International Food Research Journal 20(4): 1521-1527 (2013)

Journal homepage: *http://www.ifrj.upm.edu.my*

Evaluation of physical properties of rice cultivars grown in the temperate region of India

Mir, S. A., *Bosco, S. J. D. and Sunooj, K. V.

Department of Food Science and Technology, Pondicherry University, Kalapet, Puducherry, 605 014, India

Article history

Received: 29 August 2012
Received in revised form: 19 January 2013
Accepted:27 January 2013

Keywords

Paddy
brown rice
physical properties
color
hardness

Abstract

Seven rice cultivars namely Jehlum, K-332, Koshar, Pusa-3, SKAU-345, SKAU-382 and SR-1, grown in temperate region of India, were studied for the variety difference in their physical properties. Results showed the significant difference in the physical properties including length, width, thickness, equivalent diameter, surface area, sphericity, aspect ratio, volume, bulk density, true density, porosity, thousand kernel weight, angle of repose and coefficient of friction among paddy and brown rice of cultivars ($p \leq 0.05$). From the color analysis of brown rice, L^*, a^* and b^* values were ranged from 55.99 to 67.19, 4.23 to 7.73 and 22.41 to 26.29 respectively, whereas the hardness was significantly varied from 131.48 to 73.99 N with the highest hardness found in the brown rice of Jehlum cultivar. The information of the present study would be useful for designing the post-harvest machineries for processing and storage structures in food processing industry based on the variety difference of rice cultivars.

Introduction

Rice (*Oryza sativa* L.) holds a unique position for prospective food applications in the range of products being processed like parboiled, puffed and flaked rice, etc., from different rice cultivars apart from the consumption of whole cooked rice (Juliano, 1985). A significant variation in physical, composition, and cooking quality has been shown among rice cultivars produced in different parts of world with the influence of diverse genetic and environmental factors (Singh *et al*., 2005; Izawa 2008).

India is having different geographical areas with diverse climatic conditions. Kashmir Valley lying in northern part of India comprises the extreme western of Himalayas (32.44°N and 74.54°E) and belongs to the temperate zone. The Valley of Kashmir is 121 km in length and 32 km in width with an altitude of 1,524−2,286 meters above sea level. The cultivation of rice extends from the area having altitude 1600 m above the mean sea level and is grown only once in year because of extreme climatic conditions (Parray and Shikari, 2008). Rice cultivars in different regions of the world differ in their composition depends on variety, climate, irrigation and fertilizer application (Singh *et al*., 2005).

In an attempt to postharvest processing of different rice cultivars with quality characteristics the physical properties of rice grains have to be investigated mandatory. The knowledge of physical and engineering properties of grain materials are useful for designing appropriate machineries for process operations like sorting, drying, heating, cooling, milling and find the solutions to problems associated with these processes (Sahay and Singh, 1994; Correa *et al*., 2007; Liu *et al*., 2009). These properties are important in the construction of storage facilities and the calculation of the dimensions of holding bins of a given capacity (Thompson and Ross, 1983).

The quality indicators such as color and hardness have the importance in food industry by improving the consumer acceptability profitability of the particular rice cultivar (Kwarteng *et al*., 2003). The proper interpretation of results of these indicators could provide a new classification of rice cultivars fulfilling the needs of food industry. From the industrial standpoint, it is a realistic approach to simplify rice cultivars categorization in order to control the rice quality. Hence the objective of present study was to evaluate the physical properties of selected rice cultivars from the temperate region of India.

Materials and Methods

The paddy grains used in this study were obtained from Sher-e-Kashmir University of Agriculture Science and Technology, Shalimar, Jammu and Kashmir, India. Seven cultivars (Jehlum, K-332, Koshar, Pusa-3, SKAU-345, SKAU-382 and SR-1) were used in the current study, which are the prevalent cultivars in the Kashmir region. The grains were

*Corresponding author.
Email: *sjdbosco@yahoo.com*

dried and cleaned manually and foreign matters such as stones, straw and dirt were removed. The dried and cleaned paddy samples were dehusked in a THU-34A Stake Testing Rice Husker (Stake, Japan) to obtain brown rice.

