Varietal distinctness in physical and engineering properties of paddy and brown rice from southern India

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Abstract Paddy and brown rice samples were investigated for its physical characteristics which would aid in designing of the equipment and apparatus for processing of grains as sorting, grading and transportation with ease. Significant difference was observed among the different physical properties as geometrical (length, breadth, thickness, equivalent diameter, sphericity, volume, surface area, aspect ratio) gravimetical (bulk density, true density, porosity etc.) and frictional characteristic such as angle of repose, hygroscopic properties as moisture and water activity and color of paddy and brown rice kernels. Among geometrical properties length was found the maximum in paddy of Mapillai samba (8.21 mm) and Palkudavazhai brown rice (6.34 mm). Among flow properties, Mapillai samba displayed the maximum value for true density of paddy and brown rice varieties respectively. Hardness was reported in the range of $(344.1 \pm 14.4\text{--}594.88 \pm 9.5$ and $209.31 \pm 4.00\text{--}395.99 \pm 7.05$ N) for different varieties of paddy and brown rice cultivars. The color of the brown rice was read as L^* , a^* , b^* where it varied from $36.22 \pm 0.71\text{--}61.71 \pm 0.81$, $4.00 \pm 0.18\text{--}15.29 \pm 0.48$ and $16.59 \pm 0.52\text{--}23.81 \pm 0.15$ respectively. Brown rice varieties can generally be categorized as short bold, long bold and medium slender as per their length and breadth ratio. The significant differences in physical properties of

the various cultivars studied, emphasis on varying processing techniques. The physical properties of selected brown rice varieties studied are widely cultivated in southern India, owing to its high nutraceutical potentials.

Keywords Physical · Geometrical · Color · Water activity · Hardness

Introduction

Rice is the most commonly consumed staple food commodity for approximately half of the world's population. According to the study of Lin et al. (2011), about more than 2000 million Asian people get their calories consumption (60–70%) from different rice varieties either as white rice or brown rice. Singh et al. (2005) reported that cooking, textural, physical and chemical characteristics of rice are significantly affected by genetic diversity and different environmental conditions. Brown rice is comparatively more beneficial as it is rich in different nutrients as minerals, vitamins, fiber, polyphenol, and antioxidants (Lamberts et al. 2007; Mir et al. 2016). They are highly efficient in combating different health conditions as it acts as an antioxidant, antiallergic and anticarcinogenic. In spite of all its benefits, it is consumed less because of its undesirable textural properties and prolonged cooking time (Hudson et al. 2000).

Recently, pigmented brown rice varieties have gained increased attention among individuals due to the presence of phytochemicals and other bioactive molecules (Gunnaratne et al. 2013). Apart from this, it also contains various microminerals like zinc, selenium, iron and manganese, unsaturated fats, flavonoids, γ -oryzanol, γ -aminobutyric acid (GABA) etc. (Deepa et al. 2008). During the course of green revolution, traditional rice varieties

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have lost their priority and identity because of the introduction of high yielding rice varieties and the patronage provided by the State. In the recent years, in the process of revisiting traditional knowledge system in the field of agronomy and the process of discerning food that are relatively better than what has been consumed popularly, several traditional varieties of rice have been resurfacing. These brown rice varieties vary in their physical characteristics and the influence of its characteristics in processing technique is still a milestone to achieve.

The physical characteristics of paddy or rice is very crucial in determining the market potential of rice as an agricultural commodity. The most crucial criteria in rice processing industry include the percentage of whole grain. Trop Rice International Rice Research Institute (2004) reported that broken rice holds only half of the market value of head rice (head rice = Hundred percent of the whole kernel deducted from 75). Properly designed machinery and precise operations can reduce the breaking and cracking of rice kernels which ultimately reduces the market loss. Physical properties of rice are considered as an important parameter concerning processing, handling and storage of rice as it ultimately affects the milling and cooking quality which directly affects consumer acceptability (Correa et al. 2007; Varnamkhasti et al. 2008). Knowledge of physical properties as geometrical, gravimetric, frictional and hygroscopic properties of rice grain are useful for designing different equipment for different phases of processing as sorting, grading, drying and milling of rice. Ghasemlou et al. (2010) reported about the importance of gravimetric properties like bulk density, tapped density, true density, Hausner ratio and Carr's index for designing of different machinery related to processing as drying, transportation, and storage of grains, etc. Adu-Kwarteng et al. (2003) reported on the importance of appearance as color properties and different mechanical characteristics such as hardness and the angle of repose which also affect consumer acceptability of a rice variety. Hence the knowledge of different physical properties such as length, diameter, surface area, color, flow properties as bulk density, Hausner ratio, hardness, the angle of repose, etc. of brown rice varieties will be beneficial from consumer and industrial point of view for quality production. This study aimed at studying the physical properties of selected brown rice varieties that are widely cultivated in Southern India, owing to its high nutraceuticals potentials.

