Cultivars effect on the physical characteristics of rice (rough and milled) (*Oryza Sativa L.*) of temperate region of Kashmir (India)

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Abstract The aim of present research was to evaluate physical and engineering properties of traditional paddy and rice cultivars native to temperate region of India. Length, width, thickness, equivalent diameter, surface area, aspect ratio, volume, bulk density, true density, porosity, thousand kernels weight, angle of repose and coefficient of friction were evaluated, which are required in designing of various post harvest operations and storage structures. The low bulk density of cultivars, *Mushki budgi*, *Mushki tujan* and *Kaw kareed* may be due to the presence of long awns possessed by these cultivars which were bulky and occupied more space. The wide variations were found in rice kernels with respect to colour, which determined the functional properties and energy requirement during polishing of these cultivars. Results indicated significant differences in the physical properties among various paddy and brown rice cultivars when compared with earlier reported results. Thousand kernel weight, width, arithmetic mean diameter and equivalent diameter showed significant positive correlations with sphericity, surface area, volume, true density, and angle of repose; but negatively correlated with bulk density. These desirable characteristics exploit agriculturists/institutions to preserve these races and encourage farmers to cultivate these cherished rice cultivars.

Keywords Rice cultivars · Physical characteristics · Aspect ratio · Static friction · Pearson correlation coefficient

Introduction

Rice (*Oryza Sativa L.*) is one of the oldest cultivated and the most widely grown food grain crop in the world, serving as the major source of staple food for about half the world's population (Zhout et al. 2002). The slogan “Rice is life” initiated by FAO (2011) is concerned with the importance of rice as a primary source of food, which is due to its role in food security, improving the livelihood and alleviation of poverty (www.Fao.org). The varietal differences among rice cultivars in terms of their physical, chemical and cooking characteristics are due to their varied genetic and environmental adaptation to different regions of the world (Izawa 2008).

Traditional cultivars in India are repository of high genetic diversity and are highly impressive, thus motivating the cultivars in conserving and maintaining this varied diversity (Singh et al. 2005). In India, the state of Jammu and Kashmir ranges from 33°17' to 37°20'N latitude and 73°25' to 80°30'E longitude is typographically more complex. It comprises an area, of 2, 22, 236 sq. km and covers a distance of 640 km from north to south and 480 km from east to west (Singh et al. 2000). The traditional cultivars have been consumed and cultivated by the farmers since ancient times and possess a diverse range appearances and colors, thus representing an excellent cultural landscape heritage of the valley (Sultan and Subba-Rao 2013). Research has been undertaken to collect and conserve available rice genetic

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diversity from the high altitude areas of Kashmir and collection of knowledge about these traditional resources from local farmers.

Quality characteristics associated with physical properties of rice grains have a major determinant role in grading and determining the marketing value of the rice after processing, as the demand of rice ranks highest for the head rice kernels and broken kernels fetches less income for the processors (Marchezan 1991). The knowledge of the physical properties of grains have an importance to determine the design of various food processing machines (Silva and Correa 2000), dimensioning and designing storage structures of the grains, constraints related with transportation, calculation and fixation of different models associated with different processes like drying kinetics, heat and mass transfer processes, aeration through the grains and power consumption in milling grains (Varnamkhasti et al. 2008).

Porosity, volume and specific gravity are the basic attributes used to solve problems of agricultural products during drying and storage periods and to maintain the quality characteristics until consumption. Knowledge of angle of repose and coefficient of friction have an important role in designing of grain moving equipments, processing machines and silos (Suthar and Das 1996). Colour is also an important quality attribute which increases the consumer acceptability for particular variety and is an indicator of nutritional and functional value of the selected variety.