Physical properties

The moisture content of each of the samples was determined on wet basis using the AOAC (2003) standard method. Paddy and brown rice grains were randomly selected from each cultivar and their principal dimensions length (L), width (W) and thickness (T) were measured using vernier caliper.

The equivalent diameter (D_e) in mm considering a prolate spheroid shape for a paddy and brown rice were determined by using expression as described under (Mohsenin, 1986; Jain and Bal, 1997).

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

The sphericity (Ø) 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 (Mohsenin, 1986).

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

Grain volume (V) and surface area (S) were of paddy and brown rice were calculated by using different expressions (Jain and Bal, 1997).

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

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

Where,

$$B = \sqrt{WT}$$

The aspect ratio (Ra) was determined by using following formulae (Varnamkhasti *et al*., 2008).

$$R_a = \frac{W}{L}$$

Bulk and true density

The bulk density (ρ_b) was determined by using the mass/volume relationship (Fraser *et al*., 1978) by filling an empty plastic container of predetermined volume and tare weight with the grains by pouring from a constant height, striking off the top level and weighing. The true density (ρ_t) was determined by the toluene displacement (Mohsenin, 1986).

Porosity

Porosity (ε) was defined as the ratio of intergranular void space volume and the volume of the bulk grain. Porosity was computed using an expression as described (Jain and Bal, 1997).

$$\varepsilon = \left(\frac{\rho_t - \rho_b}{\rho_t}\right) \times 100$$

Thousand kernel weight

The thousand kernel weight was determined by randomly selecting one thousand grains from paddy and brown rice samples and weighed (Varnamkhasti *et al*., 2008).

Angle of repose

The angle of repose (θ_f) was determined by using an empty cylindrical mold of 15 mm diameter and 25 mm height. The cylinder was placed at the centre of galvanized iron plate, filled with rice grains and raised gradually until it forms a cone of grain. The height of the cone was measured and the filling angle of repose was calculated by the following relationship (Ozguven and Kubilay, 2004).

$$\theta_f = tan^{-1}\left(\frac{2H}{D}\right)$$

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

Static coefficient of friction

The static coefficient friction (µ) for the grains was measured against three different surfaces, plywood, glass and galvanized iron sheet by using a cylinder of diameter 75 mm and depth 50 mm filled with paddy and brown rice grains, respectively. While the cylinder resting on the surface, it was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006). The static coefficient of friction was then calculated from the following relationship.

$$\mu = \tan \alpha$$

Where α is the angle of tilt (degree).

Color Characteristics

The color of brown rice were determined by CIE color scales L^*, a^* and b^* using Hunter Lab digital colorimeter (Model D25M, Hunter Associates Laboratory, Reston, VA). Where L^* indicates the degree of lightness or darkness of the sample extended from 0 (black) to 100 (white). a^* and b^* indicates degree of redness (+a) to greenness (-a) and whereas b^* indicates the degree of yellowness (+b) to blueness (-b) respectively.

Hardness

Hardness of the rice grain 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 rice grain along the thickness, at a test speed of 0.10 mm/sec and return to its original position. The original clearance between the probe and the base in load cell of the instrument was fixed at 8 mm, so that when the probe moved down it would compress the test sample kept horizontally on the base to a distance of 0.500 mm. Program was set to move the probe at 1.0 mm/min in both pre-test and post-test phases. A 5 mm diameter stainless steel probe (P/5) was used to compress a single grain. The test was repeated 5 times from the same sample lot, for all the seven cultivars. The peak force indicated by the force time curve was taken as the maximum compressive force/hardness.

Statistical analysis

The data were analyzed statistically using SPSS software (SPSS PASW 18.0) and the means were separated using the Duncan's multiple range test ($p \leq 0.05$). All the data are presented as the mean with the standard deviation.

