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Research Paper

PHYSICAL AND ENGINEERING PROPERTIES OF SOME INDIAN PADDY CULTIVARS AND THEIR INTERRELATIONS

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Physical and engineering properties of grains are important to design processing equipment, storage and process optimization. In this study, twenty paddy cultivars mainly grown in southern part of India were evaluated for various physical and engineering propertiessuch as bulk density, true density, porosity, volume, thousand kernel weight, equivalent diameter, geometric mean diameter, sphericity, slenderness ratio, hardness, angle of repose, static coefficient of friction, and colour values at a moisture content of 12±0.5%. The data was statistically analysed and the correlation ($p \leq 0.05$) among the various parameters were investigated. Resultexhibited a wide variation in length (7.1-9.7 mm), breadth (2.3-3.2 mm), thickness (1.4-2.1 mm), slenderness ratio (2.46-3.55), bulk density (514-632 kgm^{-3}), true density (1139-1254 kgm^{-3}) and porosity (45.2-54.1%) among the paddy cultivars. Angle of repose and static coefficient of friction values ranged between 32-45^{o} and 0.32-0.48respectively. Highest hardnessvalue (82.88kg)was observed by TKM9, whereas lowest hardness value (48.57 kg) exhibited by Burma black, indicating high and poor milling quality respectively. Colour analysis revealed that L* (lightness) values $\leq$ 88.54 combined with ΔE (average colour difference) value $\geq$ 10.57 indicated pigmented paddy cultivars. High positive correlation was observed among parameters like, thickness and geometric mean diameter (r = 0.759); volume and geometric mean diameter (r = 0.884) whereas negative correlation was observed between slenderness and sphericity (r = -0.640). These findings are useful in designing and optimizing the postharvest machineries in rice processing industries.

Keywords: Paddy, Pigmented, Geometric mean diameter, Sphericity, Hardness, Correlation

INTRODUCTION

Rice is one of the leading food crops of the world, constituting as the basic food for large number of the world's population (Reddy and Chakravarthy, 2004). The marketing value of rice as an agricultural crop depends on its physical and engineering qualities after harvesting (Fraser *et al.*, 1978). The data on physical properties such as, bulk density, porosity, volume, angle of repose, etc., of paddy is important for designing various

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processing machineries like hoppers, graders, dryers, milling machineries and storage facilities (Iraj Bagheri *et al.*, 2013). Results on bulk density can aid us in designing of silos and storage bins (Shitanda *et al.*, 2001). The angle of repose determines the maximum angle of a pile of grain with horizontal plane which is essential for hopper designing (Jain and Bal, 1997). Knowledge of friction of coefficients of paddy is essential for designing conveying equipment. Thousand grain weight of paddy grain is used for calculating the head rice yield and it can be used as an index for measuring milling outrun (Bhattacharya *et al.*, 1972; Luh, 1980; and Marchezan, 1991). Hardness is one of the important physical parameters which maximizes the milling yield. Variation in hardness of different paddy cultivars is due to the compact arrangement of starch granules (Mir *et al.*, 2015). Studying the sphericity and volume helps to determine the energy required for drying and the drying rate (Mohammad Jouki and Naimeh Khazaei, 2012). Although details on physical and engineering properties of many paddy cultivars are reported, the information on these presently chosen paddy cultivars widely grown in southern part of India is scarce. India is a vast country having different agro-climatic conditions like different soil characteristics, temperature, humidity, rainfall, which synergistically affect the paddy cultivation. This is the reason for prevalence of specific paddy cultivars in particular parts of the country. Hence it is necessary to know the physical properties of different cultivars of paddy for their processing and commercial production. Therefore, the present investigation was carried out to evaluate the physical properties of twenty paddy cultivars which would be useful for their commercial adoption.

MATERIALS AND METHODS

Paddy grains used for this study were procured from different rice research stations from southern part of India. The paddy cultivars were cleaned manually for foreign materials such as dust, sticks, stones etc. Moisture content of these paddy cultivars were adjusted to 12±0.5% and used for further experiments.

Principal Dimension Measurement and Slenderness Ratio

Paddy was randomly selected from each cultivar and their principal dimensions, i.e., length (l), breadth (b) and thickness (t) were measured using digital verniercaliper for at least 40grains and mean dimensions were reported.

