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Studies on Physical and Engineering Properties of Different Varieties of Paddy for Designing a Power Operated Paddy Drum Thresher Cum Winnower

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ABSTRACT: The physical properties of the paddy grain were determined by taking three varieties (Devbhog, Mahamaya and Rajeshwari) at five moisture levels (7, 10, 14, 18, and 22% db) to design the different components of the machine. The data were analyzed statistically using Completely Randomized Design (CRD). The physical properties of the paddy grain such as length, width, thickness, sphericity, terminal velocity, coefficient of friction, angle of repose, bulk density and true density were found to be increased with an increase in moisture content while the porosity decreased with increase in moisture content. The effect of moisture content on various physical properties of paddy grains; five levels of moisture content varying from 7 to 22% (d.b.) were examined. It was observed that as the moisture content increased from 7 to 22% (d.b.), there were increases in the average length Devbhog, Mahamaya and Rajeshwari paddy varieties ranged from 7.99 to 9.035 mm, the width from 2.02 to 2.63 mm, and the thickness from 1.503 to 2.1 mm, coefficient of static friction (from 0.351 to 0.419), terminal velocity (from 4.145 to 5.869 m/s), and angle of repose (from 23.014° to 32.369°. Furthermore, the bulk density and true density for Devbhog, Mahamaya and Rajeshwari paddy of the grains were found to increase from 549.44 to 628.54 kg/m³ and 937.72 to 1085.54 kg/m³, respectively, with increasing moisture content, while the porosity decreased from 45.05% to 29.287%.

Keywords: Moisture content, Paddy varieties, Width, Angle of repose, Terminal velocity.

INTRODUCTION

India is the world's largest producer of rice, accounting for 22% of the world's rice production after China. In fiscal year 2018, rice production contributed over 1.8 trillion Indian rupees to the Indian economy (Anon., 2020a). India is also one of the largest exporters of rice, exporting nearly 10 million metric tons annually (Mooventhan *et al*., 2015). Chhattisgarh, known as the "Rice Bowl of Central India," covers an area of 3.88 million hectares (Mha) and produces 5.74 million tons (MT) of rice with a productivity of 1.48 tons per hectare (t/ha) (Anon., 2017).

The total population of Chhattisgarh is around 25.5 million, with about 70% engaged in agriculture. There are approximately 3.746 million farm families in the state, with about 80% being small and marginal farmers. The major Kharif crops include paddy, soybean, urd, and arhar, while the Rabi season is mainly dominated by chickpea and lathyrus. The total area under paddy cultivation was 3.876, 3.903, and 3.899 million hectares, with productivity of 3002, 3438, and 3212 kg/ha during the years 2019-20, 2020-21, and 2021-22, respectively (Anon., 2023).

Chhattisgarh became the second-largest contributor of paddy during the Kharif season in India. In the financial year 2021, rice production in Chhattisgarh amounted to over seven million metric tons. The state has an average rice cultivation area of 3.6 million hectares, with productivity ranging between 1.2 to 1.6 t/ha depending on rainfall. Approximately 36% of India's total rice production comes from three states: West Bengal (13.62%), Uttar Pradesh (12.81%), and Punjab (9.96%). During various stages of rice production, paddy arrives at each stage with a specific moisture content, which decreases from 22% to 8% from harvesting to milling. Variations in moisture content change the physical properties of paddy grains. If the equipment is not adjusted proportionally to the specific properties of the grain, it may lead to excessive cracking and breaking of rice grains. Therefore, optimizing the various stages of rice processing requires determining the physical properties of paddy grains. This information is crucial for designing equipment used in harvesting, transportation, milling, processing, and storage of rice. The size, shape, and structural characteristics of paddy are important for designing separating, sizing, and grinding machines. Bulk density, true density, and porosity (the ratio of inter-granular space to the total space occupied by the grain) are used in the design of storage bins and silos and for separating desirable materials from impurities. The angle of repose is used in designing equipment for processing particulate solids, such as hoppers or silos for storing material, or sizing conveyor belts for transporting material. The static coefficient of friction of the grain against various surfaces is also necessary for designing handling and storing structures (Soyaye, 2020).

The objective of this study was to determine some physical properties of three varieties of paddy grains (Devbhog, Mahamaya, and Rajeshwari) such as length, width, thickness, sphericity, terminal velocity, coefficient of friction, angle of repose, bulk density, true density, and porosity in the moisture content range from 7 to 22% (d.b.) (Dahare *et al.,* 2019).

MATERIAL AND METHODS

A. Physical and Engineering Properties of Different Paddy Varieties

(i) Moisture content. The three paddy varieties (Devbhog, Mahamaya and Rajeshwari), used for this study was obtained from the IGKV Raipur, Chhattisgarh. The varieties (Devbhog, Mahamaya and Rajeshwari) used in the current study is one of the popular rice varieties in Chhattisgarh state. Before starting experiments, the samples were cleaned manually to remove all foreign materials and broken grains. The initial moisture content of seed was determinedby using the standard hot air oven method using the following formula (Sahay and Singh 2001).

$$\mathrm{MC}\ (\%) = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \qquad (1)$$

Where,

MC = Moisture content on dry basis (%);

W_1 =Initial weight of the container, g;

W_2 = Sample weight before drying + container weight, g;

W_3 =Sample weight after drying + container weight, g.