Results and Discussion

Physical properties

A summary of the physical properties of paddy and brown rice are presented in the Table 1 and 2, respectively. The moisture content of rice samples were varied from 12.17 to 12.68% on wet basis. There was a significant difference between the physical dimensions of the rice cultivars ($p \leq 0.05$). Among the cultivars, the length of paddy varied from 6.80 (K-332) to 11.93 mm (Pusa-3), whereas the variation in length of the brown rice ranged from 4.74 (K-332) to 8.32 mm (Pusa-3). Similarly, the variation in width was observed from 2.27 (Pusa-3) to 3.16 mm (Koshar) for the paddy respectively, along with variation for the brown rice ranged from 2.02 (Pusa-3) to 3.03 mm (Koshar). The thickness of the paddy showed a variation from 1.94 (Jehlum) to 2.31 mm (K-332), while the thickness of the brown rice was in the range of 1.79 (Pusa-3) to 2.10 mm in Koshar. Similarly different investigations have also reported the wide range of grain dimensions while studying with different rice varieties (Correa *et al*., 2007; Shittu *et al*., 2012). These principal axial dimensions of the rice grains are important in designing in selecting sieve separators and calculating power during the rice milling operations (Varnamkhasti *et al*., 2008).

The equivalent diameter and sphericity for paddy and brown rice were differ significantly ($p \leq 0.05$). The mean equivalent diameters of paddy varied from 3.60 (K-332) to 3.79 mm (Pusa-3) and in brown rice the mean varied from 3.03 (K-332) to 3.28 mm (SKAU-345), however, the lowest sphericity values were observed 31.71% (Pusa-3) and highest 52.71 % (K-332) in case of paddy, whereas in brown rice, the lowest were also obtained 37.40% in same cultivars (Pusa-3) and highest 63.44% (K-332). Similarly the sphericities of paddy grains were observed to be lower than the brown rice (Shittu *et al*., 2012). This might be due to the typical shape of paddy, which has pointed tips along the length axis thereby increasing the characteristic length compared to the brown rice with more rounded tips (Thakur and Gupta, 2007).

Determination of aspect ratio distribution is important to classify the grains and determine the extent of off-size in market grade (Varnamkhasti *et al*., 2008). The aspect ratio was found to be lowest in Pusa-3 cultivar both for paddy (0.19) and brown rice (0.24), whereas highest in Koshar (0.44) and (0.61) for paddy and brown rice, respectively. The aspect ratio of paddy and brown rice were found to differ significantly ($p \leq 0.05$) between the cultivars. The mean aspect ratios were found in the range of 0.24 to 0.28 for paddy varieties as reported in literature (Varnamkhasti *et al*., 2008).

Significant differences were observed in the kernel volume and surface area among the rice cultivars. The mean kernel volume values were ranged from 24.46 (K-332) to 28.45 mm3 (SR-1) for paddy cultivars. However, in brown rice it varied from 14.54 (K-332) to 18.51 mm3 (SKAU-345). While the surface area for paddy was observed from 34.32 (K-332) to 43.78 mm2 (Pusa-3) and for brown rice, the values varied from 23.80 (K-332) to 35.84 (Pusa-3). The grain volume and surface area in this study were higher than those reported for Sorkheh and Sazandegi varieties (Varnamkhasti *et al*., 2008). The effects of surface area on drying rates of particulate materials can also be characterized by using the surface to volume ratio. Also, the ratio of surface area to volume affects drying time and energy requirements (Zareiforoush *et al*., 2011).

Bulk density values showed significant differences among the cultivars at the 5% level of significance. The bulk densities of paddy and brown rice were ranged from 498.59 to 599.63 and 736.49 to 817.85 kg/m^3, respectively. In paddy maximum value was found to be for SKAU-382 and minimum in Pusa-3. While in case of brown rice, the maximum was observed in Koshar. The respective values for the true densities also were ranged between 1217.47 to 1449.42 and 1270.81 to 1484.42 kg/m^3. This property increased when the volume is reduced by processing, probably due to de-husking. According to Brooker *et al*. (1992) the bulk density of the long type rice variety varies from 541 to 579 kg/m^3. However, Wratten *et al*. (1969) found the bulk density value of 582 kg/m3 for long type grain with 12% (w.b.) moisture content and for the same rice characteristics. To determine the