Methodology

Materials

All the seven brown rice varieties including Rathasali, Thengaipoo samba, Kothamalli samba, Mapillai samba,

Palkudavazhai, Varappukodanchan, Kalanamak, were obtained from SVR organic farm, Tamilnadu, India. Paddy varieties were cleaned by hand for removing dirt, stones, and other foreign particles. All the samples were dehusked in a Stake Testing Rice Husker (THU-34A, Stake, Japan) to obtain brown rice. After processing, they are packed in a plastic bag at 4 °C for further analysis.

Physical properties of brown rice cultivars

Moisture

Moisture content was determined by drying a weighed sample in hot air oven (at 105 °C) until a constant weight gain was achieved (5 h) and percentage of moisture was calculated as followed by the method of Bashir and Haripriya (2016):

$$\text{Moisture (\%)} = \frac{\text{Loss of sample weight}}{\text{Total weight of the sample}} * 100 \quad (1)$$

Dimensional properties of brown rice

For determining axial dimension as length (L), breadth (W) and thickness (T), Paddy and brown rice grains (100 each) from each cultivar were randomly selected. The principal dimensions were measured using vernier calliper (Mitutoyo, Japan).

Equivalent diameter (ED) and sphericity (Ø)

The equivalent diameter (ED) and Sphericity (Ø) were calculated by using the formula as described below (Mohsenin 1986; Jain and Bal 1997):

$$ED = \left[L \frac{(W + T)^2}{4} \right]^{1/3} \quad (2)$$

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

Volume (V) and surface area (S)

Grain volume (V) and surface area (S) of paddy and brown rice were determined by using following formula given by Jain and Bal (1997):

$$V = 0.25 \left[\left(\frac{\pi}{6} \right) L(W + T)^2 \right] \quad (4)$$

and,

$$S = \frac{\pi BL}{(2L - B)} \quad (5)$$

Where, $B = \sqrt{WT}$

Aspect ratio (R_a)

The aspect ratio (R_a) of paddy and brown rice was determined by using following formula (Varnamkhasti et al. 2008)

$$R_a = \frac{W}{L} \quad (6)$$

Bulk and tapped densities

Paddy and brown rice varieties were analyzed for bulk density using the method of Wani et al. (2013). According to this method, 10 ml graduated cylinder was taken and filled with grains up to 10 ml mark. The weight of the cylinder was recorded after gentle tapping to calculate bulk density (g/ml). Tapped density was determined from the tapped volume after 100 tapping.

True density

True density was analyzed by the method of Bashir and Haripriya (2016). According to this, sample (1 g) was taken in the measuring cylinder (10 ml) with a glass stopper. It was followed by the addition of 5 ml of petroleum ether to the sample. The mixture was shaken to suspend all the grain particles. Further again 1 ml petroleum ether was added, and final volume of the contents was recorded. True density was calculated by the following equation:

$$\text{True density} \left(\frac{\text{g}}{\text{mL}} \right) = \frac{\text{The weight of the grain (g)}}{\text{The total volume of petroleum ether and suspended particles (mL)} - 6} \quad (7)$$

Compressibility index

The compressibility index of brown rice and paddy was determined according to Carr's Index after determining bulk and tapped densities (Bashir and Haripriya 2016).

$$\text{Carr's index} = \frac{\text{Tapped density} - \text{bulk density}}{\text{Tapped density}} \times 100 \quad (8)$$

Hausner ratio

Hausner ratio reflects the cohesiveness of the grain particles. It was measured after determining bulk and tapped densities as given below by the method of Bashir and Haripriya (2016).

$$\text{Hausner ratio} = \frac{\text{Tapped density}}{\text{Bulk density}} \quad (9)$$

Porosity

Porosity is a desired property determined from the true density and tapped density value using the following formula (Bashir and Haripriya 2016).

$$\text{Porosity}(\%) = \frac{\text{True density} - \text{Tapped density}}{\text{True density}} \times 100 \quad (10)$$

Thousand kernel weight

Determination of the thousand kernel weight was done by random selection of paddy and brown rice grains (1000 each) from each cultivar and weighing in an electronic balance (Shimadzu, ELB 30000) by the method given by Varnamkhasti et al. (2008).

Angle of repose

Angle of repose (θ) was measured by using a fixed height funnel fitted at the height of 10 cm from the base (the funnel is 60° , 10 cm in diameter, 0.7 cm internal stem diameter with 9.6 cm stem length). 20 g of the grain was allowed to flow through the funnel into the base and a pile was formed at the base. The angle of repose was then calculated as follows (Bashir and Haripriya 2016):

$$\theta = \tan^{-1}(2H/D) \quad (11)$$

Where H and D represent height and diameter of cone respectively.

Color

The color of paddy and brown rice samples was read using Hunter Lab Colorimeter (D-25, Hunter Associates Laboratory, Ruston, USA) as L^* , a^* and b^* . Calibration of instrument was done by using Hunter color standards before measuring the color values of paddy and brown rice (Reddy et al. 2015). From the data (L^* , a^* , b^*), chroma value and intensity was calculated.

Hardness

Paddy and brown rice hardness was measured by Texture Analyzer (TA-XT2i, Stable Micro Systems, Surrey, UK) by compression of grain.

