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Physical properties of selected South Indian heritage paddy varieties

Priya Dharshini Veeraragavan[a] & Sathya Albert[a,*]

[a]School of Chemical and Biotechnology, SASTRA Deemed University, Tirumalaisamudram, Thanjavur 613 401

[*]E-mail: sathyaravi@carism.sastra.edu

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There is an increasing trend in the production processing and marketing of traditional crops with a special focus on rice in the southern peninsular region of India. In this context, the current study was carried out to evaluate the dimensional, gravimetric, and frictional characteristics of selected eleven heritage paddy varieties in both raw and parboiled conditions adopting standard procedures. Among the dimensional properties, the L/B ratio classified Muttrinasannam, Thanga samba, and Basmati into an extra-long slender category with reduced volume both in the raw and parboiled conditions. In contrast, bold varieties (Mapillai samba) recorded an increase in volume both in raw and parboiled conditions. The geometric aspect ratio value recorded for Basmati was the lowest indicating good rolling properties in both the raw and parboiled conditions. The traditional rice varieties, Mapillai samba (30.18 g) and Kattuyaanam (30.03 g) scored high for thousand grain weight in raw and parboiled conditions respectively, which is a positive parameter for marketability. A strong correlation has been observed between volume with and surface area, volume with geometric mean diameter and surface area in both raw and parboiled conditions. The present study provides insights on varying post-harvest processing suitability of traditional rice varieties of south India.

Keywords: Physical properties, Heritage paddy varieties, Geometrical, Gravimetric properties

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Paddy (*Oryza sativa* L.) is the most essential and widely grown food crop in the Asian continent, it's a prime and inevitable food source around the globe[1,2]. The farmers have been cultivating and consuming the traditional cultivars for ages, and these crops exhibit a wide range of colors and appearances, making them an exceptional representation of the cultural landscape heritage of the valley[3]. The knowledge of some important physical properties such as dimensional properties, namely axial dimensions and geometric dimensions are significant in post-harvest processing mechanics. In addition, gravimetric properties and frictional properties are indispensable for the design of several drying, separating, storing, and handling systems[4]. Parboiling is a hydrothermal process that involves the partial cooking of raw paddy; it alters various physical, chemical, and mechanical properties of paddy[3]. Currently, there is an overall preference for diets that include cereals and millets due to their perceived health benefits. Evaluating post-harvest processing suitability of these traditional rice varieties is crucial for their wider consumption, conservationand promotion of health benefits.

[*]Corresponding author

The physical characteristics of paddy grains considerably delineate their post-harvest processing characteristics, storage, milling, and subsequent processing[5]. Knowledge of axial dimensions are beneficial in choosing sieve separators and calculating requisite power during the milling process. Gravimetric properties are significant properties used in designing machinery related to processing, such as drying, transportation, storage of grains, etc.[6]. Bulk density plays a major role in determining the type of conveyor and sufficient planning for stocking of piles[7]. Porosity is yet another significant gravimetric property that determines airflow detention during the drying activity and air circulation. It determines the storage quality, moisture content, texture, and quality of dryness. Thousand grain weight which is an essential parameter for the estimation of head rice yield. Head rice also includes broken kernels 75%-80% of the whole grain[2] apart from whole grains. The angle of repose is one of the frictional properties, which describes the flow properties of grains, and it plays a vital role in designing conveyor systems and designing the angle of hoppers[6].

The traditional rice varieties in general possess a wide range of phytonutrients such as flavonoids, phenolics, antioxidants and anthocyanins which can possibly contribute to the therapeutic potentials of these varieties[8,9].

The primary aim of this study was to assess the physical and engineering characteristics of various heritage paddy varieties, both in their raw and parboiled states. These findings are crucial in designing appropriate post-harvest processing and handling machinery, as well as storage facilities, to optimize the preserving quality of these folk varieties.

Materials and Methods

Sample collection and parboiling

The traditional rice varieties investigated under the present study were collected from local organic farmers. Eleven heritage paddy samples, namely Arubadamkuruvai, Sandikar, Kullakar, Muttrinasannam, Mysore malli, Salem sanna, Thanga samba, Karunkuruvai, Kattuyaanam, Mappillai samba, and Basmati were harvested and parboiled for this study (Fig. 1). The parboiling process was done by adopting the modified method of Bhattacharya[10].

Physical properties

The axial dimensions such as length (L), width (W), and thickness (T) were measured using a Vernier caliper with an accuracy of 0.01mm. These axial parameters were utilized to compute several physical parameters of paddy, including surface area (S), volume (V), equivalent diameter (De), geometric mean diameter (Dg), sphericity (∅), and aspect ratio (Ra)[11].