Table 1. Physical characteristics of paddy cultivars

Property	Rice cultivars						
	Jehlum	K-332	Koshar	Pusa-3	SKAU-345	SKAU-382	SR-1
Moisture (% wet basis)	12.25	12.43	12.52	12.17	12.68	12.39	12.46
Length (mm)	8.59±0.16^{c}	6.80±0.31^{g}	7.20±0.21^{f}	11.93±0.37^{a}	8.83±0.25^{b}	8.13±0.23^{e}	8.34±0.20^{d}
Width (mm)	2.76±0.10^{de}	2.92±0.09^{bc}	3.16±0.11^{a}	2.27±0.09^{f}	2.66±0.06^{e}	2.83±0.17^{cd}	2.96±0.13^{a}
Thickness (mm)	1.94±0.07^{c}	2.31±0.18^{a}	2.25±0.16^{b}	2.00±0.01^{c}	2.00±0.06^{c}	2.03±0.05^{c}	2.14±0.08^{b}
Equivalent diameter (mm)	3.61±0.07^{b}	3.60±0.12^{b}	3.75±0.14^{a}	3.79±0.07^{a}	3.64±0.04^{b}	3.63±0.11^{b}	3.78±0.11^{a}
Sphericity (%)	41.66±0.96^{d}	52.71±1.60^{a}	51.52±1.26^{b}	31.71±0.84^{e}	40.92±0.87^{d}	44.22±1.33^{c}	44.98±0.97^{c}
Aspect ratio	0.32±0.01^{c}	0.43±0.02^{a}	0.44±0.01^{a}	0.19±0.01^{e}	0.30±0.01^{d}	0.34±0.02^{b}	0.35±0.01^{b}
Volume (mm^3)	24.75±1.53^{b}	24.46±2.48^{b}	27.67±3.07^{a}	28.43±1.53^{a}	25.21±0.87^{b}	25.10±2.27^{b}	28.45±2.51^{a}
Surface area (mm^2)	35.97±1.35^{cd}	34.32±2.50^{d}	37.02±2.77^{c}	43.78±1.57^{a}	36.88±1.04^{c}	35.83±1.93^{cd}	38.84±2.15^{b}
Bulk density (kg/m^3)	594.36±5.89^{ab}	596.03±6.62^{a}	584.25±5.23^{c}	498.59±8.23^{d}	586.37±4.92^{bc}	599.63±5.49^{a}	586.57±6.49^{bc}
True density (kg/m^3)	1401.68±70.77^{ab}	1308.01±64.24^{ab}	1267.38±50.66^{bc}	1217.47±46.49^{c}	1449.42±61.33^{a}	1316.92±46.13^{abc}	1335.58±61.65^{ab}
Porosity (%)	57.43±2.09^{ab}	54.29±2.20^{cd}	52.70±2.04^{d}	59.45±2.49^{a}	58.67±1.73^{ab}	53.52±2.32^{cd}	56.04±1.86^{bc}
Thousand kernel weight	27.45±0.30^{b}	22.23±0.22^{e}	26.71±0.30^{c}	27.24±0.63^{b}	28.63±0.16^{a}	24.84±0.42^{d}	28.39±0.21^{a}
Angle of repose (deg.)	38.63±1.80^{ab}	41.11±1.70^{a}	40.00±1.56^{ab}	35.70±1.01^{c}	37.74±1.57^{bc}	36.92±1.09^{bc}	37.78±1.93^{bc}

Values are expressed as mean ± standard deviation. Means having different letters within the same row differ significantly at $p \leq 0.05$ (n = 10)