(ii) Bulk density. The bulk density is then calculated by dividing the weight of the sample by the volume of the cylinder. The bulk density of the sample is calculated from the following formula (Landry *et al*., 2004).

$$\rho_b = \frac{W_2 - W_1}{V} \qquad (2)$$

Where,

ρ_b= Bulk Density, kg/m^3; W_1 = the weight of the cylinder, kg; W_2 = the weight of the cylinder and sample, kg; and V = The volume of the cylinder, m^3.

$$V = \frac{\pi}{4} \times d^2 \times h$$

Where,

d = diameter of cylinder, m;h = height of cylinder, m.

(iii) True density. The true density, determined using the toluene displacement method as described by Mohsenin (1986); Bhise *et al*. (2014).

$$\rho_t = \frac{M}{V} \qquad (3)$$

Where,

ρ_t= True density, kg/m^3; M = Mass of the paddy grain, kg; and V = Volume of paddy grain including displaced toluene, m^3.

(iv) Porosity. The porosity of the paddy grain is a measure of the void spaces in the material and a fraction of the volume of voids over the total volume. Porosity of paddy grain sample was determined by using the following formula (Mohsenin, 1986).

$$\varepsilon = \left(1 - \frac{BD}{TD}\right) \times 100 \qquad (4)$$

Where,

ε = Porosity, %; BD = Bulk density, kg/m^3; TD = True density, kg/m^3.

(v) Coefficient of static friction. The static coefficient of friction was determined for four different surfaces: plywood, stainless steel, glass, and galvanized iron. A known weight of paddy grain was placed in the container. Weights were added to the pan until the weight exceeded that of the sample and friction, causing the container to start sliding on the selected surface. The static coefficient of friction was calculated using the appropriate equation suggested by Sahay and Singh (1994).

$$\mu = \tan \alpha \qquad (5)$$

Where,

μ = Coefficient of friction; α = tilt angle of paddy grain, degree.

(vi) Terminal velocity. Terminal velocity refers to the air velocity at which a grain neither rises nor falls but remains suspended. The terminal velocities of paddy grain at various moisture levels were determined using an air column device. In each experiment, a sample was dropped into an air stream from the top of the column. The airflow rate was gradually increased until the seed remained suspended in the air stream. The velocity of the air that maintained the seed in suspension was measured using a pivot tube along with a micro manometer (Gupta and Das 1997; Sacilink *et al*., 2003).

(vii) Angle of repose. The angle of repose represents the angle formed between the base and the slope of the cone created when a mixture falls freely from a vertical position to a horizontal plane. This angle characterizes the flow ability of a substance, with each substance possessing its unique angle of repose. Factors such as particle size, shape, moisture content, and particle orientation affect this angle. Measurement of the angle of repose is conducted using an apparatus comprising a metal conical funnel fixed onto a metal stand, with an iron disc positioned below, marked with various diameters. The sample is poured into the funnel and allowed to flow freely onto the iron disc from its open bottom. The dimensions of the resulting cone, including its height and diameter, are measured. The angle of repose is then determined using an appropriate equation (Sahay and Singh 2001)

$$\emptyset = \tan^{-1}\frac{2H}{D} \tag{6}$$

Where,

$\emptyset$ = angle of repose in degree; H = height of the cone, cm; D = diameter of the plate, cm.

RESULT AND DISCUSSIONS

A. Physical and engineering properties of paddy grain

The physical and engineering properties of the paddy grain of three varieties namely Devbhog, Mahamaya and Rajeshwari were determined at five levels of moisture content (7, 10, 14, 18, and 22 %, db) with three replications. The study was conducted in post-harvest laboratory, Department of Agricultural Processing and Food Engineering. The detail data were analysed statistically by CRD (Completely Randomised Design).

(i) Effect of variety and moisture content on the length of the paddy grain. The effects of the Devbhog, Mahamaya, and Rajeshwari varieties and varying moisture contents (7%, 10%, 14%, 18%, and 22%, db) on the width of the paddy grain were recorded. The detailed data were analyzed statistically using Completely Randomized Design (CRD) and are presented in Table 1. Fig. 1 illustrates the relationship between moisture content and the length of the three paddy varieties: Devbhog, Mahamaya, and Rajeshwari. The varietal differences in length were significant at the 1% level, and moisture content significantly affected grain length. The highest length of 9.035 mm was observed at a moisture content of 22% (db), while the lowest length of 7.99 mm was recorded at a moisture content of 7%. This variation may be due to the limited availability of intercellular spaces for further moisture absorption inside the seeds. The graph demonstrated that the length of each paddy variety increased with an increase in moisture content. Specifically, the Rajeshwari variety consistently exhibited the greatest length across all moisture content levels, followed by the Mahamaya and Devbhog varieties. For the Devbhog variety, the length started at approximately 7.5 mm at 8% moisture content and increased to about 8.5 mm at 22% moisture content. Similarly, the Mahamaya variety began at around 8 mm at 8% moisture content and reached just over 9 mm at 22% moisture content. The Rajeshwari variety showed the most significant length, starting from about 8.5 mm at 8% moisture content and increasing to nearly 9.8 mm at 22% moisture content. The trend lines for all three varieties indicate a positive correlation between moisture content and length, demonstrating that as the moisture content of the paddy increased, so did its length. This increase in length may be attributed to the swelling of seeds at higher moisture content, resulting from the expansion due to increased moisture absorption in the intercellular spaces. Similar findings were also observed by Zareiforoush *et al.* (2011) for paddy crops and Powar *et al.* (2018) for finger millet grains.

