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Assessment of Engineering and Physical Characteristics of Paddy, Popped Rice and Husk

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A B S T R A C T

Rice is a staple food in many Asian countries, including India, where it serves as a primary source of nutrition and agricultural income. Physical properties are important in the design and manufacturing of processing machines. In this research work, the engineering properties of paddy, popped rice and husk was determined. In this study, CG madhuraj- 55 variety of paddy was used to determine physical property. The study examined the physical properties of paddy, popped rice and husk. The sphericity and geometric mean diameter of paddy, popped rice and husk were found to be 0.42, 0.53, 0.24 and 3.52, 6.37, 2.04. Bulk density (kg/m^3), true density (kg/m^3), and porosity (%), of paddy, popped rice and husk were found to be 604, 60.6, 200, true density 1240, 109, 866, porosity 51.30, 44.24, and 76.91, respectively. Angle of repose of paddy, popped rice and husk was found to be 30.15, 40.91, 36.59, and coefficient of friction for paddy in different surfaces *i.e.,* stainless sheet 0.34, iron 0.57, mild sheet 0.50, and galvanized sheet 0.37. Similarly, for popped rice stainless sheet 0.48, iron 0.62, mild sheet 0.55, galvanized sheet 0.41, and husk stainless sheet 0.48, iron 0.54, mild sheet 0.53, galvanized sheet 0.40, respectively.

Introduction

Rice is the most important cereal crop in the developing world and serves as a staple food for over half of the global population, over 90% of the world's rice is grown and consumed in Asia. Globally, rice feeds about three billion people, providing 27% of dietary energy, 20% of dietary protein, and 3% of dietary fat. China and India are the world's largest rice producers. China ranking first and India second together accounting for 51.4% of global milled rice production. Along with Indonesia, Bangladesh, and Vietnam, these countries contribute to over 80% of the world's rice production (USDA FAS, 2024).

In India, rice serves as the main food source for over 65% of the Indian population and contributes around 40% to the overall food grain production. The leading rice producing states include West Bengal, Uttar Pradesh, Punjab, Telangana, Odisha, Tamil Nadu, and

Chhattisgarh (Agricultural Statistics at a Glance, 2022). In the agricultural year 2024-25, the *Kharif* food grain production is projected at 1663.91 LMT, while Rabi season production is estimated at 1645.27 LMT. *Kharif* Rice production is expected to reach 1206.79 LMT, marking an increase of 74.20 LMT compared to 1132.59 LMT in 2023-24. Production of Rabi Rice is estimated at 157.58 LMT (MOA and FW, 2024).

In India, a wide range of rice-based products are prepared, consumed, and distributed**.** Puffed rice, popped rice, and flaked rice are the most popular ready-to-eat rice-based items in India.

The production of puffed rice involves the expansion of husk and conditioned parboiled rice resulting in a relatively smooth surface, whereas popped rice is a heat expanded product with cracked and irregular surface, results from the direct roasting of raw paddy (Chandrasekhar and Chattopadhyay, 1991; Chinnaswamy and Bhattacharya, 1983).

In, India popped rice is mostly consumed during special events like weddings and religious festivals. It serves as a favoured breakfast in India due to its ease of digestion and can be prepared in variety of ways with little processing (Bagchi *et al.,* 2016).

Materials and Methods

Physical properties

The research work was carried out in the Department of Agricultural Processing and Food Engineering, Swami Vivekanand College of Agricultural Engineering and Technology and Research Station and College of Food Technology, Indira Gandhi Krishi Vishwavidyalaya, Raipur (CG).

Moisture content

The moisture content was determined by the hot air oven method. To determine the moisture content, a known weight of 5 g of the test sample was dried for 24 hours at 105°C in a hot air oven. Once the process was done, the sample was removed and placed in desiccator to cool down to room temperature. Then the sample was weighed and the loss in weight was determined. The average of three replications were determined (AOAC, 2006).

The moisture content (wb) was calculated by using the following expression:

$$\text{Moisture content (\%, wb)} = \frac{W_1 - W_2}{W_1} \times 100 \quad \ldots(1)$$

Where,

W_1 = Initial weight of sample, g

W_2 = Final weight of dried sample, g

Dimension of paddy, popped rice and husk

The length, breadth and thickness of paddy and popped rice were measured separately using a digital vernier caliper with least count of 0.01 mm and the length, width and thickness of husk were measured by digital micrometer with least count of 0.001 mm.