Table 2. Physical characteristics of brown rice cultivars

Property	Rice cultivars						
	Jehlum	K-332	Koshar	Pusa-3	SKAU-345	SKAU-382	SR-1
Length (mm)	6.29±0.14^{c}	4.74±0.13^{g}	5.00±0.13^{f}	8.32±0.17^{a}	6.62±0.17^{b}	5.98±0.12^{e}	6.09±0.16^{e}
Width (mm)	2.55±0.08^{d}	2.80±0.05^{b}	3.03±0.08^{a}	2.02±0.06^{e}	2.62±0.10^{c}	2.49±0.06^{d}	2.68±0.10^{c}
Thickness (mm)	1.84±0.05^{d}	2.04±0.06^{bc}	2.10±0.05^{a}	1.79±0.06^{d}	2.00±0.04^{b}	1.83±0.08^{d}	1.93±0.11^{c}
Equivalent diameter (mm)	3.12±0.06^{c}	3.03±0.04^{d}	3.20±0.07^{b}	3.11±0.06^{c}	3.28±0.07^{a}	3.03±0.06^{d}	3.18±0.06^{b}
Sphericity (%)	49.11±0.94^{d}	63.36±1.49^{a}	63.44±0.88^{a}	37.40±0.80^{e}	49.29±1.00^{d}	50.32±1.06^{c}	51.8±1.56^{b}
Aspect ratio	0.40±0.01^{e}	0.59±0.02^{b}	0.61±0.01^{a}	0.24±0.01^{f}	0.40±0.01^{de}	0.41±0.01^{d}	0.44±0.02^{c}
Volume (mm^3)	15.88±0.92^{c}	14.54±0.63^{d}	17.17±1.17^{b}	15.84±0.86^{c}	18.51±1.17^{a}	14.65±0.92^{d}	16.91±0.91^{b}
Surface area (mm^2)	25.85±0.96^{c}	23.80±0.72^{d}	26.43±1.17^{c}	35.84±1.47^{a}	28.77±1.16^{b}	24.43±1.02^{d}	26.69±1.01^{c}
Bulk density (kg/m^3)	794.38±10.13^{bc}	790.14±12.20^{c}	817.85±7.74^{a}	736.49±6.40^{e}	805.70±7.38^{b}	794.95±8.14^{bc}	775.26±7.87^{d}
True density (kg/m^3)	1436.48±42.06^{ab}	1376.68±29.84^{bc}	1303.04±19.10^{cd}	1270.81±50.33^{d}	1484.42±38.70^{a}	1370.26±42.51^{bc}	1386.25±51.51^{b}
Porosity (%)	44.46±1.51^{ab}	41.69±2.08^{b}	41.06±1.74^{b}	46.70±1.53^{a}	46.07±2.42^{a}	43.60±2.16^{ab}	44.79±2.22^{ab}
Thousand kernel weight	21.84±0.36^{b}	18.81±0.09^{d}	21.65±0.02^{b}	21.84±0.13^{b}	22.92±0.14^{a}	19.80±0.05^{c}	22.73±0.10^{a}
Angle of repose (deg.)	31.72±1.14^{abc}	32.32±1.27^{ab}	33.04±1.21^{a}	31.13±1.56^{bc}	29.93±1.49^{c}	30.98±1.14^{bc}	31.25±1.36^{bc}

Values are expressed as mean ± standard deviation. Means having different letters within the same row differ significantly at $p \leq 0.05$ (n = 10)

weight of product in the hopper, knowledge of bulk density is necessary. The knowledge of bulk density is useful for the design of silos and hoppers for grain handling and storage (Nalladulai *et al*., 2002).

The porosity was obtained in the range of 52.70 to 59.45% in paddy, whereas 41.06 to 46.70% for brown rice cultivars. The highest porosity value was observed for Pusa-3, which might be due to the long grain length (Correa *et al*., 2007). The porosity values also showed the significant difference ($p \leq 0.05$) between the cultivars in paddy and brown rice. The porosity values were found in the same range as reported for paddy varieties (Varnamkhasti *et al*., 2008), whereas values for paddy and brown rice in this work were higher than those reported by previous investigations (Razavi and Farahmandfar, 2008).

The thousand kernel weight was observed in the range from 22.23 (K-332) to 28.63 (SKAU-345) for paddy, whereas in brown rice the values varied from 18.81 to 22.92 for the same cultivars, respectively and significantly differ from each other ($p \leq 0.05$). The thousand kernel weight decreased with the level of processing from rough to brown rice. These values were higher than those observed for rough and brown rice varieties (Ozguven and Kubilay, 2004; Varnamkhasti *et al*., 2008), respectively; whereas lower than those reported by previous investigations (Shittu *et al*., 2012) for the same correspondingly. By comparing the thousand kernel weight for the paddy and brown rice for each cultivar, it is useful index to milling outturn and in measuring the relative amount of dockage in paddy, shrivelled kernels and to determine the weight proportion of the paddy constituted by the husk (Luh, 1980).