Slenderness ratio (S_L) is defined as the ratio between length and breadth of the paddy.

$$SL = \frac{l}{b}$$

Bulk Density, True Density and Porosity

The bulk density (ρb) of paddy cultivars was determined by the modified method of Mohsenin (1970) and Fraser *et al*. (1978). Briefly, an empty measuring cylinder was filled with known quantity of paddy grains by pouring from a constant height, tapped manually 25 times and the volume was noted. The ratio between the mass of paddy and the volume after tapping was calculated. The true density (ρt) was determined by the toluene displacement method.

Porosity (ε) is defined as the ratio of inter granular void space and the true density (Nalladulai *et al.*, 2002).

$$\varepsilon = \left(pt - \frac{pb}{pt}\right) * 100$$

Static Coefficient of Friction and Angle of Repose

The static coefficient friction (μ) of paddy samples was measured by modified procedure of Razavi and Milani (2006) and Prashant Ghadge and Prasad (2012). Briefly, the paddy grains were held on a glass surface clipped on a wooden frame which was slowly tilted and the angle at which the grains started to slide down was measured. The static coefficient of friction was then calculated from the following relationship.

$$\mu = \tan \alpha$$

where α is the angle of tilt.

The frictional properties of the grain werestudied indirectly by determining their Angle of Repose (AR). A rectangular open-top box (10.3 cm wide x 12.8 cm deep x 10.1 cm high) was employed for thispurpose. The front wall was detachable, sliding through, guides, so that it could be flicked up. Grain was poured into the box, and the top levelled with a blunt-edged stroker. The front wall was then flicked open; allowing excess grain to fall at the front. A protractor was placed externally alongside the wall and adjusted till an interpolated angle line was tangent to the middle portion of the surface line, which gave the angle of repose of the grain (Razavi and Milani, 2006).

Equivalent Diameter, Geometric Mean Diameter and Volume

The equivalent diameter (D_{EQ}) of paddy was determined by using expression as described by Mohsenin (1986).

$$D_{EQ} = \sqrt[3]{[4l(b + t/4)^2]}$$

The geometric mean dimension (D_{GM}) of kernels was found using the relationship given by Mohsenin (1986) as,

$$D_{GM} = \sqrt[3]{lbt}$$

Grain volume (V) of paddy was calculated by using the following expression.

$$V = \frac{1}{4}[\frac{\Pi}{6} l(b + t)^2]$$

Sphericity, Thousand Kernel Weight and Hardness

The sphericity (ϕ) defined as the ratio of the surface area of the sphere having the same volume as that of grain to the surface area of the grain was determined using expression as described by Mohsenin (1986).

$$\phi = \sqrt[3]{(\frac{lbt}{l})}$$

One thousand sound paddy kernels were counted randomly and weighed separately. Mean of three replications was reported as thousand kernel weight (KW_t).

Hardness (H) of paddy grains was measured by using Texture Analyzer (TA-HD, Stable Micro Systems Ltd, Surrey, UK). A single compression force-versus time program was used to compress single grain along the thickness, at a test speed of 0.10 mm/sec until the grain break. The test was repeated 20 times for the same cultivars, for all the twenty cultivars. The peak force indicated by the force time curve was taken as the maximum compressive force/hardness.

Colour Characteristics

The colour of paddy grains were determined by CIE colour scales using Hunter Lab colour measuring system (colour measuring Lab Scan XE system, USA). L* values denote lightness and ΔE denotes the average colour difference.

Statistical Analysis

The data were analysed statistically using SYSTAT.12 software. All the data are presented as the mean with the standard deviation. Pearson's correlation ($p \leq 0.05$) was performed for finding the relationship between the different parameters (Table 1).