L/B ratio and shape of the paddy (mm)

The length/breadth ratio was determined by dividing the mean length of twenty grains by the mean breadth of twenty grains of each of the varieties. An average of three replications was reported. The L/B ratio contributes to the shape of the grain. Size & shape were determined based on the ISO, IRRI classification.

$$Shape = \frac{Length\ of\ the\ paddy\ (mm)}{Breadth\ of\ the\ paddy\ (mm)}$$

Geometric mean diameter (D_g) & Sphericity(∅)

The Geometric mean diameter is also known as the equivalent diameter. It was determined by the following formula,

$$D_g = (LBT)^{1/3}$$

Sphericity (∅) of both raw and parboiled paddy varieties were calculated using the following equation[12]

$$\emptyset = (LWT)^{1/3} \div L$$

Volume (mm^3) & Surface area (mm^2)

Volume (mm^3) and surface area (mm^2) of both raw and parboiled paddy varieties were calculated using the following equation[13].

$$Volume\ (V) = 0.25[(\pi/6)\ L\ (W+T)^2]$$

$$Surface\ area\ (S_a) = \pi\ (Dg)^2$$

Where, D_g = Geometric mean diameter

Aspect ratio (%)

The aspect ratio (R_a) was calculated using the method of Ghasemi-Varnamkhasti[14]. It is the ratio between the breadth and length of the paddy.

$$Ra(\%) = \frac{Breadth\ (mm)}{Length\ (mm)} \times 100$$

Fig. 1 — Morphological view of traditional paddy varieties (a) Paddy (b) Rice

Gravimetric properties

Bulk and tap density (g/mL)

The bulk density (ρb), tap density, and true density were measured[12,15]

$$Bulk\ density\ (g/mL) = \frac{Weight\ of\ paddy\ (g)}{Volume\ of\ paddy\ occupied (mL)}$$

$$Tap\ density\ (g/mL) = \frac{Weight\ of\ paddy\ (g)}{Volume\ occupied\ after\ tapping\ (mL)}$$

True density (g/mL) & Porosity (%)

The true density (ρt) was estimated by the toluene displacement method[12] as paddy has low absorption of toluene. Porosity (ε) is derived from bulk and true density values using respective formulae[15].

$$True\ density\ (g/mL) = \frac{Weight\ of\ paddy\ (g)}{True\ volume\ (mL)}$$

$$Porosity\ (\%) = \frac{True\ density - Bulk\ density}{True\ density} \times 100$$

Hausner ratio

Hausner ratio reflects the flowability and cohesiveness of the grain particles. It was measured by the method of Bashir and Haripriya[15].

$$Hausner\ ratio\ = \frac{Tap\ density}{Bulk\ density}$$

Thousand-grain weight (g)

Thousand-grain weight measured by standard procedure[16]. Ten replicative measurements were standard deviations taken, and the mean of the readings was multiplied by ten to get the mass of 1000 grains.

Frictional property

The angle of repose (Θ)

The angle of repose was calculated by Meera *et al.*[17]. The angle of repose (Θ) was calculated by the funnel method. A funnel fitted at the height of 2 cm from the base. Then the grains were allowed to flow through that funnel they formed a pile once they reached the base.

$$\Theta = tan^{-1}(2H/D)$$

Where, H – height of heap and D - represents diameter of heap respectively.

Statistical analysis

Analysis of variance (ANOVA) at a 5% significance level was performed using GraphPad Prism version 8.0.2 (263) to determine the raw and parboiled samples' variations. The data comprises mean values of three replications with respective.

Results and Discussion

Axial dimensions

The summary of the both raw and parboiled paddy cultivars are presented in Table 1 and (Fig. 2) respectively. Among the traditional varieties, the mean length for raw paddy varied from 7.47 mm (Mysore malli) to 9.46 mm (Basmati), whereas the