Table 1: Effect of variety and moisture content on length (mm) of paddy grain.

Variety	Length of paddy grain, mm					Mean
	MC1(7)	MC2(10)	MC3(14)	MC4(18)	MC5(22)	
Devbhog	7.167	7.65	8.13	8.4	8.667	8.002
Mahamaya	8.103	8.51	8.9	9	9.1	8.722
Rajeshwari	8.71	9.05	9.22	9.32	9.34	9.128
Mean	7.99	8.403	8.75	8.906	9.035	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	0.144	0.07	0.049
Factor (Moisture Content)	0.185	0.09	0.064
Factor (V×MC)	0.321	0.157	0.111

Note: MC1 to MC5: Moisture content, % db

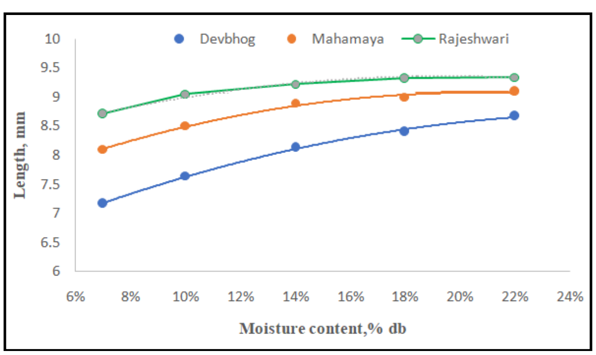

Fig. 1. Effect of variety and moisture content on length of the paddy grain.

(ii) Effect of variety and moisture content on the width of the paddy grain. The effects of the Devbhog, Mahamaya, and Rajeshwari varieties and varying moisture contents (7%, 10%, 14%, 18%, and 22%, db) on the width of paddy grains were recorded. The data were statistically analyzed using Completely Randomized Design (CRD) and are presented in Table 2. Fig. 2 illustrates the relationship between moisture content and the width of the three paddy varieties: Devbhog, Mahamaya, and Rajeshwari. It was observed that the width of each paddy variety increased with rising moisture content. Specifically, the Rajeshwari variety consistently exhibited the greatest width across all moisture content levels, followed by the Mahamaya and Devbhog varieties. For the Devbhog variety, the width started at approximately 1.9 mm at 8% moisture content and increased to about 2.4 mm at 22% moisture content. Similarly, the Mahamaya variety began at around 2.1 mm at 8% moisture content, reaching approximately 2.5 mm at 22% moisture content. The Rajeshwari variety showed the greatest width, starting from about 2.3 mm at 8% moisture content and increasing to nearly 2.7 mm at 22% moisture content. The trend lines for all three varieties indicated a positive correlation between moisture content and width, demonstrating that as the moisture content of the paddy increased, so did its width. The varietal difference in the width of the paddy grain was significant at the 1% level, while moisture content also showed a significant difference (α = 0.01) with a critical difference (CD) of 0.07. The highest width of 2.63 mm was observed at a moisture level of 22%, while the lowest width of 2.02 mm was observed at a moisture level of 7%, db. The interactive effect of variety and moisture content on the width of the paddy grain was significant at the 1% level with a CD of 0. 121. The increase in width may be attributed to the moisture absorption of seeds in their intercellular spaces. These results align with the findings of Zareiforoush *et al.* (2011) for paddy crops and Omprakash *et al*. (2019) for pearl millet grains.

Table 2: Effect of variety and moisture content on width of paddy grain.

Variety	Width of finger millet grain, mm					Mean
	MC1(7)	**MC2(10)**	**MC3(14)**	**MC4(18)**	**MC5(22)**	
Devbhog	1.817	2.01	2.243	2.393	2.503	2.184
Mahamaya	2.05	2.207	2.427	2.577	2.637	2.37
Rajeshwari	2.2	2.393	2.603	2.757	2.77	2.54
Mean	2.02	2.203	2.42	2.51	2.63	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	0.054	0.026	0.019
Factor (Moisture Content)	0.07	0.034	0.024
Factor (V×MC)	0.121	0.059	0.042

Note: MC1 to MC5: Moisture content, % db

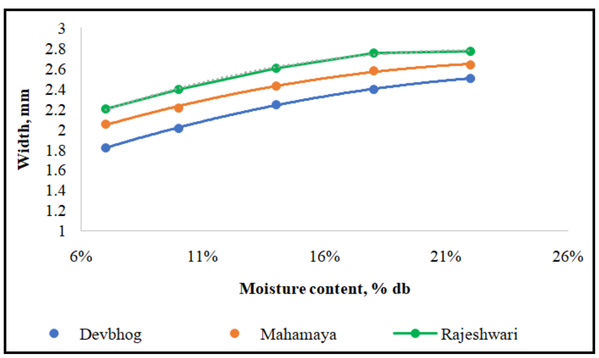

Fig. 2. Effect of variety and moisture content on width of the paddy grain.