Table 1: Pearson Correlation Coefficients ($p \leq 0.05$) Between Physical and Engineering Properties of Different Paddy Cultivars

	l	b	t	SL	ρb	ρt ε		V	D_{GM}	D_{EQ}	μ	AR	KW_t	H	ϕ	L*
b	0.307															
t	0.127	0.274														
SL	-0.404	-0.627	-0.11													
Pb	-0.475	-0.216	-0.037	-0.207												
ρt	-0.049	-0.229	-0.183	0.081	0.425											
ε	0.379	-0.181	0.111	0.445	-0.476	0.117										
V	0.61	0.564	0.6	0.004	-0.167	-0.117	0.019									
D_{GM}	0.497	0.62	0.759	0.186	-0.152	-0.157	0.035	0.884								
D_{EQ}	0.603	0.377	0.255	0.125	0.038	-0.006	-0.046	0.602	0.527							
μ	-0.066	-0.286	0.01	0.236	0.203	0.068	0.319	-0.104	-0.053	-0.109						
AR	-0.077	-0.311	0.079	0.227	-0.187	0.106	0.197	-0.125	-0.176	-0.197	-0.412					
KW_t	0.119	-0.037	0.05	0.084	0.413	0.05	-0.043	0.331	0.206	0.162	0.343	-0.257				
H	-0.366	-0.154	0.248	-0.089	0.229	0.058	0.027	-0.098	0.021	-0.438	0.271	-0.303	0.275			
ϕ	-0.355	0.525	0.51	-0.681	0.246	-0.18	-0.392	0.21	0.465	0.187	-0.151	-0.028	0.011	0.12		
L*	-0.541	-0.357	0.312	-0.06	0.258	-0.211	-0.194	-0.214	-0.061	-0.485	0.129	-0.079	0.232	0.746	0.209	
ΔE	0.579	0.284	0.145	0.115	-0.152	0.293	0.302	0.367	0.29	0.435	0.089	0.025	-0.037	-0.605	-0.217	-0.867

Note: l-length, b-breadth, t-thickness, S_L-Slenderness ratio, ρb-bulk density, ρt-true density, ε-porosity, V-Volume, D_{GM}-Geometric mean diameter, D_{EQ}-Equivalent mean diameter, μ-Coefficient of friction, AR-Angle of repose, KW_t-Thousand kernel weight, H-Hardness, ϕ-Sphericity, L*-Lightness, ΔE-Delta E.

RESULTS AND DISCUSSION

Principal Dimensions and Slenderness Ratio

The range of length, breadth and thickness of twenty paddy cultivars were 7.1-9.7 mm, 2.3-3.2 mm and 1.2-2.1 mm respectively (Table 2). Similar range was observed by Sarker and Farouk (1989) and Mohammed *et al.* (2012) for paddy cultivars from Iran. Slenderness ratio was in the range of 3.7-6.3. Among the paddy cultivars Neelam samba possessed highest value for length (9.76 mm), thickness (2.10 mm) and slenderness ratio (6.31). Principal dimensions of paddy grains are useful in selecting sieve separators, which can aid in grain grading and uniformity. They can also be used to calculate volume of kernels, which are important during modelling of grain drying, aeration, heating and cooling (Shay and Singh, 1994). Positive correlation was observed between length and volume (r = 0.610) and length and equivalent mean diameter (r = 0.623). Breadth showed a positive correlation with geometric mean diameter (r = 0.620), whereas thickness exhibited positive correlation with volume (r = 6.00) and geometric mean diameter (r = 0.759).

Bulk Density, True Density and Porosity

Bulk density, true density and porosity ranged between 514-632.4 kgm^{-3}, 1139-1254 kgm^{-3}, 45.2-54.1% respectively (Table 1). Similar trend was reported for some paddy varieties from Iran (Shay and Singh, 1994). Highest bulk density (632.40 kgm^{-3}) and true density (1254 kgm^{-3}) values were observed in CO 48 and Improved White Ponni (IWP) cultivars respectively, whereas the highest porosity value (54.18%) was observed in Norungun cultivar. Positive correlation (r = 0.427) prevailed between bulk density and true density.