These traditional rice cultivars are indigenous to the temperate regions of India cultivated by the local farmers since ancient times and still being cultivated due to their valuable traits that lead to an increased attention to “International rice research Institute” (IRRI) and other national and international germplasm conservation agencies to encourage farmers to increase the land area under rice cultivation besides their genetic manipulation into high yielding modern hybrid rice varieties. The state lacks in the efficient mechanization of various agricultural operations that resulted in a detrimental effect on the quality of the finished products. Keeping this in view, the main objective of this research was to determine the physical and engineering properties of different traditional paddy and rice cultivars grown in higher altitude regions of Kashmir (India), which would be essential to the engineering and scientists for designing of various post harvesting processing and handling machines along with their storage structures so as to maximize output and maintain the quality of these highly demanded cultivars.

Materials and methods

Raw materials selection

The paddy cultivars used for analysis of their physical and engineering characteristics are traditional cultivars grown in Kashmir valley of J&K. These cultivars include *Mush Kandi*, *Tcheri Bara*, *Gul Zag*, *Naaz Bar*, *Mushuq Budij*, *Kamad*, *Koshkari*, *Kawa Kareed*, *Shalle Keau*, *Kaw quder*, *Tilla Zag*, *Zag* were collected from the certified agencies and also from the rice research centre, Khudwani of Sher-e-Kashmir Agricultural University of Science and Technology, Kashmir (India) who are cultivating these rice cultivars for conservation of these valuable land races and to maintain the purity of these rice cultivars over a period of two consecutive years in order to obtaining the genuine and pure samples for research purposes and also for the reliability of the results, These traditional paddy cultivars were grown in the Kashmir valley altitude at an altitude of 1600 to around 2300 m above the mean sea level with an annual average temperature of 13 °C and are specific to a particular region.

Samples preparation

The samples were collected at random however the lot size used for sample collection was small but was sufficient to get the reliable results. During the experiment the composite samples were homogeneously divided into laboratory sized samples (1 kg each) by using the grain divider (Gammet type). The paddy samples were manually cleaned to remove field impurities such as dust, dirt, stones, straw, small broken and immature kernels. The clean paddy was subjected to milling using lab de-husker (Indosaw Pvt. Ltd. Ambala, India). Both milled and un-milled grains were used for analyses. All the samples were stored in air tight containers at 4 °C until used. All the analyses if otherwise stated was carried out in triplicate.

Physical properties

The initial moisture content of paddy samples was determined on wet basis by automatic moisture analyzer (Precisa Gravimetrics AG Dietikon, Switzerland). Grain micrometer (Mitutoya grain meter, Japan) with an accuracy of 0.02 mm was used to measure length (L), width (W) and thickness (T) of both paddy and brown rice kernels, chosen randomly from each particular cultivar. Other physical properties were then determined from these three major linear dimensions. The volume (V) and the surface area (S) of both paddy and brown rice samples were calculated by

using the method given by (Jain and Bal 1997), as given below.

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

and

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

where

$$B = (WT)^{\frac{1}{2}}$$

where V and S represent volume and surface area of the grain. The volume and surface area have an important role in determining the permeability and moisture absorption pattern of both paddy and rice.

Equivalent diameter (D_e)

The equivalent diameter (D_e) of the grain is defined as the diameter of a spherical particle that exhibits properties (physical, mechanical) similar to that of the analyzed grain kernel. It was measured in mm for paddy and brown rice were calculated by considering a prolate spheroid shape for both of them and determined by using the following equation (Jain and Bal 1997).

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

Geometric mean diameter “ D_g ”

The geometric mean diameter of paddy and brown rice is a kind of mean, which depicts the central tendency of length, width and thickness by using the product of their values. The geometric mean of length, width and thickness is the cube root of the product of their values. According to Sharma and Dubey (1985), the geometric mean diameter, “ D_g ” is given by the following expression.

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

Sphericity ($\emptyset$)

The sphericity ($\emptyset$) is 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 by using the expression (Mohsenin 1986).

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

Aspect ratio (R_a)

The aspect ratio (R_a) was determined by the formula below (Varnamkhasti et al. 2008).