(iii) Effect of variety and moisture content on the thickness of the paddy grain. Fig. 3 illustrates the relationship between moisture content and the thickness of three different paddy varieties: Devbhog, Mahamaya, and Rajeshwari. It was observed that the thickness of each paddy variety increased with rising moisture content. The Rajeshwari variety consistently exhibited the greatest thickness across all moisture content levels, followed by the Mahamaya and Devbhog varieties. For the Devbhog variety, the thickness started at approximately 1.2 mm at 8% moisture content and increased to about 1.7 mm at 22% moisture content. The Mahamaya variety began at around 1.5 mm at 8% moisture content and reached approximately 2.0 mm at 22% moisture content. The Rajeshwari variety showed the greatest thickness, starting from about 1.9 mm at 8% moisture content and increasing to nearly 2.5 mm at 22% moisture content. The trend lines for all three varieties indicated a positive correlation between moisture content and thickness, demonstrating that as the moisture content of the paddy increased, so did its thickness. Table 3 shows that there is a significant difference at the 1% level of significance between the thickness of paddy grains due to different varieties. The highest thickness of 2.10 mm was observed at a moisture level of 22% (db), while the lowest thickness of 1.503 mm was observed at a moisture level of 7% (db). The interactive effect of variety and moisture content on the thickness of the paddy grain was found to be significant at the 1% level of significance with a critical difference (CD) of 0.088. It was found that the thickness of the paddy grain increased with increases in moisture content in a polynomial trend, as shown in

Fig. 3. The increase in thickness may be due to moisture absorption of seeds in their intercellular spaces. Similar findings on the increase in paddy grain thickness with rising moisture content were reported by Singh *et al.* (2020) for Deenanath seeds.

Table 3: Effect of variety and moisture content on thickness of Paddy grain.

Variety	Thickness of paddy grain, mm					Mean
	MC1(7)	**MC2(10)**	**MC3(14)**	**MC4(18)**	**MC5(22)**	
Devbhog	1.183	1.357	1.557	1.717	1.843	1.531
Mahamaya	1.52	1.703	1.92	1.987	2.03	1.832
Rajeshwari	1.8067	2.043	2.183	2.317	2.45	2.15
Mean	1.503	1.701	1.88	2.007	2.10	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	0.039	0.019	0.014
Factor (Moisture Content)	0.051	0.025	0.018
Factor (V×MC)	0.088	0.043	0.03

Note: MC1 to MC5: Moisture content, % db

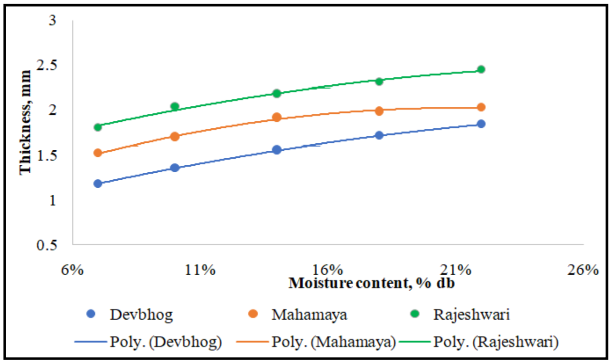

Fig. 3. Effect of variety and moisture on the thickness of the paddy grain.

(iv) Effect of variety and moisture content on the sphericity of the paddy grain. The effect of the varieties Devbhog, Mahamaya, and Rajeshwari and moisture contents (7%, 10%, 14%, 18%, and 22%, db) on the sphericity of the paddy grain was observed. The detailed data were analyzed statistically using Completely Randomized Design (CRD) and are presented in Table 4. Fig. 4 illustrates the relationship between moisture content and the sphericity of the three different paddy varieties: Devbhog, Mahamaya, and Rajeshwari.

It was observed that the sphericity of each paddy variety increased with an increase in moisture content. The Rajeshwari variety consistently exhibited the highest sphericity across all moisture content levels, followed by the Mahamaya and Devbhog varieties. For the Devbhog variety, the sphericity started at approximately 0.24 at 8% moisture content and increased to about 0.30 at 22% moisture content. The Mahamaya variety began at around 0.27 at 8% moisture content and reached approximately 0.34 at 22% moisture content. The Rajeshwari variety showed the greatest sphericity, starting from about 0.30 at 8% moisture content and increasing to nearly 0.37 at 22% moisture content. The trend lines for all three varieties indicated a positive correlation between moisture content and sphericity, demonstrating that as the moisture content of the paddy increased, so did its sphericity. It was observed that the varietal difference in sphericity of the paddy grain was significant at the 1% level. Additionally, there was a significant difference in sphericity due to moisture content at the 1% level of significance. The highest sphericity of 0.395 was observed at a moisture level of 25%, while the lowest sphericity of 0.277 was observed at a moisture level of 7%.