Paddy showed higher angle of repose compared to brown rice and the significant difference were observed between the cultivars. The mean values of angle of repose were ranging from 35.70 to 41.11for paddy and 29.93 to 33.04 degree for brown rice, respectively. The mean values are within the same range as reported for Sorkheh and Sazandegi paddy varieties (Varnamkhasti *et al*., 2008). The angle of repose was decreased by each level of processing and the milled rice was reported to be lower angle of repose values as compared to paddy (Razavi and Farahmandfar, 2008). Angle of repose finds its application in hopper designing which determines the maximum angle of a pile of grain with the horizontal plane, while the hopper wall's inclination angle should be greater than the angle of repose to ensure the continuous flow of the materials by gravity.

The static coefficients of friction, as shown Figure 1 and 2, observed to differ significantly between the cultivars and surfaces among paddy and brown rice at the 5% level probability. The highest average values of the static coefficient of friction against plywood, glass and iron sheet for paddy grains were 0.49, 0.31 and 0.38, while the lowest values were 0.42, 0.25 and 0.34, respectively. Varnamkhasti *et al.* (2008) observed that the paddy on plywood, glass and galvanized iron sheet surface showed static coefficients of friction of 0.44, 0.28 and 0.32, respectively. The static coefficient of friction values for Kashmir paddy cultivars were found in the same range. In all the cultivars and surface materials, the coefficient of friction decreased from rough to brown rice. This fact was expected because of milling operation which makes the grain surface smoother (Ozguven and Kubilay, 2004; Correa *et al.*, 2007) which affirms that the friction and consequently its coefficient are affected mainly by the nature and type of the surface in contact. For brown rice the highest values were reported to be 0.36, 0.24 and 0.29, while the lowest were 0.31, 0.21 and 0.24 against plywood, glass and iron sheet, respectively. The static friction coefficients determined in this experiment were higher to those found in rice for steel, wood and concrete surfaces (Correa *et al.*, 2007). The static coefficient of friction is used to determine the angle at which chutes be positioned in order to achieve consistent flow of materials through the chute. Such type of information is utilized in sizing motor requirements for grain transportation and handling.

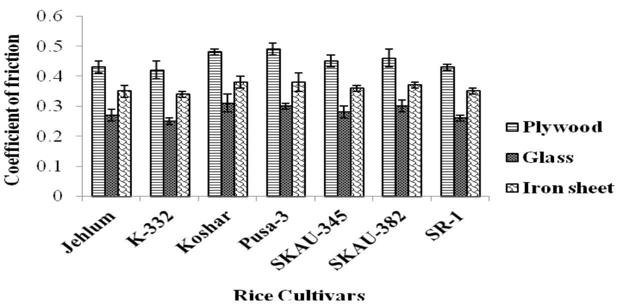

Figure 1. Static coefficient of friction for paddy cultivars

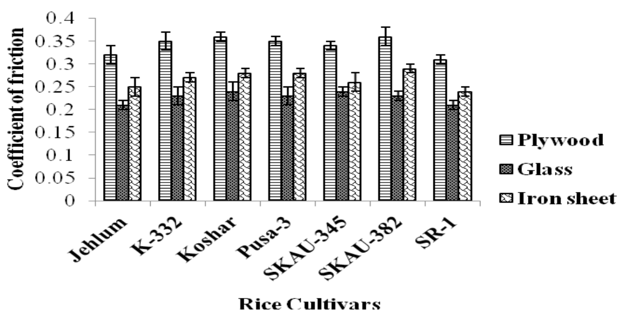

Figure 2. Static coefficient of friction for brown rice cultivars

Color

The color of rice kernels is one of the important physical properties for utilization. Significant differences were observed between color parameters like L^*, a^* and b^* among the rice cultivars is grouped in Table 3. The brown rice of Pusa-3 ($L^* = 55.99$) was found to be darkest followed by SR-1 (58.10), whereas the Jehlum ($L^* = 67.19$) was observed to be lightest. The difference in color of the rice kernels may be due to the difference in genetic makeup, colored pigments and composition of flour (Aboubakar *et al.*, 2008; Kaur *et al.*, 2011). The colored rice varieties found to be potent source of antioxidants (Sompong *et al.*, 2012). The more the color of brown rice kernel more energy it take to polishing and difficult to process (Shittu *et al.*, 2012; Saikia *et al.*, 2012). The a^* value was highest for the cultivar SR-1 (7.73), while as the lowest was observed for Jehlum (4.23). However, the b^* value was reported to be highest for Koshar (26.29) followed by Pusa-3 (25.33) cultivar. The Shittu *et al.* (2012) observed the different color of brown rice during studying with different rice varieties, but the L^* value was higher than present study.