Angle of Repose and Coefficient of Friction

The angle of repose and co efficient of friction of the paddy cultivars ranged between, 32-45^o and 0.32-0.48 respectively (Table 2). Zhout *et al.* (2002) and Prashant *et al.* (2012) also reported angle of repose and co-efficient of friction in these range. Highest (45^0) and lowest (32^0) angle of repose and were observed in CO49 and CO48 respectively, whereas highest (0.489) and lowest (0.32) static coefficient of friction were observed in ASD16 and CO49 respectively. Angle of repose finds its application in hopper designing which determines the maximum angle of a pile of a grain with the horizontal plane, while the hopper walls inclination angle should be greater than the angle of repose to ensure the continuous flow of materials by gravitational force. Similarly the static coefficient of friction is used to determine the angle at which the chutes should be positioned in order

Table 2: Principal Dimensions, Slenderness Ratio, Bulk Density, True Density and Porosity Values of Paddy Cultivars

Sample	l (mm)	b (mm)	t (mm)	S_L	ρb (kgm^{-3})	ρt (kg m^{-3})	£ (%)
CO49	7.54±0.58	2.68±0.41	1.58±0.47	2.81±0.05	609.92±1.27	1226±2.51	47.25±2.00
ASD16	7.01±0.76	2.34±0.54	1.41±0.18	2.99±0.02	594.07±2.04	1222±2.51	51.87±1.24
CO51	7.65±0.63	2.78±0.28	1.87±0.22	2.71±0.02	623.91±2.06	1139±3.05	45.28±2.14
TKM9	8.48±0.94	2.85±0.24	1.72±0.10	2.97±0.03	626.91±5.19	1203±1.58	48.41±2.71
ADT43	8.72±0.98	2.45±0.15	1.65±0.20	3.55±0.05	559.69±1.80	1192±2.51	52.93±2.83
CO50	7.45±0.84	2.65±0.74	1.89±0.21	2.81±0.01	625.01±3.24	1193±4.04	47.50±2.25
IWP	7.98±0.24	2.85±0.84	2.03±0.09	2.80±0.01	614.80±4.34	1254±1.48	50.33±1.09
Bhavani	8.56±1.95	2.95±0.92	1.87±0.14	2.90±0.05	617.34±7.62	1234±2.14	49.30±1.92
CO48	8.02±0.98	3.05±0.82	1.56±0.15	2.65±0.02	632.40±1.14	1163±1.57	46.40±1.10
Kauvni	8.52±0.92	3.12±0.54	1.25±0.16	2.73±0.03	609.75±2.24	1206±2.14	46.44±1.75
Improved kauvni	8.92±0.90	2.96±0.51	1.82±0.14	3.01±0.02	558.68±2.54	1189±1.56	52.44±1.53
Purple puttu	8.98±0.82	2.54±0.84	1.52±0.12	3.53±0.07	628.41±1.26	1235±1.84	50.28±1.09
Norungun	7.96±0.79	3.23±0.98	2.06±0.21	2.46±0.01	619.47±1.84	1197±1.86	48.24±0.62
BPT15	8.17±0.93	2.33±0.68	1.84±0.17	3.55±0.01	608.24±1.62	1175±3.24.	53.17±1.54
Neelam Samba	9.76±0.92	3.06±0.24	2.10±0.13	3.18±0.01	514.17±2.84	1139±1.52	49.78±0.69
Kowni nel	8.97±0.75	3.15±0.54	1.42±0.12	2.84±0.01	514.19±2.54	1178±2.51	53.17±1.25
Perunganar	9.02±0.72	2.31±0.24	1.56±0.09	3.09±0.02	617.28±1.24	1236±1.66	52.84±2.05
Tanga samba	9.17±0.68	3.17±0.14	2.06±0.11	2.89±0.03	591.71±1.58	1194±2.69	48.18±1.54
Kudaivazhai	9.08±0.52	2.85±0.88	1.65±0.13	3.18±0.06	625.00±1.65	1241±1.81	53.05±1.53
Burma black	8.69±0.68	2.94±0.14	1.87±0.15	2.95±0.05	612.86±2.36	1248±1.25	49.78±2.06

Note: l-Length, b-breadth, t-thickness, SL-Slenderness ratio, ρb-bulk density, ρt-true density, ε-porosity.