Table 4: Effect of variety and moisture content on sphericity of paddy grain.

Variety	Sphericity					Mean
	MC1(7)	**MC2(10)**	**MC3(14)**	**MC4(18)**	**MC5(22)**	
Devbhog	0.251	0.265	0.286	0.321	0.364	0.297
Mahamaya	0.27	0.302	0.327	0.362	0.404	0.33
Rajeshwari	0.31	0.337	0.355	0.388	0.419	0.357
Mean	0.277	0.301	0.322	0.357	0.395	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	0.007	0.004	0.003
Factor (Moisture Content)	0.009	0.005	0.003
Factor (V× MC)	0.016	0.008	0.006

Note: MC1 to MC5: Moisture content, % db

The interactive effect of variety and moisture content on the sphericity of the paddy grain was found to be significant at the 1% level with a critical difference (CD) value of 0.016. It was found that the sphericity of the paddy grain increased with increasing moisture content in a polynomial trend. The increase in sphericity may be due to the increase in linear dimensions of grains through moisture absorption. Similar results have also been reported by Powar *et al.* (2018) for finger millet grains, Omprakash *et al.* (2019) for pearl millet grains, and Singh *et al.* (2020) for Deenanath seeds.

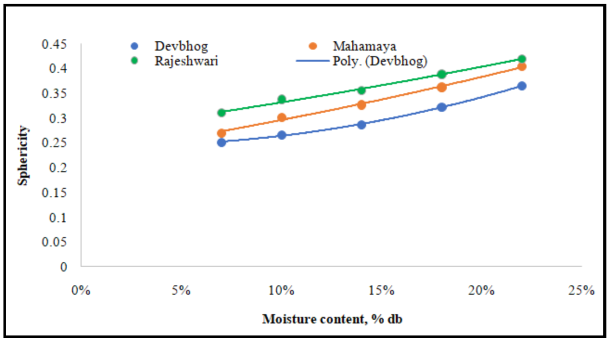

Fig. 4. Effect of variety and moisture content on the sphericity of paddy grain.

(v) Effect of variety and moisture content on the bulk density of the paddy grain. The effect of the varieties Devbhog, Mahamaya, and Rajeshwari and moisture contents (7%, 10%, 14%, 18%, and 22%, db) on the bulk density of the paddy grain was recorded. The data are presented in Table 5. Fig. 5 illustrates the relationship between moisture content and the bulk density of three different varieties of paddy: Devbhog, Mahamaya, and Rajeshwari. It was found that the bulk density of the paddy grain increased with an increase in moisture content in a polynomial trend. The varietal difference in bulk density of the paddy grain was significant at the 1% level, as was the difference due to moisture content. The highest bulk density of 628.54 kg/m³ was observed at a moisture level of 22%, while the lowest bulk density of 549.44 kg/m³ was observed at a moisture level of 7%. The bulk density of the Devbhog sample increased steadily with an increase in moisture content, starting at approximately 480 kg/m³ at 7% moisture content and reaching around 550 kg/m³ at 21% moisture content. This sample consistently had the lowest bulk density across all moisture levels compared to the other two samples. The bulk density for Mahamaya also showed an upward trend with increasing moisture content. Beginning at around 500 kg/m³ at 7% moisture content, it reached approximately 580 kg/m³ at 21% moisture content. The rate of increase in bulk density was slightly higher compared to the Devbhog sample. The Rajeshwari sample exhibited the highest bulk density among the three samples. At 7% moisture content, the bulk density was about 600 kg/m³, increasing to higher values with moisture content. These results are in agreement with the findings of Zareiforoush *et al.* (2011) for paddy crops, Damian (2014) for mustard seeds, and Swami and Swami (2010) for finger millet grains.

Table 5: Effect of variety and moisture content on bulk density of paddy grain.

Variety	Bulk density, kg/m^3					Mean
	MC1(7)	MC2(10)	MC3(14)	MC4(18)	MC5(22)	
Devbhog	498.33	523.33	543.32	560.67	589.33	542.99
Mahamaya	550	565	578.33	589.67	606.31	577.862
Rajeshwari	600	629.5	655.67	675.1	690	650.05
Mean	549.44	572.61	592.44	608.48	628.54	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	6.164	3.004	2.124
Factor (Moisture Content)	7.958	3.878	2.742
Factor (V×MC)	13.783	6.716	4.749

Note: MC1 to MC5: Moisture content, % db

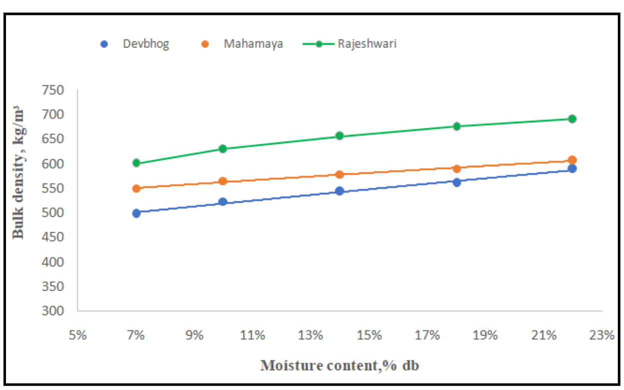

Fig. 5. Effect of variety and moisture content on the bulk density of the paddy grain.