Geometric mean diameter

The geometric mean diameter also known as equivalent diameter of paddy and popped rice which was determined by following equation (Saha *et al.,* 2020).

$$D_g = (LWT)^{\frac{1}{3}} \quad \ldots(2)$$

Where,

D_g = Geometric mean diameter, mm

L = Length, mm

W = Width, mm

T = Thickness, mm

Surface area

The surface area of paddy and popped rice was calculated using the previously determined geometric mean diameter by following relationship (Saha *et al.,* 2020).

$$A_s = \pi(D_g)^2 \quad \ldots(3)$$

Where,

A_s = Surface area, mm^2

D_g = Geometric mean diameter, mm

Sphericity

It is defined as the ratio of the diameter of a sphere with equivalent volume to the particle diameter, typically the largest dimension or the diameter of the smallest circumscribing sphere. The sphericity was calculated by following formula (Mir *et al.,* 2013).

$$\Phi = \frac{(L \times B \times T)^{\frac{1}{3}}}{L} \quad \ldots(4)$$

Where,

Φ = Sphericity

L = Length, mm

B = Breadth, mm

T = Thickness, mm

Hardness

The hardness of paddy and popped rice was measured using a Texture Analyzer (TA-HD Plus, Stable Micro System, UK) equipped with 50 kg load cell for compression was utilized.

A single compression force – versus – time program was utilized to compress a popped rice along its thickness at a speed of 0.5 mm/min, with a 5 mm diameter stainless steel probe (P/75) was used (Pal *et al.,* 2019).

Bulk density

Bulk density, was determined by filling a graduated cylinder with known quantity of sample. It is expressed as the ratio of total weight of sample to total volume of sample. The bulk density was calculated by following formula (Akaaimo and Raji, 2006).

$$\text{Bulk density}, \frac{kg}{m^3} = \frac{\text{Weight of sample}}{\text{Volume occupied by sample}} \quad \ldots(5)$$

True density

True density of paddy was determined by the toluene displacement method. In a 250 ml measuring cylinder 130 ml of toluene was filled with a known quantity of paddy added into it.

The displacement of toluene level in the beaker on putting paddy was noted down. The true density of sample was expressed as the ratio of weight of the sample to the true volume.

$$\text{True density}, \frac{kg}{m^3} = \frac{\text{Weight of grains}}{\text{True volume}} \quad \ldots(6)$$

True density of popped rice and husk was determined by sand displacement method. Popped rice was filled in a 250 ml beaker and weighed. Then the void space was filled with fine sand, sieved in a sieve, then the sand was separated from the popped rice and volume measured. True volume of popped rice was obtained by measuring the volume of popped rice with void space filled with fine sand and subtracting the volume of the separated sand (Biswal *et al.,* 2018).

$$\text{True density, kg/m}^3 = \frac{\text{Weight of sample}}{v_1 - v_2} \quad \ldots(7)$$

Where,

v_1 – Volume of popped rice or husk filled with fine sand, m^3

v_2 – Volume of fine sand, m^3

Porosity

The porosity can be defined as the intergranular void space volume and volume of bulk grain. It is calculated from the values of true density and bulk density by the following relationship (Pandiselvam *et al.,* 2015).

$$\text{Porosity} = 1 - \frac{\text{Bulk density}}{\text{True density}} \times 100 \quad \ldots(8)$$

Frictional properties

Angle of repose

The angle of repose is defined as the angle between the base and the slope of the cone formed when grains fall freely onto a horizontal surface, using the height and diameter of the naturally heaped grain piles. The angle of repose was calculated using the following formula (Saha *et al.,* 2020).

$$\theta = \tan^{-1}\frac{2H}{D} \quad \ldots(9)$$

Where,

θ = Angle of repose, degree

H = Height of the cone formed, mm

D = Diameter of circular disc, mm

Coefficient of friction

The coefficient of friction was determined using different surfaces, including stainless steel, galvanized iron, and mild steel plates, which were placed on a movable plane. A grain sample was placed on each surface, and the plane was gradually inclined until the grains just began to slide, and the angle was noted. The coefficient of friction was calculated using the following formula (Mir *et al*., 2013).

$$\mu = \tan\alpha \quad \ldots(10)$$

Thermal properties

Thermal conductivity

The thermal conductivity of paddy, popped rice and husk were measured using a digital thermal property analyser (METER TEMPOS Thermal Property Analyser). The sample of paddy, popped rice and husk were placed in a beaker and the conductivity probes were carefully inserted to ensure proper contact with the sample.