Water activity

Water activity of paddy and brown rice grains was measured using an electronic dew point water activity meter (Aqualab Series 4TE, Decagon Devices, Inc., Pullman, Washington, USA).

Statistical analysis

The data are mean values of three determinations with standard deviations. Variance analysis (ANOVA) at 5% significance level and Duncan's test was determined by SPSS statistics, Version 20.0 (IBM Corporation, Armonk, New York).

Results and discussions

Geometrical characteristics of paddy and brown rice

The axial dimension of paddy and brown rice

The results for axial dimensions of paddy and brown rice varieties are given in Tables 1 and 2. Significant difference was observed for some of the paddy cultivars and brown rice varieties. Mean length for paddy varieties varied from 6.46 mm in Rathasali to 8.21 mm (Mapillai samba) whereas the length of brown rice varieties ranged from 4.26 mm (Kothamalli samba) to 6.34 mm in Palkudavazhai rice. In case of breadth, in paddy, it ranged from 2.24 mm (Varappukodanchan variety) to 3.37 mm in Thengaipoo samba, but in brown rice, it ranged from 2.12 mm (Rathasali) to 2.88 mm in Palkudavazhai brown rice. The thickness dimension of paddy varied from 1.63 mm in Rathasali to 2.24 mm in case of Thengaipoo samba and Varappukodanchan while in brown rice it varied from 1.35 mm (Rathasali) to 2.09 mm in case of Thengaipoo samba. Mir et al. (2013) reported almost similar values of axial dimension for seven Himalayan rice varieties in which length varies from 4.74 to 8.32 mm, whereas breadth value ranged from 2.02 to 3.03 mm which was higher than that of given rice varieties. Shittu et al. (2012) also studied the significant difference between dimensional properties of brown rice varieties as length (6.87–7.76 mm), breadth (2.46–2.94 mm) and thickness (1.82–2.05 mm). Among brown rice varieties Varappukodanchan was categorized as medium slender grain rice as per length to breadth ratio (Table 3). Long grain rice is in demand of global market in terms of industrial and consumer point of view (Codex Alimentarius Commission 1990). Based on the length and breadth ratio Joshi et al. (2014) also classified Indica rice varieties into long and medium grain varieties. Varnamkhasti et al. (2008)

reported the importance of principle dimensions as length, breadth and thickness for grain grading and these are the basic necessity for the calculation of other geometrical parameters as equivalent diameter, surface area, sphericity and aspect ratio of grain kernels which is the primary basis of designing of equipment for processing of rice.

The equivalent diameter and sphericity

Equivalent diameter plays an important role in the determination of sieve size pore diameter (Simonyan et al. 2007). Traditional brown rice varieties exhibited equivalent diameters for paddy which ranged from 3.03 mm in case of Rathasali to 3.95 mm in Thengaipoo samba, while among brown rice varieties equivalent diameter varied from 2.42 ± 0.03 mm (Rathasali) to 3.38 mm in Palkudavazhai. Bhat and Riar (2016) reported the range of 3.65–4.25 mm in selected paddy varieties while for rice kernels equivalent diameter ranged from 2.98 to 3.27 mm.

The sphericity of paddy showed a variation from 46% (Thengaipoo Samba, Palkudavazhai, and Kalanamak) to 56% in Rathasali paddy while for brown rice it varied from 47.00% in Mapillai Samba variety to 57% in Kothamalli samba variety. In general, sphericity value of paddy was lower than that of their respective rice varieties as it may be due to the presence of awns at both end of paddy which contributes to the length of the paddy and length is having inverse effect on sphericity value (Thakur and Gupta 2006) but in case of Rathasali, sphericity value of paddy (56%) was greater than that of brown rice which might be due to the lesser difference between the length of paddy and rice as well as breadth and thickness. A similar study was reported by Bhat and Riar (2016) in which sphericity of Mushki-Tujan paddy (54%) was higher than that of rice cultivar (49%). A higher value for sphericity for paddy cultivars compared to their respective rice varieties was also reported Mir et al. (2013).

Volume and surface area

A significant difference was found for the volume and surface area among the different brown rice varieties studied. Value of volume for paddy ranged from $14.48 \pm .37$ mm³ (Rathasali) to 34.05 mm³ in Thengaipoo samba whereas for brown rice it varied from $6.93 \pm .13$ mm³ in Rathasali rice to 19.34 mm³ in Palkudavazhai variety. The surface area varied from 24.21 mm² (Rathasali) to 42.64 mm² in Thengaipoo Samba for paddy while for brown rice it varied from 14.60 mm² in Rathasali to 29.53 mm² (Palkudavazai). Storshine and Hamann (1994) studied the effect of volume and surface area on drying behavior of grain as it shows a great effect on drying of a particular grain. Energy and time needed for drying