(vi) Effect of variety and moisture content on the true density of the paddy grain. The true density of paddy grain was found to increase with moisture content, following a polynomial trend. Fig. 6 shows the relationship between moisture content (%) and true density (kg/m³) for three paddy varieties: Devbhog, Mahamaya, and Rajeshwari. For the Devbhog sample, true density increased from approximately 850 kg/m³ at 7% moisture content to around 950 kg/m³ at 21% moisture content. Devbhog exhibited the lowest true density values across all moisture content levels compared to Mahamaya and Rajeshwari. The Mahamaya sample also showed an increase in true density with rising moisture content, starting at approximately 950 kg/m³ at 7% moisture content and reaching about 1050 kg/m³ at 21% moisture content. This increase was more pronounced than in Devbhog but less so than in Rajeshwari. The Rajeshwari sample demonstrated the highest true density among the three varieties, increasing from around 1100 kg/m³ at 7% moisture content to approximately 1250 kg/m³ at 21% moisture content. Rajeshwari exhibited the most significant increase in true density with moisture content. The data indicated a positive correlation between moisture content and true density for all three varieties. The variation in true density suggested differences in inherent physical properties such as composition, structure, and specific gravity. Rajeshwari's higher true density could be attributed to a more compact particle arrangement or higher specific gravity compared to Devbhog and Mahamaya. The graph demonstrated that moisture content had a significant impact on the true density of the samples, with Rajeshwari consistently showing the highest true density values across all moisture levels, suggesting superior density characteristics. The detailed data were statistically analyzed using the Completely Randomized Design (CRD) and are presented in Table 6. The varietal difference in true density of the paddy grain was significant, as was the difference due to moisture content. The highest true density of 1085.54 kg/m³ was observed at a moisture level of 22%, while the lowest true density of 937.72 kg/m³ was observed at a moisture level of 7%. However, the interactive effect of variety and moisture content on true density was found to be non-significant. These results align with the findings of Zareiforoush *et al.* (2011) for paddy crops and Damian (2014) for mustard seeds.

Table 6: Effect of variety and moisture content on true density of paddy grain.

Variety	True density, kg/m³					Mean
	MC1(7)	MC2(10)	MC3(14)	MC4(18)	MC5(22)	
Devbhog	818.873	858.65	865.37	886.897	930.183	871.99
Mahamaya	883.66	924.1	951.91	985.207	1026.14	954.20
Rajeshwari	1110.63	1175.52	1235.70	1256.94	1300.31	1215.82
Mean	937.72	986.09	1017.66	1043.01	1085.54	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	21.46	10.46	7.39
Factor (Moisture Content)	27.71	13.50	9.55
Factor (V× MC)	NS	23.38	16.54

Note: MC1 to MC5: Moisture content, % db

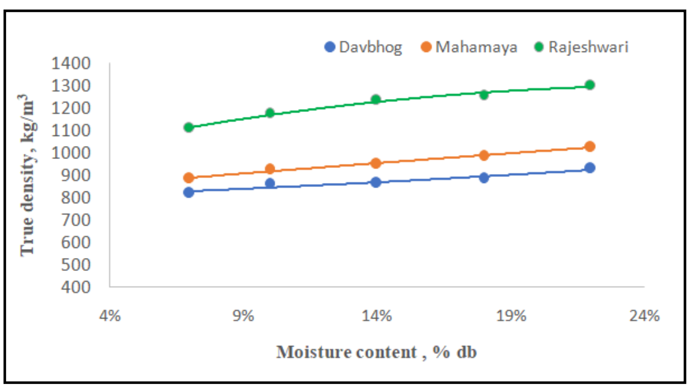

Fig. 6. Effect of variety and moisture content on the true density of the paddy grain.

(vii) Effect of variety and moisture content on the porosity of the paddy grain. The effect of varieties (Devbhog, Mahamaya, and Rajeshwari) and moisture contents (7, 10, 14, 18, and 22%, db) on the porosity of paddy grain was recorded. The data were analyzed statistically using a Completely Randomized Design (CRD) and are presented in Table 7. The varietal difference in porosity of paddy grain was significant, as was the difference due to moisture content. The highest porosity of 45.05% was observed at a moisture level of 7%, while the lowest porosity of 29.287% was observed at a moisture level of 22%.

Table 7: Effect of variety and moisture content on porosity of paddy grain.

