and 0.72. Bulk density was 0.743–0.744 g cm^{-3}, true density 1.082 and 1.095 g cm^{-3}, and porosity about 31–32%. Grain terminal velocity was 15.28 and 15.75 m s^{-1}, compared with 1.22–1.23 m s^{-1} for husk, and grain angle of repose was 30.5° and 31.6°.

No property differed significantly between the varieties (Welch's t-test, $p > 0.05$), but Phule Maharshi was more variable in every property, significantly so for bulk density and porosity. Its shelled cob diameter reached 32.1 mm, so an adjustable concave is needed for both varieties. A dehusker cum sheller sized from these values shelled 99.2–99.3% of Rajarshi grain with under 0.4% breakage. Tests across a range of moisture contents, larger samples, and machine trials with Phule Maharshi would extend these results.

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