Table 1 Physical properties of various paddy cultivars of southern India

Property	Paddy cultivars						
	RSR	TSR	KMSR	MSR	PKVR	VKR	KNR
Length (mm)	6.46 ± 0.05 ^b	8.00 ± 0.42 ^a	6.26 ± 0.12 ^b	8.21 ± 0.08 ^a	7.96 ± 0.15 ^a	8.09 ± 0.11 ^a	8.06 ± 0.05 ^a
Breadth (mm)	2.46 ± 0.06 ^c	3.37 ± 0.06 ^a	3.12 ± 0.06 ^b	3.13 ± 0.15 ^b	3.28 ± 0.10 ^a	2.24 ± 0.05 ^b	3.09 ± 0.01 ^b
Thickness (mm)	1.63 ± 0.02 ^d	2.24 ± 0.05 ^a	1.97 ± 0.08 ^b	2.18 ± 0.02 ^{ab}	2.06 ± 0.15 ^{bc}	2.24 ± 0.06 ^a	2.08 ± 0.03 ^{bc}
ED (mm)	3.03 ± 0.10 ^d	3.95 ± 0.06 ^a	3.32 ± 0.10 ^c	3.90 ± 0.06 ^a	3.65 ± 0.19 ^b	3.86 ± 0.04 ^a	3.84 ± 0.07 ^a
Sphericity (%)	56 ± 0.02 ^a	46 ± 0.01 ^b	55 ± 0.01 ^a	45 ± 0.01 ^b	46 ± 0.02 ^b	47 ± 0.01 ^b	46 ± 0.01 ^b
Volume (mm ³)	14.48 ± 0.37 ^f	34.05 ± 0.11 ^a	21.26 ± 0.05 ^e	31.00 ± 0.11 ^b	29.91 ± 0.24 ^c	29.86 ± 0.07 ^c	27.70 ± 0.15 ^d
Surface area (mm ²)	24.21 ± 0.13 ^f	42.64 ± 0.17 ^a	30.44 ± 0.11 ^e	40.28 ± 0.06 ^b	38.75 ± 0.17 ^d	40.01 ± 0.10 ^c	37.55 ± 0.18 ^c
Aspect ratio	0.36 ± 0.01 ^d	0.41 ± 0.01 ^b	0.48 ± 0.01 ^a	0.39 ± 0.01 ^{bc}	0.41 ± 0.01 ^b	0.38 ± 0.01 ^{cd}	0.38 ± 0.01 ^d
Angle of repose (deg)	35.69 ± 0.68 ^a	33.01 ± 0.60 ^{cd}	33.09 ± 0.60 ^{cd}	35.15 ± 1.31 ^{ab}	34.28 ± 0.66 ^{bc}	32.46 ± 0.47 ^d	29.67 ± 0.43 ^e
TKW (g)	14.32 ± 0.10 ^g	26.08 ± 0.38 ^c	16.84 ± 0.56 ^f	28.29 ± 0.61 ^b	31.02 ± 0.06 ^a	25.17 ± 0.26 ^d	24.18 ± 0.18 ^e
Hardness (N)	534.11 ± 9.66 ^d	592.86 ± 10.0 ^b	464.39 ± 12.3 ^f	564.62 ± 14.5 ^c	418.11 ± 12.6 ^g	492.11 ± 5.9 ^e	594.88 ± 9.5 ^a
Moisture (%)	8.40 ± 0.25 ^a	7.65 ± 0.13 ^c	7.60 ± 0.17 ^c	6.92 ± 0.15 ^d	8.78 ± 0.11 ^a	8.23 ± 0.11 ^b	8.77 ± 0.10 ^a
Water activity (a _w)	0.46 ± 0.01 ^d	0.47 ± 0.00 ^d	0.53 ± 0.01 ^c	0.48 ± 0.01 ^d	0.48 ± 0.01 ^d	0.58 ± 0.01 ^a	0.55 ± 0.01 ^b
Bulk density (g/ml)	0.64 ± 0.02 ^a	0.49 ± 0.01 ^e	0.55 ± 0.02 ^d	0.61 ± 0.02 ^{ab}	0.55 ± 0.01 ^d	0.59 ± 0.02 ^{bc}	0.56 ± 0.01 ^{cd}
Tapped density (g/ml)	0.67 ± 0.02 ^a	0.55 ± 0.00 ^c	0.58 ± 0.03 ^c	0.64 ± 0.02 ^a	0.59 ± 0.02 ^{bc}	0.63 ± 0.02 ^{ab}	0.59 ± 0.02 ^{bc}
True density (g/ml)	1.24 ± 0.02 ^{bc}	1.09 ± 0.07 ^c	1.22 ± 0.02 ^{bc}	1.59 ± 0.11 ^a	1.29 ± 0.04 ^b	1.48 ± 0.16 ^a	1.23 ± 0.01 ^{bc}
Porosity (%)	45.66 ± 3.21 ^d	49.33 ± 3.78 ^{cd}	52.66 ± 3.21 ^{bc}	59.33 ± 4.04 ^a	53.66 ± 3.21 ^{abc}	57.00 ± 3.00 ^{ab}	52.00 ± 2.64 ^{bc}
Carr's index	5.37 ± 1.44 ^b	10.90 ± 3.14 ^a	6.19 ± 3.17 ^b	6.19 ± 0.22 ^b	7.24 ± 3.33 ^{ab}	5.81 ± 1.10 ^b	5.59 ± 0.73 ^b
Hausner ratio	1.05 ± 0.01 ^b	1.12 ± 0.04 ^a	1.06 ± 0.03 ^b	1.06 ± 0.00 ^b	1.07 ± 0.03 ^{ab}	1.06 ± 0.01 ^b	1.05 ± 0.01 ^b