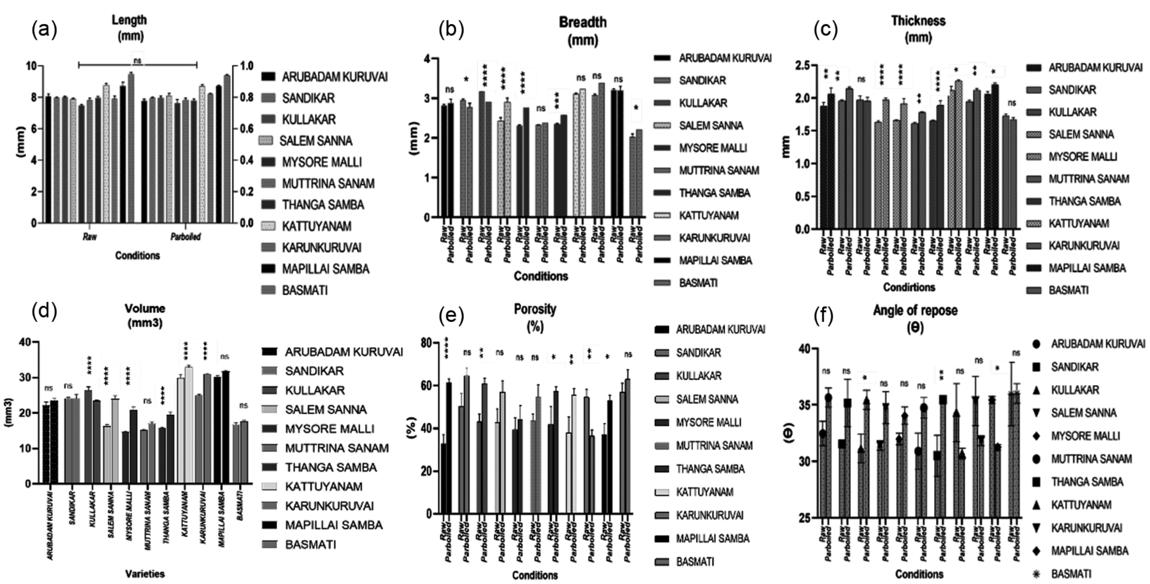

Fig. 2 — Physical key characteristics of both raw and parboiled paddy varieties. (a) Length, (b) Breadth, (c) Thickness, (d) Volume, (e) Porosity, (f) Angle of repose

Table 1 — Physical properties of selected heritage raw and parboiled paddy varieties. Values are means of triplicate expressed as mean±standard deviation. Significance was observed by a statistical tool.

Property	Condition	Arubadam Kuruvai	Sandikar	Kullakar	Salem Sanna	Mysore Malli	Muttrina Sanam	Thanga Samba	Kattuyaanam	Karunkuruvai	Mapillai Samba	Basmati
L (mm)	R	8.05±0.23	7.98±0.26	8±0.31	7.89±0.25	7.47±0.33	7.83±0.27	7.94±0.34	8.76±0.41	7.9±0.29	8.74±0.44	9.46±0.56
	PB	7.74±0.4	7.95±0.3	7.95±0.3	8.12±0.3	7.6±0.4	7.82±0.3	7.79±0.2	8.66±0.3	8.22±0.2	8.73±0.3	9.39±0.2
B (mm)	R	2.82±0.11	2.96±0.08	3.17±0.11	2.43± 0.12	2.31±0.1	2.33±0.08	2.34 ± 0.07	3.12 ±0.1	3.08±0.12	3.21±0.12	2.04±0.14
	PB	2.89±0.2	2.79±0.3	2.91±0.1	2.91±0.1	2.77±0.1	2.38±0.1	2.58± 0.1	3.25± 0.1	3.39±0.1	3.2±0.1	2.21±0.1
T (mm)	R	1.9±0.1	1.96±0.1	1.98±0.1	1.64±0.1	1.66±0.1	1.61±0.1	1.66±0.0	2.12±0.1	1.95±0.0	2.05±0.1	1.73±0.1
	PB	2.05±0.1	2.14±0.1	1.95±0.2	1.97±0.1	1.9±0.1	1.78±0.1	1.89±0.1	2.26±0.15	2.12±0.01	2.2±0.1	1.67±0.1
L/B ratio	R	2.86±0.3	2.7±0.3	2.52±0.4	3.24±0.5	3.23±0.2	3.35±0.3	3.39±0.2	2.82±0.3	2.57±0.5	2.72±0.5	4.67±0.7
	PB	2.69±0.5	2.87±0.8	2.74±0.3	2.87±0.7	2.76±0.7	3.28±0.5	3.02±0.5	2.68±0.2	2.42±0.1	2.73±0.5	4.26±0,1
Shape	R	Long Bold	Long Bold	Long Bold	Long Bold	Extra-long slender	Extra-long slender	Extra-long slender	Long Bold	Long Bold	Long Bold	Extra-long slender
	PB	Long Bold	Long Bold	Long Bold	Long Bold	Long Bold	Extra-long slender	Extra-long slender	Long Bold	Long Bold	Long Bold	Extra-long slender
V (mm^3)	R	22.2±0.86	24.07±0.38	26.41±0.99	21.43±0.49	14.73±0.17	15.17±0.28	15.85±0.14	29.99±0.93	24.93±0.39	30.14±0.48	16.73±0.51
	PB	23.64±0.4	24.07±1.15	23.45±0.18	24.04±0.9	20.77±1.07	16.96±0.4	19.46±0.82	32.94±0.49	31.09±0.9	31.73±0.26	17.67±0.26
GMD (mm)	R	3.49±0.05	3.59±0.02	3.68±0.05	3.15±0.03	3.06±0.01	3.08±0.02	3.13±0.01	3.87±0.05	3.62±0.02	3.86±0.03	3.21±0.03
	PB	3.58±0.03	3.62±0.05	3.56±0.02	3.59±0.04	3.42±0.06	3.21±0.02	3.36±0.05	4±0.02	3.89±0.01	3.94±0	3.26±0.02
S (Ø)	R	43.3±0.4	44.9±0.32	46.1±0.34	40±0.56	41±0.23	39.5±0.48	39.5±0.46	44.1±0.51	45.7±0.83	44.3±1.1	34±0.43
	PB	46.2±1.08	45.4±0.94	44.7±0.82	44.4±0.78	44.9±0.8	41.1±0.41	43.1±0.91	45.9±0.49	47.4±0.14	45.2±0.16	34.7±0.17
SA (mm^2)	R	38.4±1.08	40.4±0.4	19.9±0.34	15.1±0.39	13.6±0.18	14.3±0.21	14.6±0.17	21.44±0.23	19.1±0.43	22±0.4	15.1±0.58
	PB	40.3±068	41.1±1.16	39.8±0.39	40.5±0.84	36.8±1.25	32.4±0.5	35.5±1.05	50.1±0.52	47.5±0.2	48.8±0.37	16.3±0.05
AR (%)	R	35±0.49	37±0.44	39.7±0.17	30.8±1.19	30.9±0.35	29.8±0.54	29.5±0.62	35.5±0.57	38.9±0.87	36.8±1.35	21.4±0.72
	PB	37.13±0.92	34.87±0.4	36.53±0.89	35.95±0.81	36.26±1.38	30.45±0.38	33.1±0.66	37.26±0.3	41.28±0.41	36.67±0.78	23.5±0.25