Table 3: Volume, Geometric Mean Diameter, Equivalent Diameter, Static Coefficient of Friction and Angle of Repose Values of Paddy Cultivars

Sample	V (mm^3)	D_{GM} (mm)	D_{EQ} (mm)	μ	AR (^{0})
CO49	17.79±0.5	3.17±0.1	3.25±0.21	0.32±0.4	45±0.2
ASD16	13.25±0.4	2.88±0.6	3.14±0.08	0.48±0.1	37±0.4
CO51	21.50±0.1	3.41±0.5	3.45±0.5	0.41±0.2	41±0.5
TKM9	23.02±0.1	3.46±0.1	3.53±0.8	0.47±0.2	35±0.2
ADT43	19.05±0.2	3.27±0.7	3.32±0.1	0.38±0.8	44±0.2
CO50	19.96±0.2	3.39±0.7	3.41±0.2	0.36±0.1	40±0.5
IWP	24.07±0.1	3.58±0.5	3.65±0.5	0.37±0.2	42±0.3
Bhavani	25.85±0.3	3.61±0.2	3.67±0.5	0.37±0.5	35±0.4
CO48	22.16±0.1	3.36±0.7	3.84±0.4	0.36±0.4	32±0.2
Kauvni	18.47±0.1	3.27±0.5	4.02±0.7	0.37±0.3	38±0.1
Improved kauvni	19.24±0.2	3.19±0.6	3.86±0.5	0.36±0.6	42±0.1
Purple puttu	28.96±0.5	3.26±0.8	4.03±0.9	0.38±0.5	43±0.5
Norungun	26.13±0.5	3.75±0.7	3.64±0.7	0.42±0.8	41±0.6
BPT15	17.56±0.1	3.27±0.1	3.84±0.5	0.46±0.4	38±0.5
Neelam Samba	34.84±0.1	4.07±0.5	4.02±0.8	0.38±0.5	40±0.4
Kowni nel	21.46±0.2	3.32±0.7	3.36±0.1	0.37±0.0	38±0.2
Perunganar	17.56±0.4	3.25±0.8	3.68±0.5	0.41±0.1	40±0.4
Tanga samba	32.36±0.4	3.9±0.6	4.01±0.2	0.42±0.1	35±0.4
Kudaivazhai	23.90±0.2	3.49±0.5	3.61±0.2	0.47±0.4	36±0.5
Burma black	26.16±0.1	3.76±0.7	4.12±0.1	0.40±0.2	39±0.6

Note: V-Volume, D_{GM}-Geometric mean diameter, D_{EQ}-Equivalent mean diameter, μ-Coefficient of friction, AR-Angle of repose.

Table 4: Thousand Kernel Weight, Hardness, and Sphericity and Colour Indices of Paddy Cultivars

Sample	KW_t (g)	H (kg)	¤(%)	L*	a E
CO49	21.42±0.6	61.33±0.04	0.40±0.01	89.54±0.01	10.37±0.02
ASD16	21.55±0.4	74.90±0.04	0.39±0.01	92.14±0.01	7.65±0.01
CO51	22.49±0.8	56.45±0.05	0.44±0.01	92.1±0.01	7.55±0.01
TKM9	23.66±0.5	82.88±0.05	0.40±0.01	88.29±001	11.85±0.02
ADT43	19.82±0.7	72.58±0.05	0.37±0.01	90.47±0.02	10.31±0.02
CO50	20.92±0.9	68.10±0.05	0.45±0.02	92.65±0.05	8.01±0.01
Improved white ponni	21.87±1.1	71.84±0.01	0.44±0.02	90.91±0.01	9.17±0.01
Bhavani	23.82±1.2	84.49±0.01	0.42±0.02	92.32±0.05	6.98±0.01
CO48	22.01±0.9	69.13±0.01	0.41±0.04	90.98±0.05	8.24±0.02
Kauvni	22.84±1.1	49.85±0.02	0.45±0.05	78.48±0.02	14.28±0.02
Improved kauvni	18.56±0.8	52.84±0.03	0.40±0.05	80.65±0.01	10.57±0.03
Purple puttu	24.65±1.2	50.47±0.03	0.36±0.01	77.25±0.04	16.94±0.03
Norungun	23.55±1.1	72.41±0.03	0.47±0.01	85.61±0.04	14.62±0.03
BPT15	22.84±0.7	66.64±0.01	0.40±0.01	90.48±0.06	9.88±0.02
Neelam Samba	23.54±1.0	60.28±0.05	0.42±0.03	88.54±0.05	12.05±0.02
Kowni nel	19.64±0.9	52.84±0.05	0.37±0.02	75.14±0.01	18.14±0.02
Perunganar	23.15±1.0	60.84±0.01	0.36±0.02	85.45±0.01	14.58±0.01
Tanga samba	22.45±0.8	62.54±0.02	0.42±0.00	84.24±0.02	15.06±0.01
Kudaivazhai	24.27±1.1	58.24±0.02	0.38±0.01	84.74±0.01	16.08±0.01
Burma black	18.54±0.7	48.57±0.02	0.43±0.01	76.24±0.02	20.17±0.02