RSR Rathasali, TSR-Thengupoo samba, KMSR-Kothamalli samba, MSR-Mappilai samba, PKVR-Palkudavazhai, VKR-Varappukodanchan, KNR-Kalanamak, TKW-total kernel weight

All data were means of triplicates. Values with the same superscripts in a row did not differ significantly ($P \leq 0.05$) by DMRT

Table 2 Physical properties of various brown rice cultivars of southern India

Property	Rice varieties					
	RSR	TSR	KMSR	MSR	PKVR	VKR
Length (mm)	4.57 ± 0.07 ^{3e}	5.97 ± 0.20 ^b	4.26 ± 0.12 ^e	6.17 ± 0.04 ^a	6.34 ± 0.09 ^a	5.68 ± 0.01 ^c
Breadth (mm)	2.12 ± 0.07 ^d	2.76 ± 0.11 ^{ab}	2.46 ± 0.16 ^c	2.27 ± 0.10 ^d	2.88 ± 0.07 ^a	2.22 ± 0.02 ^d
Thickness (mm)	1.35 ± 0.04 ^c	2.09 ± 0.09 ^a	1.72 ± 0.09 ^b	2.04 ± 0.08 ^a	1.98 ± 0.04 ^a	1.97 ± 0.06 ^a
ED (mm)	2.42 ± 0.03 ^d	3.28 ± 0.14 ^{ab}	2.55 ± 0.04 ^d	3.16 ± 0.08 ^b	3.38 ± 0.06 ^a	2.93 ± 0.05 ^c
Sphericity (%)	49.67 ± 1.15 ^c	52.67 ± 1.15 ^b	57.00 ± 1 ^a	47.00 ± 1 ^d	53.33 ± 1.52 ^b	49.67 ± 1.52 ^c
Volume (mm ³)	6.93 ± 0.13 ^g	16.76 ± 0.27 ^b	8.49 ± 0.15 ^f	15.12 ± 0.10 ^c	19.34 ± 0.11 ^a	13.50 ± 0.16 ^e
Surface area (mm ²)	14.60 ± 0.23 ^f	26.43 ± 0.40 ^b	16.57 ± 0.17 ^e	24.08 ± 0.12 ^c	29.53 ± 0.15 ^a	23.23 ± 0.23 ^d
Aspect ratio	0.46 ± 0.01 ^c	0.46 ± 0.01 ^c	0.54 ± 0.01 ^a	0.37 ± 0.01 ^d	0.46 ± 0.00 ^c	0.38 ± 0.01 ^d
Angle of repose (deg)	32.85 ± 0.55 ^{ab}	33.26 ± 0.36 ^a	32.10 ± 0.7 ^{bc}	33.63 ± 0.20 ^a	32.69 ± 0.64 ^{ab}	32.04 ± 0.59 ^{bc}
TKW (g)	11.84 ± 0.09 ^g	22.11 ± 0.29 ^c	13.52 ± 0.24 ^f	23.04 ± 0.17 ^b	25.59 ± 0.33 ^a	18.79 ± 0.16 ^e
Hardness (N)	352.94 ± 1.06 ^b	395.99 ± 2.0 ^a	247.06 ± 3.4 ^e	270.61 ± 2.03 ^d	236.13 ± 1.2 ^e	200.09 ± 1.02 ^f
Moisture (%)	9.96 ± 0.10 ^{cd}	11.26 ± 0.07 ^a	11.25 ± 0.18 ^a	10.20 ± 0.09 ^c	9.76 ± 0.24 ^d	10.78 ± 0.2 ^b
Water activity (a _w)	0.55 ± 0.01 ^{bc}	0.55 ± 0.00 ^{bc}	0.54 ± 0.00 ^c	0.56 ± 0.02 ^{abc}	0.57 ± 0.01 ^{ab}	0.58 ± 0.01 ^a
Bulk density (g/ml)	0.85 ± 0.04 ^{ab}	0.87 ± 0.04 ^a	0.85 ± 0.04 ^{ab}	0.83 ± 0.00 ^{ab}	0.87 ± 0.04 ^a	0.80 ± 0.04 ^{bc}
Tapped density (g/ml)	0.93 ± 0.05 ^a	0.96 ± 0.05 ^a	0.93 ± 0.05 ^a	0.90 ± 0.0 ^{ab}	0.96 ± 0.05 ^a	0.87 ± 0.04 ^{ab}
True density (g/ml)	1.52 ± 0.24 ^a	1.38 ± 0.24 ^a	1.38 ± 0.24 ^a	1.80 ± 0.63 ^a	1.25 ± 0.00 ^a	1.72 ± 0.75 ^a
porosity	38.95 ± 2.6 ^a	30.4 ± 2.1 ^a	32.8 ± 1.6 ^a	50.15 ± 2.0 ^a	22.66 ± 0.8 ^a	49.09 ± 2.3 ^a
Carr's index	8.52 ± 0.01 ^a	9.26 ± 0.01 ^a	8.52 ± 0.01 ^a	7.78 ± 0.0 ^a	9.26 ± 0.01 ^a	8.00 ± 0.00 ^a
Hausner ratio	1.09 ± 0.02 ^a	1.10 ± 0.02 ^a	1.09 ± 0.01 ^a	1.08 ± 0.00 ^a	1.10 ± 0.01 ^a	1.08 ± 0.01 ^a