(*Contd.*)

Table 1 — Physical properties of selected heritage raw and parboiled paddy varieties. Values are means of triplicate expressed as mean±standard deviation. Significance was observed by a statistical tool. (*Contd.*)

Property	Condition	Arubadam Kuruvai	Sandikar	Kullakar	Salem Sanna	Mysore Malli	Muttrina Sanam	Thanga Samba	Kattuyaanam	Karunkuruvai	Mapillai Samba	Basmati
BD (g/mL)	R	0.56±0	0.55±0.01	0.56±0	0.58±0.01	0.57±0.01	0.56±0.01	0.56±0.02	0.53±0.03	0.48±0.01	0.52±0.06	0.45±0.02
	PB	0.48±0.01	0.43±0.01	0.42±0.01	0.44±0.01	0.46±0.03	0.46±0.01	0.37±0	0.39±0.01	0.50±0.01	0.44±0.02	0.36±0.01
TAP (g/ml)	R	0.59±0.01	0.62±0	0.61±0.01	0.64±0.01	0.57±0.06	0.61±0.01	0.62±0.01	0.62±0.01	0.54±0.01	0.57±0.01	0.52±0.01
	PB	0.46±0.02	0.48±0.01	0.47±0	0.5±0.01	0.51±0.03	0.5±0.02	0.4 4±0	0.46±0.01	0.56±0.01	0.51±0.01	0.41±0.01
TD (g/mL)	R	0.89±0.04	1.26±0.16	1.07±0.06	1.12±0.13	0.94±0.05	1.07±0.06	1.08±0.14	1.01±0.1	1.20±0.08	0.91±0.08	1.2±0.02
	PB	1.2±0.08	1.37±0.1	1.2±0.08	1.17±0.14	0.91±0.08	1.12±0.13	1.04±0.06	1.04±0.06	0.88±0.44	1.07±0.06	1.12±0.13
P (%)	R	32.7±4.4	50.3±6.1	43.05±3.6	42.85±6.2	39.52±5.5	43.54±3.3	42.03±8.3	37.97±7.3	54.74±3.65	36.83±5.6	56.99±4.1
	PB	61.43±1.9	64.72±3.5	60.78±2.8	56.98±5.3	44.1±6.5	54.74±5.6	57.28±2.2	55.72±2.9	36.38±2.9	52.83±2.6	62.88±4.6
H	R	1.07±0.01	1.14±0.03	1.09±0.01	1.1±0.02	0.99±0.11	1.07±0.02	1.11±0.01	1.16± 0.06	1.14±0.02	1.11±0.14	1.15±0.08
	PB	0.960.04	1.12±0.04	1.12±0.01	1.12±0.01	1.1±0.01	1.1±0.03	1.19±0.01	1.18±0.02	1.12±0.01	1.16±0.04	1.16±0.05
TGW (g)	R	21.62±0.04	23.9±0.23	24.17±0.37	17.31±0.24	20.61±0.07	17.18±0.02	17.66±0.08	28.35±0.5	23.59±1	30.18±0.5	20.39±0.57
	PB	22.07±0.2	24.34±0.2	22.19±0.4	17.51±0.03	18.09±0.4	17.36±0.1	17.97±0.7	30.03±0.2	26.67±0.2	29.47±0.5	19.51±0.4
AOR (θ)	R	32.46±1.08	31.54±0.25	31.15±1.28	31.4±0.43	31.98±0.51	30.89±1.62	30.49±1.82	34.33±2.57	35.35±2.18	35.44±0.32	35.96±2.82
	PB	35.6±0.84	35.2±2.1	35.5±0.84	34.8±1.42	34±0.77	34.7±0.9	35.4±0.32	30.7±0.47	31.8±0.44	31.3±0.24	36±0.87