Variety	Porosity, %					Mean
	MC1(7)	MC2(10)	MC3(14)	MC4(18)	MC5(22)	
Devbhog	40.613	41.237	36.753	33.977	27.723	36.06
Mahamaya	45.283	44.087	41.897	38.11	29.073	39.69
Rajeshwari	49.28	47.953	46.127	42.763	31.067	43.438
Mean	45.05	44.42	41.59	38.28	29.287	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	2.736	1.333	0.943
Factor (Moisture Content)	3.532	1.721	1.217
Factor (V×MC)	NS	2.981	2.108

Note: MC1 to MC5: Moisture content, % db

The interactive effect of variety and moisture content on porosity was found to be non-significant. It was observed that porosity decreased with an increase in moisture content, following a polynomial trend. This decrease in porosity may be attributed to its direct relationship with the bulk density and true density of the grains. These results align with the findings of Swami and Swami (2010) for finger millet grains.

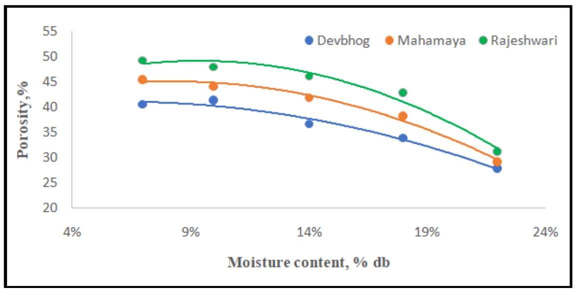

Fig. 7. Effect of variety and moisture content on the porosity of the paddy grain.

(viii) Effect of variety and moisture content on the coefficient of static friction of the paddy grain. The effect of varieties (Devbhog, Mahamaya, and Rajeshwari) and moisture contents (7, 10, 14, 18, and 22%, db) on the coefficient of static friction of paddy grain was recorded. The data were analyzed statistically using a Completely Randomized Design (CRD) and are presented in Table 8. The varietal difference in the coefficient of static friction of paddy grain was significant, as was the difference due to moisture content. The highest coefficient of static friction, 0.419, was observed at a moisture content of 22%, while the lowest coefficient of static friction, 0.351, was observed at a moisture content of 7%. The interactive effect of variety and moisture content on the coefficient of static friction was found to be non-significant. It was found that the coefficient of static friction of paddy grain increased with an increase in moisture content, following a polynomial trend. This increase may be attributed to the increased moisture on the surface of the seeds. These results agree with the findings of Damian (2014) for mustard seeds and Swami and Swami (2010) for finger millet grains.

Table 8: Effect of variety and moisture content on coefficient of static friction of paddy grain.

Variety	Coefficient of static friction					Mean
	MC1(7)	MC2(10)	MC3(14)	MC4(18)	MC5(22)	
Devbhog	0.382	0.395	0.413	0.419	0.435	0.408
Mahamaya	0.364	0.385	0.403	0.415	0.428	0.399
Rajeshwari	0.309	0.331	0.352	0.375	0.394	0.352
Mean	0.351	0.370	0..389	0.403	0.419	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	0.017	0.008	0.006
Factor (Moisture Content)	0.022	0.011	0.007
Factor (V×MC)	NS	0.018	0.013

Note: MC1 to MC5: Moisture content, % db

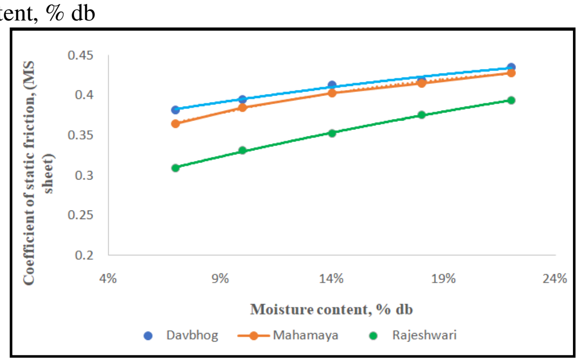

Fig. 8. Effect of variety and moisture content on coefficient of static friction of the paddy grain.

(ix) Effect of variety and moisture content on the terminal velocity of the paddy grain. The effect of varieties (Devbhog, Mahamaya, and Rajeshwari) and moisture contents (7, 10, 14, 18, and 22%, db) on the terminal velocity of paddy grain was evaluated. The data were analyzed statistically using a Completely Randomized Design (CRD) and are presented in Table 9. It was observed that varietal differences in terminal velocity were non-significant, whereas moisture content had a significant effect. The highest terminal velocity of 5.869 m/s was recorded at a moisture level of 25%, while the lowest terminal velocity of 4.145 m/s was observed at a moisture level of 7%. The interactive effect of variety and moisture content on terminal velocity was found to be non-significant. The terminal velocity of paddy grain increased with rising moisture content, following a polynomial trend. This increase is likely due to the increased mass of the seeds as moisture content rises. These findings are consistent with those of Powar *et al.* (2018) for finger millet grains and Omprakash *et al.* (2019) for pearl millet grains.

Table 9: Effect of variety and moisture content on terminal velocity of paddy grain.