RSR-Rathasali, TSR-Thengaipoo samba, KMSR-Kothamalli samba, MSR-Mappilai samba, PKVR-Palkudavazhai, VKR-Varapukodanchan, KNR-Kalanamak TKW-total kernel weight

All data were means of triplicates. Values with the same superscripts in a row did not differ significantly ($P \leq 0.05$) by DMRT

can be calculated with Surface area and volume ratio as heat and mass transfer rate is directly proportional to it (Zareiforoush et al. 2011).

Aspect ratio

Among the rice and paddy of brown rice varieties, Kothamalli Samba showed the highest value for aspect ratio 0.54 and 0.48 respectively. Among paddy, Rathasali (0.36 ± 0.01) and among brown rice, Mapillai Samba (0.37 ± 0.01) showed the lowest value for aspect ratio. This study showed similarities with those reported by Mir et al. (2013) in which Pusa-3 showed the lowest value for paddy and rice (0.19 and 0.24 respectively) while the highest value for aspect ratio was shown by Koshar variety for paddy (0.44) and rice (0.61). Varnamkhasti et al. (2008) reported the importance of aspect ratio for classification of grains as it decides the market value of a particular grain. Apart from this aspect ratio also determines the movement of grain (sliding or rolling behavior) on a flat surface as grain with low aspect ratio will roll rather than sliding on surfaces (Al-Mahasneh and Rababah 2007).

Gravimetric properties of paddy and brown rice

Bulk and tapped densities

Bulk density values of paddy and brown rice are depicted in Tables 1 and 2. The bulk density of paddy was varied from 0.49 g/ml in Thengaipoo Samba to 0.64 g/ml in Rathasali variety while for brown rice it ranged from 0.76 g/ml (Kalanamak) to 0.87 g/ml in Thengaipoo and Palkudavazhai rice. Bulk density values for rice are higher than that of their respective paddy variety which may be due to the presence of husk and long awns which causes bulkiness and occupy more space while keeping together which increase volume and results in a decrease in bulk density of paddy (Zareiforoush et al. 2011). A similar study was reported by Mir et al. (2013) in which bulk density of paddy (0.49–0.59 g/ml) was lower than that of several rice varieties (0.73–0.081 g/ml). Bulk density is having great impact of grain shape and porosity as more slender the grain is, porosity increases and bulk density decreases (Bhattacharya 2011). Nalladurai et al. (2002) studied the importance of bulk density in designing of instruments useful for handling and storage during processing of grains as silos, hoppers, etc.

Compressibility index and Hausner ratio

Compressibility index and Hausner ratio are the important parameters to determine the flowability of grain. While determining the free-flowing characteristics, Carr's index

should be small as Carr's index below 15 represents good flowability while a value above 25 depicts poor flowability behavior and for Hausner ratio value more than 1.25 also indicates poor flowability. Among paddy cultivars, Carr's index value ranged from 5.37 ± 1.44 (Rathasali) to 10.90 in Thengaipoo Samba while Hausner ratio value ranged from 1.05 in Rathasali and Kalanamak to 1.12 in Thengaipoo Samba.

True density and porosity

True density and porosity varied significantly among the different cultivars of paddy and brown rice. True densities values ranged from 1.09 ± 0.07 g/ml in Thengaipoo Samba to 1.59 g/ml in Mapillai samba for paddy and for brown rice it ranged from 1.25 g/ml in Palkudavazhai to 1.80 g/ml in Mapillai samba variety. True density of brown rice is higher than that of their respective paddy variety. True density is a critical aspect while removing different impurities from grain through the aeration process as impurities as well as grain both possess different true density (Ashtiani Araghi et al. 2010).

The porosity of paddy varied from 45.66% in Rathasalili to 59.33% in Mapillai samba variety while for brown rice it ranged from 22.68% (Palkudavazhai) to 50.15% in Mapillai Samba rice. The same range of porosity value was reported by different authors (Varnamkhasti et al. 2008; Mir et al. 2013). Adebowale et al. (2011) studied the drying behavior and porosity as grains with higher porosity dry quickly than that of grain with lower porosity as porosity gives the space for aeration and diffusion of water.

Thousand kernel weight

Thousand kernel weight values for paddy cultivars varied from 14.32 g (Rathasali) to 31.02 g in Palkudavazhai while for brown rice varieties it ranged from 11.84 in Rathasali to 25.59 g (Palkudavazhai). Mohapatra and Bal (2012) reported the same range of thousand kernel weight for Pusa Basmati, Swarna, ADT37 varieties of rice but a higher value of thousand kernel weight was reported by Shittu et al. (2012) for different rice varieties. Thousand kernel weight of grain is an important aspect for determining the quality of grain as the presence of shriveled or immature kernels, dockage, and presence of foreign materials (Luh 1980).