L-Length; B-Breadth; T-Thickness; GMD- Geometric mean diameter; S- Sphericity; SA- Surface area; AR- Aspect ratio; BD- Bulk density; TAP- Tap density; TD- True density; P- Porosity; H- Hausner's ratio; TGW- Thousand grain weight; AOR- Angle of repose.

length of parboiled paddy varied from 7.6 mm in Mysore malli to 9.39 mm in Basmati. According to ISO, IRRI classification, all the varieties (except Muttrinasannam, Thanga samba, Basmati) were observed to fall under the long bold category. In the case of the width of the raw and parboiled paddy, raw paddy ranged from 2.31 mm in Mysore malli to 3.2 mm in Mappillai samba, while parboiled paddy ranged from 2.2 mm (Basmati) to 3.4 mm in Karunkuruvai. The thickness of raw paddy varied from 1.6 mm in Salem sanna to 2.1 mm (both Kattuyaanam and Mappillai samba); in the case of parboiled paddy, it ranged from 1.7 mm in Basmati to 2.3 mm Kattuyaanam. Meera *et al.*[18] reported almost similar values of axial dimensional properties for raw Mapillai samba paddy (length -8.21 mm, breadth- 3.13 mm, and thickness- 2.18 mm. The axial dimensions of paddy are valuable for the grading process, as they enable the selection of appropriate sieve separators. Grain size is a critical character that serves as the basis for consistent grading. When grains are uniformly graded, they ensure even germination, leading to a significantly increased crop yield.

The L/B ratio determines the size of the paddy. The size of the raw paddy varied from 2.57 (*i.e.,*) long bold paddy category (Karunkuruvai) to 4.3 extra-long category (Basmati), whereas the parboiled paddy ranged from long bold paddy 2.4 (Karunkuruvai) to 4.3 mm extra-long category (Basmati). Overall, it was observed that in most of the parboiled paddy varieties, the length was reduced (non-significantly), whereas their breadth and thickness increased (significantly in six varieties) in comparison with their corresponding raw conditional values. Bhattacharya *et al*[19] reported that the reduction in length is due to the limited water system, and in partial affirmation to this, Bhattacharya[10] reported that parboiled is shorter and thicker than raw kernels. As a special mention, Salem sanna recorded a non-significant increase in length and a significant increase in thickness under the parboiled condition, which is a positive attribute towards bowl filling culinary property.

Geometric mean diameter and Sphericity

The geometric mean diameter of grains enables us to determine the sieve size diameter[20]. These sieves are a vital part of rice processing equipment, enabling the segregation of materials based on size. Traditional paddy varieties exhibited geometric mean diameter for raw paddy, which varied from 3.1 mm (Mysore malli) to 3.9 mm (Kattuyaanam & Mappillai samba), in the case of parboiled paddy, it ranged from 3.26 mm (Muttrinasannam) to 4 mm (Kattuyaanam). Except for the Kullakar variety, the geometric mean diameter of parboiled paddy varieties increased significantly (Salem sanna, Mysore malli, Muttrinasannam, Thanga samba, Katuuyaanam) and non-significantly (Arubadamkuruvai, Mapillai samba, Basmati) than the raw paddy varieties. The geometric mean diameter/equivalent diameter is a significant variable to determine grain characteristics. Mir *et al.*[4] reported about the Geometric mean diameter of Indian cultivars ranging from 3.60 (K-332) to 3.79 (Pusa-3) mm which is relatively equal with this current finding.

Volume

Raw paddy volume varied from 14.73 mm^3 (Mysore malli) to 30 mm^3 (Kattuyaanam & Mappillai samba) which falls in line with the findings of Meera *et al.*[17]. They reported that the Mapillai samba, had a volume of 31 mm^3. Whereas in the present study on parboiled paddy, it spanned from 16.96 mm^3 in Muttrinasanam to 32.94 mm^3 in Kattuyaanam. Based on shape both in raw and parboiled paddy varieties, the recorded volume was found to be high in 'long bold' paddy varieties (Raw - 22.23 mm^3 to 30.14 mm^3; Parboiled paddy - 20.774 mm^3 to 32.937 mm^3) (Fig. 2). On the other hand, the recorded volume was low in 'extra slender' paddy varieties (Raw- 15.17 mm^3 to 16.73 mm^3; Parboiled – 16.95 mm^3 to 19.46 mm^3). Accurate measurements of grain volume play a crucial role in the design of effective drying, heating, and cooling equipment necessary for rice processing[21]. Knowledge of the volume-to-surface area of grains is crucial in designing grain cleaning equipment, aspirators, pneumatic separators, and dryers, as it determines the projected area of grains suspended in a turbulent air stream[22].