Thermal resistivity

The thermal resistance/resistivity of paddy, popped rice and husk were measured using a digital thermal property analyser (METER TEMPOS Thermal Property Analyser). The sample of paddy, popped rice and husk were placed in a beaker and the conductivity probes were carefully inserted to ensure proper contact with the sample. The measurement was recorded multiple replications and the average were taken.

Results and Discussion

Physical properties

The length of paddy, popped rice and husk 8.31 ± 0.36 mm, 11.86 ± 0.64 mm, and for husk 8.49 ± 0.32 mm, respectively. The width of paddy, popped rice and husk 2.66 ± 0.13 mm, 5.38 ± 0.36 mm and husk 2.68 ± 0.14 mm, respectively. The thickness of paddy, popped rice and husk 2.04 ± 0.09 mm, of 4.28 ± 0.40 mm and husk 0.38 ± 0.06 mm, respectively. The geometric mean diameter of paddy, popped rice and husk 3.52 ± 0.11 mm, 6.37 ± 0.32, husk 2.04 ± 0.12.

The surface area is relevant for determining the shape of the seed and rice. The surface area of the paddy, popped rice and husk 38.90 ± 2.46 mm^2 and of popped rice 127.53 ± 12.67 mm^2, and of husk 13.20 ± 1.57 mm^2, respectively. The results were similar to (Sahu *et al.,* 2018).

The value of sphericity of paddy, popped rice and husk 0.42 ± 0.01, popped rice 0.53 ± 0.02 and of husk 0.24 ± 0.01, respectively. The lower value of sphericity generally suggests that getting a difficulty of paddy in rolling that of spheroid grain the results were similar to (Mohapatra and Bal, 2012). The hardness of the paddy and popped rice were found to be 253.5 ± 9.29, 17 ± 0.87 respectively, and that of husk was found to be 252 ± 9.29, respectively

Gravimetric properties

The value of bulk density for the selected paddy, popped rice and husk were found to be of 604 ± 3.39 kg/m^3, 60.6 ± 1.15 and that of husk was found to be 200 ± 4 kg/m^3 respectively. The value of true density for the paddy, popped rice and husk were found to be 1240 ± 17.60, 109 ± 4.53 and that of husk 866 ± 20.87 respectively.

Table.1 Physical property of paddy, popped rice and husk

S.No	Parameters	N	Paddy	Popped rice	Husk
1	Length, mm	100	8.31 ± 0.36	11.86 ± 0.64	8.49 ± 0.32
	Breadth, mm	100	2.66 ± 0.13	5.38 ± 0.36	2.68 ± 0.14
	Thickness, mm	100	2.04 ± 0.09	4.28 ± 0.40	0.38 ± 0.06
2	Geometric mean diameter, mm	100	3.52 ± 0.11	6.37 ± 0.32	2.04 ± 0.12
3	Surface Area, mm^2	100	38.90 ± 2.46	127.5 ± 12.67	13.20 ± 1.57
4	Sphericity	100	0.42 ± 0.01	0.53 ± 0.02	0.24 ± 0.01
5	Hrdness, N	10	253.5 ± 9.29	17.0 ± 0.87	252 ± 9.29

Table.2 Gravimetric property of paddy, popped rice and husk

S.No	Parameters	N	Paddy	Popped rice	Husk
1	Bulk density, kg/m^3	10	604 ± 3.39	60.6 ± 1.15	200 ± 4.00
2	True density, kg/m^3	10	1240 ± 17.60	109 ± 4.53	866 ± 20.87
3	Porosity, %	10	51.30 ± 0.79	44.24 ± 2.12	76.91 ± 0.30

Table.3 Thermal property of paddy, popped rice and husk

S.No	Parameters	N	Paddy	Popped rice	Husk
1	Thermal conductivity, W/m.K	10	0.04 ± 0.001	0.01 ± 0.001	0.03 ± 0.002
2	Thermal resistance, K-m/W	10	24.66 ± 1.15	74.66 ± 3.21	31.5 ± 1.19

Table.4 Frictional property of paddy, popped rice and husk

Parameters	N	Paddy	Popped rice	Husk
Angle of Repose, degree	10	30.15 ± 0.70	40.91 ± 0.53	36.59 ± 1.05
Coefficient of friction				
Stainless sheet	10	0.34 ± 0.01	0.48 ± 0.01	0.48 ± 0.02
Iron	10	0.57 ± 0.02	0.62 ± 0.02	0.54 ± 0.01
Mild sheet	10	0.50 ± 0.02	0.55 ± 0.02	0.53 ±0.01
Galvanized sheet	10	0.37 ± 0.01	0.41 ± 0.01	0.40 ± 0.02