Mechanical properties of paddy and brown rice

Angle of repose

The angle of repose varied significantly for brown rice and paddy. For paddy Angle of repose varied from 29.67° in

Table 3 Classification of brown rice kernel based on length and length/breadth ratio

Rice varieties	L/B	Category
Rathasali	2.15	Short bold
Thengaipoo samba	2.16	Short bold
Kothamalli samba	1.73	Short bold
Mapillai samba	2.71	Long bold
Palkudavazhai	2.20	Long bold
Varappukodanchan	2.55	Medium slender
Kalanamak	2.06	Short bold

Kalanamak to 35.69° (Rathasali) while in rice it ranged from 31.65° in Kalanamak to 33.63° in Mapillai Samba. The angle of repose for brown rice was found to be lower than that of paddy cultivars. Mir et al. (2013) reported the same for paddy and rice cultivars from the temperate region of India. The angle of repose plays an important role in designing instruments as a hopper for uninterrupted flow of the materials (Mir et al. 2013).

Hardness

Grain hardness affects the processing behavior of grain which ultimately affects the product development. Hardness mostly depends on the endosperm structure as corneous endosperm will be harder than that of floury endosperm. Hardness, breakage resistance and density of grain kernel greatly affect the milling yield. Grain hardness in paddy was found in the range of 418.11 N in Palkudavazhai to 594.88 N in kalanamak while for brown rice highest value for hardness was found in Thengaipoo Samba (395.99 N) whereas lowest value was shown by Varappukodanchan (200.09 N). These values for hardness was higher than that reported in different studies of rice (Mir et al. 2013; Correa et al. 2007)

Hygroscopic properties of paddy and brown rice

Water activity

Water activity is one of the important parameters which determines the shelf life of food as it measures the free water present in the grain. Higher water activity leads to increased microbial growth and biochemical reactions which results in the decreased shelf life of grain (Bashir and Haripriya 2016). The water activity (aw) values of brown rice ranged from 0.54 in Kothamalli Samba rice to 0.58 in Varappukodanchan which proves high affinity to more microbial infestation and spoilage when compared to all other rice varieties. In paddy cultivars, water activity

values varied from Rathasali (0.46) to 0.58 in Varappukodanchan. The water activity of brown rice was lower than that of paddy which assures longer shelf life.

Moisture

Moisture is an important quality indicator during rice processing as it affects the head rice yield and hence customer acceptance and market value. The moisture content of rice and paddy varied significantly. The moisture content of brown rice was observed in the range of 9.76% in Palkudavazhai to 11.26% in Thengaipoo Samba, and for paddy cultivars, it was in the range of 6.92% (Mappillai Samba) to 8.78% (Palkudavazhai). The moisture content of brown rice was found higher than that of paddy. Mir et al. (2013) reported a higher value for moisture content in paddy for temperate rice varieties.

Tristimulus color values

Color is the most crucial parameters for analyzing the quality of the product (Kays 1999) as well as customer preferences as it affects the total appearance of the food product (Fig. 1). The color parameters like L^* , a^* , b^* for paddy as well as rice showed a significant difference among the different cultivars (Tables 4 and 5). As L^* towards 100 denotes lightness, Kothamalli paddy (53.32) had presented highest value while Kalanamak (37.67) has shown lowest value which indicates the darker color of paddy due to the presence of pigment which imparts color to the brown rice. Among the brown rice variety, Kalanamak rice (46.60) shown the highest value for L^* . Among the paddy cultivars, highest value for a^* was shown by Mappillai Samba (15.29) while lowest value was seen for Rathasali (11.17) among the rice cultivars while for the paddy, the highest value was observed in Mapillai Samba (10.39) and the lowest value was seen in Kalanamak (5.75). Value for yellowness (b^*) was highest in Varappukodanchan (27.76) while lowest was seen in Kalanamak (15.43) among paddy cultivars and for rice it ranged from 16.59 in Mapillai Samba to 19.26 (Palkudavazhai). Among other derived color properties like chroma or chromaticity which denotes saturation of the color was measured highest in Rathasali paddy variety (30.79) while lowest was in Kalanamak paddy (16.47). Among the brown rice varieties, chroma value ranged from 20.91 (Kalanamak) to 23.53 (Palkudavazhai). Hue angle which denotes the perception of color was found to lie in the first quadrant of the hue angle (0° – 90°) corresponding to the range of reddish-purple to yellow for paddy (69.35–74.83) and brown rice (47.19–64.39). Color intensity was also found significantly different for paddy and rice varieties. Genetic makeup of specific paddy

Fig. 1 Images of different variety of paddy and brown rice (a Rathasali, b Thengaipoo samba, c Kothamalli samba, d Mappilai samba, e Palkudavazhai, f Varappukodanchan and g Kala namak)