Surface area

It was observed that grain size differed within the same variety; hence, the diffusion rate of water could vary even in the same variety. The rate of diffusion is directly proportional to the area of the surface of the flowability[3]. In raw paddy, it varied from 29.4 mm^2 (Mysore malli) to 46.7 mm^2 (Mappillai samba), whereas in parboiled paddy, it ranged from 32.4 mm^2 (Muttrinasannam) to 50.1 mm^2 (Kattuyaanam). Based on the values recorded for the surface area, it is evident that except Kullakar variety, all other parboiled paddy varieties showed higher surface area values resulting in a high diffusion rate. Salem sanna and Mysore malli were significantly different, while all other varieties of paddy showed no significant difference. Mir *et al.*[4] reported that the surface area of the Indian paddy varieties ranged from 34.32 mm^2 (K-332) to 43.78 mm^2 (Pusa-3) and is similar to this current finding. The thickness and surface area of the specific grain determines the cooking time. Hence in the present study, it can be inferred that varieties such as Mappillai samba and Kattuyaanam in raw and parboiled conditions respectively, will require more cooking time as they have a larger surface area.

Aspect ratio and Sphericity

The aspect ratio determines the marketability of the grains[14]. Apart from this, it also determines the sliding or rolling behavior of the grains on the surface. The aspect ratio impacts grains' rolling/sliding nature on a given surface, and grains with a low aspect ratio display rolling instead of sliding. The aspect ratio of the selected raw paddy varieties ranged from 21% (Basmati) to 40% (Kullakar) whereas, for parboiled paddy, the value ranged from 24% (Basmati) to 41% (Karunkuruvai). According to Mir *et al.*[4], the lowest aspect ratio of raw paddy was found in Pusa-3 cultivar (19%) and the highest in Koshar variety (44%). In the present study, the recorded values for aspect ratio for the lowest and the highest in both raw and parboiled conditions were observed to fall within the extreme values as reported by Mir *et al.*[4].

Sphericity is measured in terms of percentage. In raw paddy varieties it is valued from 34% (Basmati) to 46% (Kullakar & Karunkuruvai). Parboiled paddy varieties varied from 35% (Basmati) to 48% (Karunkuruvai). Sphericity was observed higher in parboiled paddy varieties (non-significant) compared to the raw paddy varieties. The finding of Meera *et al.*[17] was similar to the sphericity value (45%) recorded for raw Mapillai samba in the present study. The length of a grain of paddy is affected by the presence of its husk, while its sphericity is negatively correlated with its length. As a result, paddy with a less spherical shape will experience obstacles in its ability to glide smoothly over a separating plane[23].

Gravimetric properties of raw and parboiled paddy

Bulk density and Tap density

Bulk density and tap density were estimated for raw and parboiled paddy and depicted in Table 1. The cooking time is influenced by the bulk density of grain. In the current study, the recorded bulk density values of raw paddy ranged from 0.45 g/mL (Basmati) to 0.58 g/mL (Salem sanna). The raw grains have low bulk densities (Basmati) because their long awns prevent them from being densely packed together. The tap density measured 0.52 g/mL (Basmati) to 0.64 g/mL (Salem sanna) range in raw paddy varieties. In parboiled paddy, bulk density ranged from 0.36 g/mL (Basmati) to 0.5 g/mL (Karunkuruvai), tap density valued from 0.41 g/mL (Basmati) to 0.56 g/mL (Karunkuruvai). On an overall observation it was noted the bulk density range in parboiled condition is less than raw condition. According to Zareiforoush *et al.*[2], a decrease in the bulk density of paddy is proportional to an increase in the volume of the paddy which holds good in our present study in all the cases except for Kullakar variety. Bulk density will decrease when the grain is slenderer[24]. The size of the grain and porosity has a remarkable impact on Bulk density[19]. The bulk density of materials indicates the amount of storage space and transportation systems required[25].

Hausner ratio

Hausner ratio is the essential parameter that governs the flowability of the grain. Poor flowability was observed for the Hausner ratio value of more than 1.25. Hausner ratio for both raw and parboiled paddy varieties was calculated, as shown in Table 1. Among raw and parboiled paddy cultivars, it ranged from 0.99 (Mysore malli) to 1.16 (Kattuyaanam) in raw, while in parboiled paddy, it ranged from 0.96 (Arubadamkuruvai) to 1.19 (Thanga samba). In the present study, it was noted that all the selected paddy varieties showed good flowability with Hausner ratio values < 1.25. Good flowability of grain is a fluid mechanical phenomenon[26] that prevents grain clogging, bridging and arching in processing equipment.

True density and Porosity

True density values of raw paddy varieties are given in Table 1. It was determined to range from 0.9 g/mL (Arubadamkuruvai, Mappillai samba, and Msysoremalli to 1.3 g/mL (Sandikar). In case of parboiled paddy varieties, the values ranged from 0.9 g/mL (Mysore malli & karunkuruvai) to 1.4 g/mL (Karunkuruvai). Aragh, Sadeghi, and Hemmat[27] reported the true density is a critical parameter for eliminating different impurities from grain through the aeration process as the impurities and grains possess differential true densities. True density is useful in designing hydrodynamic separation systems[25].