Table 3. Lab color values of brown rice cultivars

Rice cultivars	L*	a*	b*
Jehlum	67.19±2.41^{a}	4.23±0.26^{d}	23.62±0.75^{c}
K-332	60.10±2.34^{d}	6.12±0.67^{b}	25.09±1.22^{b}
Koshar	63.02±1.55^{bc}	6.25±0.32^{b}	26.29±0.85^{a}
Pusa-3	55.99±2.02^{f}	7.44±0.78^{a}	25.33±1.41^{b}
SKAU-345	64.31±1.76^{b}	4.78±0.55^{c}	23.80±1.10^{c}
SKAU-382	62.67±2.17^{c}	5.14±0.29^{c}	22.41±0.87^{d}
SR-1	58.10±1.86^{e}	7.73±0.81^{a}	23.95±1.63^{c}

Values are expressed as mean ± standard deviation. Means having different letters within the same row differ significantly at $p \leq 0.05$ (n = 3)

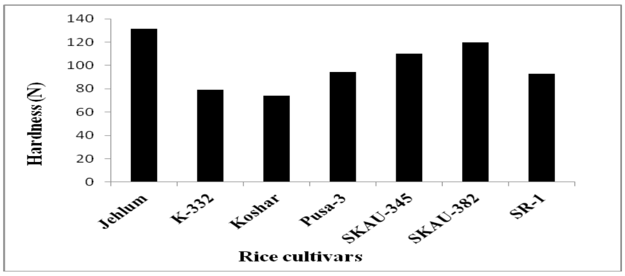

Figure 3. Grain hardness of brown rice cultivars

Hardness

Hardness is one of the important physical parameter which maximizes the milling yield. Figure 3 depicts the compression force in Newton (N), which significantly differs among the rice cultivars. The Jehlum observed for the highest degree of hardness (133.48 N) followed by SKAU-382 (124.88 N) and SKAU-345 (124.88 N), respectively, while the lowest were found in Koshar (72.99 N) and Pusa-3 (124.87 N) cultivar respectively. The variation in hardness of rice grain is due to the compact arrangement of starch granules. The results are similar to those found by Correa *et al*. (2007) while working with different varieties of rice.

Conclusion

This study concludes with information on physical properties of rice cultivars from temperate region of Kashmir Valley, India. The investigation has showed that the physical dimensions and size related characteristics of the paddy and brown rice from different cultivars vary significantly. The wide variation is found in rice grain varying from short to long varieties. This information is useful for optimizing milling operations, designing the storage structures and machinery, which will help to avoid the postharvest and milling losses and to find the end use of the particular rice cultivar. The color and hardness showed the wide variation among the cultivars, which is useful to find the suitable use of the particular cultivar.

References

AOAC. 2003. Official Methods of analysis of AOAC. 17th edn. Arlington, VA: Association of Official Analytical Chemists (AOAC) International.

Aboubakar, Njintang, Y. N., Scher, J. and Mbofung, C. M. F. 2008. Physicochemical, thermal properties and microstructure of six varieties of taro (*Colocasia esculenta* L. Schott) flours and starches. Journal of Food Engineering 86 (2): 294–305.

Brooker, D. B., Bakker-Arkema, F. W. and Hall C. W. 1992. Drying and Storage of Grains and Oilseeds. The AVI Publishing Company Westport 450 pp.

Correa, P. C., Silva, F. S., Jaren, C., Junior, P. C. A. and Arana, I. 2007. Physical and mechanical properties in rice processing. Journal of Food Engineering 79 (1): 137-142.

Fraser, B. M., Verma, S. S. and Muir, W. E. 1978. Some physical properties of fababeans. Journal of Agricultural Engineering Research 23 (1): 53–57.

Izawa, T. 2008. The process of rice domestication: A new model based on recent data. Rice 1 (2): 127–134.

Jain, R. K. and Bal, S. 1997. Properties of pearl millet. Journal of Agricultural Engineering Research 66 (2):85–91.