Table 4 Color properties of different paddy cultivars

Property	Paddy cultivars						
	RSR	TSR	KMSR	MSR	PKVR	VKR	KNR
L*	46.88 ± 0.30 ^d	48.34 ± 0.37 ^c	53.32 ± 0.49 ^a	47.53 ± 0.67 ^{cd}	47.41 ± 0.32 ^{cd}	50.71 ± 0.16 ^b	37.67 ± 1.0 ^e
a*	10.18 ± 0.33 ^a	7.61 ± 0.08 ^c	6.84 ± 0.17 ^d	10.39 ± 0.22 ^a	8.08 ± 0.20 ^b	7.87 ± 0.14 ^{bc}	5.75 ± 0.30 ^d
b*	27.10 ± 0.14 ^a	23.21 ± 0.41 ^c	25.27 ± 0.58 ^b	27.67 ± 0.65 ^a	25.02 ± 0.13 ^b	27.76 ± 0.59 ^a	15.43 ± 0.74 ^d
Chroma value	28.94 ± 0.25 ^a	24.43 ± 0.40 ^c	26.18 ± 0.61 ^b	29.56 ± 0.63 ^a	26.28 ± 0.17 ^b	28.85 ± 0.60 ^a	16.47 ± 0.79 ^d
Hue angle	69.36 ± 0.51 ^d	71.81 ± 0.33 ^c	74.83 ± 0.04 ^a	69.35 ± 0.56 ^d	72.07 ± 0.35 ^c	74.13 ± 0.07 ^b	69.50 ± 0.31 ^d
Intensity	55.09 ± 0.21 ^{bc}	54.15 ± 0.50 ^c	59.39 ± 0.70 ^a	55.97 ± 0.79 ^b	54.21 ± 0.36 ^c	58.34 ± 0.35 ^a	41.11 ± 1.22 ^c

RSR-Rathasali, TSR-Thengaipoo samba, KMSR-Kothamalli samba, MSR-Mappilai samba, PKVR-Palkudavazhai, VKR-Varappukodanchan, KNR-Kalanamak

All data were means of triplicates. Values with the same superscripts in a row did not differ significantly ($P \leq 0.05$) by DMRT

variety, pigments present in rice kernels and flour composition of a particular rice variety plays a great role in color variations among different samples (Aboubakar et al. 2008, Kaur et al. 2013). Different color values were reported by author while working with different varieties of brown rice (Shittu et al. 2012; Mir et al. 2013; Bhat and Riar 2016).

Conclusion

This study provided information about physical and mechanical properties of brown rice and paddy which is helpful in designing instruments for various agricultural practices as processing, milling, drying, heating, cooling, handling, transfer and storage of grains and thus minimizing post-harvest losses. Significant difference was found in different physical parameters as dimension, bulk density, true density, Carr index, Hausner ratio, thousand

Table 5 Color properties of different brown rice varieties

Property	Rice cultivars						
	RSR	TSR	KMSR	MSR	PKVR	VKR	KNR
L*	38.78 ± 0.55 ^c	37.78 ± 0.23 ^d	36.22 ± 0.71 ^e	40.02 ± 0.50 ^b	39.66 ± 0.09 ^{bc}	39.27 ± 0.81 ^{bc}	46.60 ± 0.50 ^a
a*	11.17 ± 0.11 ^d	13.34 ± 0.09 ^c	14.29 ± 0.54 ^b	15.29 ± 0.48 ^a	13.51 ± 0.21 ^c	14.14 ± 0.41 ^b	9.01 ± 0.15 ^e
b*	19.12 ± 0.10 ^a	17.33 ± 0.32 ^c	17.72 ± 0.00 ^{bc}	16.59 ± 0.52 ^d	19.26 ± 0.30 ^a	18.17 ± 0.25 ^b	18.86 ± 0.12 ^a
Chroma value	22.14 ± 0.12 ^{cd}	21.87 ± 0.23 ^d	22.76 ± 0.34 ^{bc}	22.56 ± 0.70 ^{bcd}	23.53 ± 0.36 ^a	23.02 ± 0.43 ^{ab}	20.91 ± 0.17 ^e
Hue angle	59.62 ± 0.22 ^b	52.27 ± 0.75 ^d	50.94 ± 1.08 ^e	47.19 ± 0.26 ^f	54.84 ± 0.00 ^e	52.06 ± 0.54 ^d	64.39 ± 0.27 ^a
Intensity	44.66 ± 0.53 ^c	43.66 ± 0.31 ^d	42.78 ± 0.42 ^e	45.95 ± 0.13 ^b	46.11 ± 0.11 ^b	45.52 ± 0.69 ^b	51.07 ± 0.43 ^a

RSR-Rathasali, TSR-Thengaipoo samba, KMSR-Kothamalli samba, MSR-Mapillai samba, PKVR-Palkudavazhai, VKR-Varappukodanchan, KNR-Kalanamak

All data were means of triplicates. Values with the same superscripts in a row did not differ significantly ($P \leq 0.05$) by DMRT

kernel weight, water activity, moisture and color of different brown rice cultivars. Varietal difference in the different varieties of brown rice cultivars might be due to its different genetic make-up and agro climatic conditions. Further investigation is required to discover nutritional benefits of brown rice and other commercial uses.

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