Note: KW_t-Thousand kernel weight, H-Hardness, ϕ-Sphericity, L*-Lightness, ΔE-Average colour difference.

to achieve consistent flow of materialsthrough the chute. Such information is essential for designing motor requirements for grain transportation and handling (Mir *et al.*, 2013).

Volume, Equivalent Diameter and Geometric Mean Diameter

Volume, equivalent diameter and geometric mean diameter of the paddy cultivars ranged from 13.2-34.8 mm^3, 3.24-4.12 mm and 2.8-4.0 mm respectively (Table 3). Paddy cultivars grown in temperate regions of India showed the results for the above parameters within this range. Results revealed that Neelam samba possessed highest values for volume (34.84 mm^3) and geometric mean diameter (4.07 mm) whereas Burma black showed highest value for equivalent mean diameter (4.12 mm). Moreover lowest value for volume (17.56 mm^3) was observed in Perunganar cultivar, whereas ASD16 paddy cultivar exhibited lowest values for equivalent diameter (2.8 mm) and geometric mean diameter (3.14 mm). High positive correlation was obtained between volume and geometric mean diameter (r = 0.884); volume and equivalent mean diameter (r = 0.614); also in geometric mean diameter and equivalent mean diameter (r = 0.548).

1000 Kernel Weight, Hardness and Sphericity

The 1000 kernel weight, hardness and sphericity of the paddy cultivars ranged between 18-23 g, 48.5-84.49 N and 0.36-0.47 respectively (Table 4). Reddy *et al.* (2004) and Zareiforoush *et al.* (2011) also reported 1000 kernel weight in this range while studying the physical properties of raw and parboiled paddy. Highest value of thousands kernel weight (24.27 g) was observed in Kudaivazhai cultivar, whereas Burmablack cultivar exhibited lowest value (18.54 g). Highest value for hardness (82.88 kg) and sphericity (0.47%) were observed in TKM9 and Norungun respectively. Lowest values for hardness (48.57 kg) and sphericity (0.36%) were observed in Burmablack and Purpleputtu cultivars respectively. Lower sphericity values suggest the kernels tend to have a cylindrical shape, which indicates difficulty in getting the kernels to roll than that of grains with high sphericity value. This property of either rolling or sliding is necessary in the design of hoppers for milling process. High hardness value is desirable to achieve more head rice yield. Hardness had a slightly negative correlation with equivalent mean diameter (r = -0.442).

Colour Indices

Colour parameters like L* (lightness) and average colour difference (ΔE) of paddy cultivars ranged between 75-92 and 7.65-20.17 (Table 3). Paddy cultivar *CO50* exhibited the highest L value (92.65) indicating lightest in colour, whereas *Kowninel* cultivar exhibited darkest colour with a least value of L* (75.14). Highest and lowest ΔE values were observed in*Burmablack* (20.17) and *Bhavani* cultivar (6.98) respectively. L value showed negative correlation with ΔE (r = -0.870).

CONCLUSION

Physical properties of twenty paddy cultivars grown in southern part of India were studied at 12% moisture content (dry basis). Correlation among the various physical parameters was also studied. Results revealed that wide variations in physical properties exhibit among the paddy cultivars. The colour analysis showed that L*($\leq$88.54) combined with ΔE ($\geq$10.57) for paddy cultivars such as *TKM9, Kauvni, Improved kauvni, Purple puttu, Norungun, Neelamsambha, Kowninel, Perunganar, Tanga samba, Kudaivazhai and Burmablack* were pigmented whereas others were non-pigmented cultivars. High positive correlation was observed for geometrical diameter with volume and thickness of paddy cultivars. These results are useful for designing and optimizing post-harvest machineries in paddy processing industries for their commercial adaption.

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