The porosity of raw traditional paddy varieties ranged from 32.7% (Arubadamkuruvai) to 56.99% (Basmati) (Fig. 2). In parboiled paddy, it ranged from 36.38% (Karunkuruvai) to 64.72% (Sandikar) (Fig. 2). A high porosity value was detected in raw Basmati due to the long grain length and presence of awns. Adebowale *et al.*[25] reported that grains with higher porosity values would dry quicker than grains with low porosity, as well as that porosity allows for aeration and diffusion of water into the grains. Hence, Basmati (raw) and Sandikar (parboiled) would provide increased aeration and water diffusion into the grains.

Thousand-grain weight

The thousand grain weight helps to measure the contamination of foreign matter in a given volume of paddy grains. Thousand-grain weight of traditional paddy cultivars varied from 17.37 g (Salem sanna) to 30.18 g (Mapillai samba) in raw paddy varieties. Whereas, for parboiled paddy varieties, it varied from 17.36 g (Muttrinasannam) to 30.03 g (Kattuyaanam). Our current findings of 30.18 g in raw Mapillai samba correlates with the thousand-grain weight of Mapillai samba variety 29.47 g reported by Pandarinathan[28]. The rice variety with the highest thousand grain weight is likely to produce the highest grain yield. Therefore, promoting the cultivation of such rice varieties with high thousand grain weight would also be beneficial in terms of increasing profitability. In addition, Meera *et al.*[17] has mentioned that the thousand grain weight plays crucial role in estimating the presence of impurities such as straw, pebbles, sand, and stones in the grains harvested from the field.

Angle of repose

The angle of repose ranged from 30.5° (Thanga samba) to 35.96° (Basmati) in raw paddy varieties and 30.7° (Kattuyaanam) to 36.08° (Basmati) in parboiled paddy of all varieties (Fig. 2). Kullakar and Thanga samba recorded significantly high ($p<0.05$) angle of repose in parboiled conditions than raw (Graph 2). Except for Kattuyaanam, Karunkuruvai, all other selected parboiled paddy varieties showed a non-significant increase in angle of repose values than the raw paddy varieties. Mapillai samba recorded significantly high angle of repose ($p<0.05$) in raw condition. This current finding for angle of repose value in raw Mapillai samba (35.44°) is on par with Meera *et al.,* (2019) findings (35.15°) for raw Mapillai samba. Sahu *et al.*[29] reported that the angle of repose of paddy varieties were found to be 32.69° (Madhuraj), 29.85° (Hanthipanjra), and 32.98° (Mahamaya), which is comparatively equal with the current findings. Grains with larger sizes and rough surfaces may have higher angles of repose because their surface properties hinder the smooth flow of grains over each other[30].

Pearson correlation coefficient

Correlation coefficient for all the physical parameters of both raw and parboiled paddy varieties has been observed and shown in Table 2 & Table 3 respectively. Significant positive correlation ($p<0.05$) of breadth with thickness, geometric mean diameter, volume, sphericity, surface area and aspect ratio in both raw and parboiled conditions was observed. Volume is positively correlated ($p<0.05$) with geometric mean diameter, sphericity, surface area, aspect ratio, thousand grain weight in both raw and parboiled conditions. Surface area was positively correlated ($p<0.05$) with aspect ratio and thousand grain weight in both the conditions.

L/B ratio of raw and parboiled paddy varieties showed negative correlation ($p<0.05$) with geometric mean diameter, volume, sphericity, surface area, aspect ratio, bulk density, tap density in both raw and parboiled conditions.

Table 2 — Pearson correlation matrix between physical properties of selected raw paddy varieties. Two tailed test was performed significance was observed at 95% confidence interval. (bold values represent significance $p<0.05$).

	L	B	T	LB ratio	V	GMD	S	SA	AR	BD	TAP	TD	P	H	TGW	AOR
L	1.00															
B	-0.01	1.00														
T	0.36	**0.90**	1.00													
LB ratio	0.50	-0.87	-0.61	1.00												
V	0.32	**0.94**	**0.98**	-0.66	1.00											
GMD	0.35	**0.93**	**0.99**	-0.64	**1.00**	1.00										
S	-0.36	**0.93**	**0.73**	-0.97	**0.76**	**0.75**	1.00									
SA	0.35	**0.93**	**0.99**	-0.64	**1.00**	**1.00**	**0.74**	1.00								
AR	-0.37	**0.93**	**0.71**	-0.97	**0.75**	**0.74**	**1.00**	**0.73**	1.00							
BD	-0.74	0.00	-0.28	-0.42	-0.23	-0.25	0.24	-0.25	0.24	1.00						
TAP	-0.58	0.05	-0.16	-0.39	-0.12	-0.15	0.23	-0.14	0.22	**0.92**	1.00					
TD	0.10	-0.16	-0.11	0.24	-0.16	-0.13	-0.16	-0.14	-0.15	-0.38	-0.18	1.00				
P	0.26	-0.25	-0.13	0.41	-0.19	-0.16	-0.29	-0.17	-0.28	-0.67	-0.54	**0.90**	1.00			
H	0.65	0.24	0.50	0.11	0.45	0.47	0.02	0.47	0.00	-0.68	-0.35	0.59	0.56	1.00		
TGW	0.41	**0.82**	**0.94**	-0.52	**0.94**	**0.93**	0.63	**0.94**	0.61	-0.30	-0.21	-0.25	-0.19	0.43	1.00	
AOR	**0.73**	0.22	0.48	0.18	0.46	0.47	-0.04	0.47	-0.05	-0.87	-0.81	0.03	0.31	0.59	0.58	1.00