Variety	Terminal velocity, m/s					Mean
	MC1(7)	MC2(10)	MC3(14)	MC4(18)	MC5(22)	
Devbhog	4.11	4.557	5.19	5.357	5.617	4.96
Mahamaya	4.147	4.557	5.207	5.603	6.053	5.11
Rajeshwari	4.18	4.613	5.2	5.57	5.937	5.1
Mean	4.145	4.57	5.19	5.51	5.869	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	NS	0.12	0.085
Factor (Moisture Content)	0.319	0.155	0.11
Factor (V× MC)	NS	0.269	0.19

Note: MC1 to MC5: Moisture content, % db

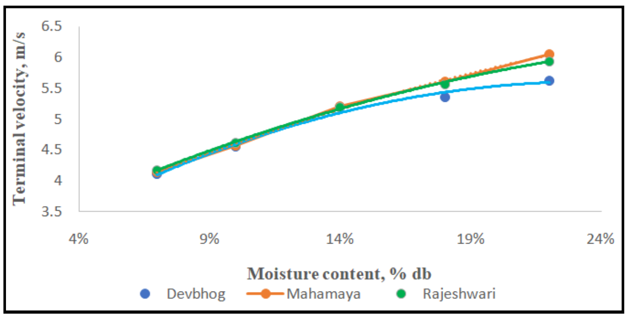

Fig. 9. Effect of variety and moisture content on the terminal velocity of the paddy grain.

(x) Effect of variety and moisture content on the angle of repose of the paddy grain. The effect of paddy varieties (Devbhog, Mahamaya, and Rajeshwari) and moisture contents (7, 10, 14, 18, and 22%, db) on the angle of repose was investigated. The data were analyzed using a Completely Randomized Design (CRD) and are presented in Table 10. Significant differences were observed in the angle of repose among the varieties as well as across different moisture levels. The highest angle of repose of 32.369° was recorded at a moisture level of 25%, while the lowest angle of repose of 23.014° was observed at 7% moisture content.

Table 10: Effect of variety and moisture content on angle of repose of paddy grain.

Variety	Angle of repose, degrees					Mean
	MC1(7)	MC2(10)	MC3(14)	MC4(18)	MC5(22)	
Devbhog	20.733	22.733	25.19	27.053	30.007	25.143
Mahamaya	23.083	25.397	28.293	31.317	32.643	28.1466
Rajeshwari	25.227	28.363	30.543	33.17	34.457	30.352
Mean	23.014	25.497	28.008	30.513	32.369	

Factors	C.D.	SE(d)	SE(m)
Factor (Variety)	0.328	0.16	0.113
Factor (Moisture Content)	0.423	0.206	0.146
Factor (V×MC)	0.733	0.357	0.253

Note: MC1 to MC5: Moisture content, % db

The interaction effect between variety and moisture content on the angle of repose was found to be non-significant. Fig. 10 illustrates the impact of various paddy varieties and moisture levels on the angle of repose. The angle of repose increased with moisture content following a polynomial trend. This increase is likely attributed to the moisture absorption in the intercellular spaces of the seeds. These findings are consistent with the results reported by Ramashia *et al.* (2017) for finger millet grains.

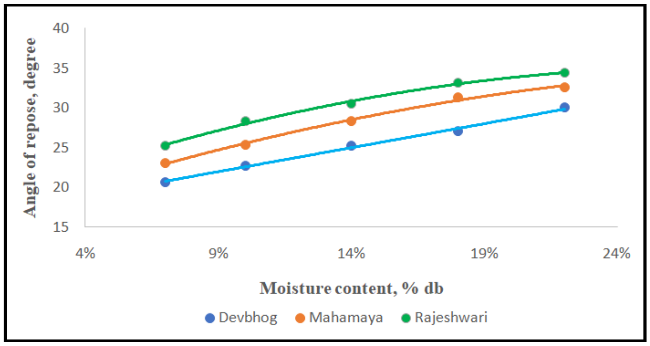

Fig. 10. Effect of variety and moisture content on the angle of repose of the paddy grain.

CONCLUSIONS

The physical parameters play vital role in the determination of the dimensions of the machine parts like sieve size, threshing cylinder type, cleaning system, threshing cylinder diameter as well as its length. The mean value of length of paddy varieties Devbhog, Mahamaya and Rajeshwari was observed as 8.002 mm, 8.722 mm and 9.128 mm respectively. The mean value of width of paddy varieties Devbhog, Mahamaya and Rajeshwari was measured as 2.18 mm, 2.37 mm and 2.54 mm respectively. The mean value of thickness of paddy varieties Devbhog, Mahamaya and Rajeshwari was obtained as 1.53 mm, 1.83 mm and 2.15 mm, respectively. The mean value of sphericity of paddy varieties Devbhog, Mahamaya and Rajeshwari was measured as 0.297, 0.33 and 0.357 respectively. The mean value of bulk density of paddy varieties Devbhog, Mahamaya and Rajeshwari was measured as 542.99kg/m^3, 577.86kg/m^3 and 650.05 kg/m^3 respectively. The mean value of porosity of paddy varieties Devbhog, Mahamaya and Rajeshwari was measured as 36.06%, 39.69 % and 43.43 % respectively. The physical properties of paddy grain were significantly affected by moisture content. It was concluded that as moisture content increased, the mean values of linear dimensions (length, width, thickness, sphericity), angle of repose, coefficient of friction, and terminal velocity also increased, while bulk density, true density, and porosity decreased.

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Conflict of Interest. None.

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