Figure.1 Gravimetric measurement

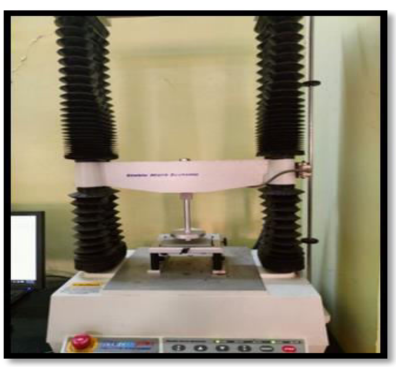

Figure.2 Angle of repose of paddy, popped rice and husk

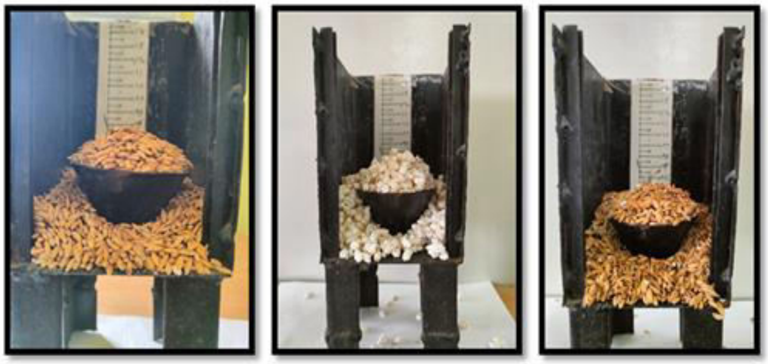

Figure.3 Thermal conductivity of paddy, popped rice, husk through thermal analyser

The value of true density greater than 1 indicate that given material is denser than water. The value of porosity for the paddy, popped rice and husk were found to be 51.30 ± 0.79, 44.24 ± 2.12 and that of husk 76.91 ± 0.30, the above results were in range with Mohapatra and Bal (2012).

Frictional properties

The angle of repose of paddy, popped rice and husk 30.15 ± 0.70, 40.91 ± 0.53 and that of husk 36.59 ± 1.05. The value of coefficient of static friction for paddy was found 0.34 ± 0.01 on stainless steel, 0.57 ± 0.02 on iron, 0.50 ± 0.02 on mild steel and 0.37 ± 0.01 on galvanised steel and for popped rice the values were found 0.48 ± 0.01 on stainless steel, 0.62 ± 0.02 on iron, 0.55 ± 0.02 on mild steel and 0.41 ± 0.01 on galvanised steel and for husk the values were found 0.48 ± 0.02 on stainless steel, 0.54 ± 0.01 on iron, 0.53 ± 0.01 on mild steel and 0.40 ± 0.02 on galvanised steel.

Thermal property

The value of thermal conductivity of paddy, popped rice and husk was found to be 0.04 ± 0.001, popped rice 0.01 ± 0.001 and husk 0.03 ± 0.002 and thermal resistivity of paddy, popped rice and husk was found to be 24.66 ± 1.15, popped rice be 74.66 ± 3.21and husk 31.5 ± 1.91, respectively.

The study evaluated the physical, gravimetric, thermal, and frictional properties of paddy, popped rice, and husk, revealing significant differences among them. Popped rice exhibited the highest geometric mean diameter (6.37 mm), surface area (127.53 mm^2) indicating significant expansion during popping. The hardness of popped rice (17N) was markedly lower than that of paddy and husk facilitating easier milling or crushing.

Bulk density and true density values showed that popped rice is much lighter (60.6 kg/m^3 and 109 kg/m^3, respectively) compared to paddy and husk. Thermal conductivity was lowest for popped rice (0.01 W/m·K), and its thermal resistivity was highest (74.66 K·m/W), suggesting good insulation properties.

Frictional properties showed that the angle of repose was highest in popped rice (40.91 ± 0.53°), followed by husk and paddy. The frictional properties showed that all samples had the highest coefficient of static friction on iron surfaces. The findings provide essential engineering data for the design and optimization of post-harvest processing and separation equipment, especially for popped rice handling and husk separation.

Author Contributions

Sandesh Dahare: Investigation, formal analysis, writing—original draft. Niraj Mishra: Validation, methodology, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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