L-Length; B-Breadth; T-Thickness; GMD- Geometric mean diameter; S- Sphericity; SA- Surface area; AR- Aspect ratio; BD- Bulk density; TAP- Tap density; TD- True density; P- Porosity; H- Hauser's ratio; TGW- Thousand grain weight; AOR- Angle of repose.

Table 3 — Pearson correlation matrix between physical properties of selected parboiled paddy varieties. Two-tailed test was performed significance was observed at 95% confidence interval. (bold values represent significance p<0.05)

	L	B	T	LB ratio	V	GMD	S	SA	AR	BD	TAP	TD	P	H	TGW	AOR
L	1.00															
B	-0.04	1.00														
T	-0.03	**0.89**	1.00													
LB ratio	0.55	-0.85	-0.77	1.00												
V	0.25	**0.94**	**0.91**	-0.66	1.00											
GMD	0.23	**0.94**	**0.93**	-0.68	**1.00**	1.00										
S	-0.54	**0.84**	**0.82**	-0.99	0.67	0.69	1.00									
SA	0.24	**0.94**	**0.93**	-0.66	**1.00**	**1.00**	0.68	1.00								
AR	-0.46	**0.90**	**0.79**	-0.98	**0.72**	**0.73**	**0.98**	**0.72**	1.00							
BD	-0.52	0.45	0.30	-0.60	0.25	0.24	0.60	0.24	0.63	1.00						
TAP	-0.45	0.63	0.45	-0.72	0.44	0.43	**0.71**	0.42	**0.76**	**0.96**	1.00					
TD	-0.05	-0.30	0.01	0.19	-0.23	-0.18	-0.12	-0.19	-0.25	-0.19	-0.33	1.00				
P	0.20	-0.52	-0.21	0.48	-0.37	-0.33	-0.44	-0.33	-0.56	-0.63	-0.75	**0.86**	1.00			
H	0.56	0.03	0.08	0.23	0.22	0.20	-0.26	0.22	-0.24	-0.78	-0.58	-0.21	0.17	1.00		
TGW	0.41	**0.77**	**0.84**	-0.44	**0.91**	**0.91**	0.48	**0.91**	0.50	0.09	0.24	-0.09	-0.18	0.29	1.00	
AOR	-0.29	-0.78	-0.72	0.50	-0.87	-0.84	-0.49	-0.85	-0.55	-0.21	-0.42	0.53	0.56	-0.34	-0.80	1.00

L-Length; B-Breadth; T-Thickness; GMD- Geometric mean diameter; S- Sphericity; SA- Surface area; AR- Aspect ratio; BD- Bulk density; TAP- Tap density; TD- True density; P- Porosity; H- Hausner's ratio; TGW- Thousand grain weight; AOR- Angle of repose.

Conclusion

The overall findings of current study endorse favorable post-harvest handling, processing, and marketing practices. Most of the focused varieties were long bold paddy types, occupying more volume. All of the raw and parboiled heritage paddy varieties in present study displayed excellent flow properties aiding in the smooth glide in the conveyor belts of processing equipments. Particularly, Salem sanna variety exhibited high bulk density, indicating efficient packaging. Mapillai samba and Kattuyaanam scored high for thousand grain weight in raw and parboiled conditionsrespectively projecting high volume of yield augmenting high returns to the farmers. Ease of aeration and drying of grains could be advocated for raw paddy of Basmati and Parboiled paddy of Sandikar due to highest porosity.All of the traditional paddy varieties in parboiled condition employed in the present study displayed high water diffusion rate due to larger surface area except Kullakar. Cooking time is directly proportional to surface area, warranting longer cooking time. The raw grains of Mapillai samba and parboiled grains of Kattuyanam possessing highest surface area respectively could demand increased time of cooking which can be overcome by mild pulverizing and soaking of the grains. Correlation analysis inferred positive links between breadth and various parameters in both raw and parboiled states, implying advantageous packaging and marketing prospects. We have made scientific physical analytical study in evaluating the post-harvest handling and processing properties in eleven traditional paddy varieties both in raw and parboiled conditions, which could be extrapolated in future with other phytochemical investigations in both or more conditions on the nutritional and therapeutic potentials of these varieties for the benefit of consumers.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

SA: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Methodology, Software, Writing- Reviewing and Editing, Validation. PDV: Visualization, Investigation, Formal analysis, Data curation, Writing- Original draft preparation.

Data Availability

Data will be made available by the corresponding author upon reasonable request.

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