Juliano, B. O. 1985. Rice: Chemistry and technology (2nd ed.). St. Paul, MN, USA: American Association of Cereal Chemists.

Kaur, M., Kaushal, P. and Sandhu, K. S. 2011. Studies on physico-chemical and pasting properties of Taro (*Colocasia esculenta* L.) flour in comparison with a cereal, tuber and legume flour. Journal of Food Science and Technology DOI 10.1007/s13197- 010-0227-6.

Kwarteng, E. A., Ellis, W. O., Oduro, I. and Manful, J. T. 2003. Rice grain quality: a comparison of local varieties with new varieties under study in Ghana. Food Control 14 (7): 507-514.

Liu, K., Cao, X., Bai, Q., Wen, H. and Gu, Z. 2009. Relationships between physical properties of brown rice and degree of milling and loss of selenium. Journal of Food Engineering 94 (1): 69-74.

Luh, B. S. 1980. Rice: Production and Utilization. Inc., West port, CT. AVI publishing company.

Mohsenin, N. N. 1986. Physical properties of plant and animal materials (2nd edn.). New York: Gordon and Breach.

Nalladulai, K., Alagusundaram, K. and Gayathri, P. 2002. Airflow resistance of paddy and its byproducts. Biosyststems Engineering 831 (4): 67–75.

Ozguven, F. and Kubilay, V. 2004. Some physical, mechanical and aerodynamic properties of pine (*Pinus pinea*) nuts. Journal of Food Engineering 68 (2): 191-196.

Parray, G. A. and Shikari, A. B. 2008. Benefit-cost ratio in producing aromatic and non-aromatic rice genotypes in Kashmir Valley. International Rice Research Notes 32: 38-39.

Razavi, S. M. A. and Farahmandfar, R. 2008. Effect of hulling and milling on the physical properties of rice grains. International Agrophysics 22 (4): 353-359.

Razavi, S. M. A. and Milani, E. 2006. Some physical properties of the watermelon seeds. African Journal of Agricultural Research 1 (3): 65–69.

Sahay, K. M. and Singh, K. K. 1994. Unit Operations of Agricultural Processing. 1st edn. Vikas Publishing House Pvt. Ltd., New Delhi, India.

Saikia, S., Dutta, H., Saikia, D. and Mahanta, C. L. 2012. Quality characterisation and estimation of phytochemicals content and antioxidant capacity of aromatic pigmented and non-pigmented rice varieties. Food Research International 46 (1): 334-340.

Shittu, T. A., Olaniyi, M. B., Oyekanmi, A. A. and Okeleye, K. A. 2012. Physical and water absorption characteristics of some improved rice varieties. Food and Bioprocess Technology 5 (1) 298-309.

Singh, N., Kaur, L., Singh, S. S. and Sekhon, K. S. 2005. Physiochemical, cooking and textural properties of milled rice from different Indian rice cultivars. Food Chemistry 89 (2): 253-259.

Sompong, R., Siebenhandl-Ehn, S., Linsberger-Martin, G. and Berghofer, E. 2012. Physicochemical and antioxidative properties of red and black rice varieties from Thialand, China and Sri Lanka. Food Chemistry 124 (1): 132-140.

Thakur, A. K. and Gupta, A. K. 2007. Water absorption characteristics of paddy, brown rice and husk during soaking. Journal of Food Engineering 75 (2): 252–257.

Thompson, S. A. and Ross, I. J. 1983. Compressibility and frictional coefficient of wheat. Transactions of the ASAE 26: 1171–1176.

Varnamkhasti, M. G., Mobli, H., Jafari, A., Keyhani, A. R., Soltanabadi, M. H., Rafiee, S. and Kheiralipour, K. 2008. Some physical properties of rough rice (*Oryza sativa* L.) grain. Journal of Cereal Science 47 (3): 496–501.

Wratten, F. T., Poole, W. D., Chesness, J. L., Bal, S. and Romaroa, V. 1969. Physical and thermal properties of rough rice. Transactions of the ASAE 126: 801–803.

Zareiforoush, H., Hosseinzadeh, B., Adabi, M. E. and Motavali, A. 2011. Moisture dependent physical properties of paddy grains. Journal of American Science 7 (7):175-182.