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

where W, L and T represent Width, Length and Thickness of the grain kernel.

Both the sphericity and aspect ratio are considered important properties to characterize the shape of the grain.

True density, bulk density and porosity

The true density of kernel is defined as the ratio of mass of seed to the volume occupied by it and was calculated by means of toluene displacement method. The actual volume of the grain kernel was calculated by immersing a weighted quantity of paddy grains in the measured toluene and the volume of toluene displaced was recorded. Toluene was used in spite of water because of its low surface tension and is absorbed by kernels to a lesser extent. The true density was calculated as the ratio of the mass of the grains to the volume of displaced toluene (Garnayak et al. 2008). The bulk density (ρ_b) was determined by using the mass/volume relationship. An empty glass container was filled up to known volume with grains followed by measured weight of the grains of the given volume by pouring the sample from a constant height. Porosity (ε) defined as the percentage of air between the grains as compared to a unit volume of grains, was calculated from bulk and true densities by using the following relationship (Jain and Bal 1997)

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

where ε is the porosity (%), ρ_b is the bulk density (kg/m^3) and ρ_t is the true density (kg/m^3).

Thousand kernel (seed) weight and angle of repose (ϕ)

Thousand kernels (seed) weight was determined by weight of randomly selected 100 kernels by means of electronic balance (accuracy of 0.001 g) and multiplying their weight by 10 (Varnamkhasti et al. 2008). The angle of repose (ϕ) is defined as the angle in degrees with the horizontal at which the material will stand forming a heap, when piled. It was determined by using an empty cylinder of known diameter and height and filled with rice grains and raised gradually until it forms a heap of grain. From the height and diameter of the heap of grains angle of repose can be determined by using the following expression (Ozguven and Kubilay 2004).

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

where H and D represent height and diameter of heap respectively.

Angles of repose have been reported to be useful in designing of processing and handling equipment (Abdul-Rasaq et al. 2011).

Static coefficient of friction (μ)

The static coefficient of friction of paddy and rice grains against three different surfaces, namely, glass, galvanized iron sheet and plywood was computed by using a shallow cylinder of 75 mm diameter and 50 mm depth and filled with grains. The resting surface of the cylinder was raised slowly until the cylinder filled with grains just started to slide down (Razavi and Milani 2006). The static coefficient of friction was calculated from the following relationship.

$$\mu = \tan \alpha,$$

where α is the angle of tilt (degree).

Static coefficient of friction indicates the relationship between the grain and the contacted surface and could be useful in calculating the net force (total force minus frictional force) applied on the grain to move on a particular surface at a required speed and displacement.

Statistical analysis

All the experiments were carried out in triplicates. The data were analyzed by using statistical software (statistica.v.7) and the means were displayed using the Duncan's multiple range tests ($p \leq 0.05$). All the data are tabulated as the mean with the standard deviation.

Results and discussion

Physical properties

Seed dimensions

No significant variations were observed between the selected individual samples collected over a period of two seasons for their dimensional analysis and thousand kernel weight. This might be due to sample purity and somewhat consistent growing conditions maintained by the substations and centers.

The summary of the results for all the physical properties of twelve traditional paddy and brown rice cultivars are presented in Tables 1, 2, 3 and 4. The moisture content of all the paddy cultivars varied from 11.48 to 13.09% (wet

basis). Grain moisture content has an important effect in determining the different parameters of paddy and rice quality. It is an essential parameter in ensuring the optimum milling potential in order to obtain highest yield of head rice. The lower temperature had been reported to enhance the milling quality of rice having moisture in the range of 11–13%. The structure of endosperm tissue in the rice grains is damaged by increasing the temperature, as the thermal stress and the resulting shrinkage affects the network structures between starch granules and protein.

The samples chosen for the evaluation of dimensional and physical properties revealed a significant difference among different cultivars for their physical properties. For the dimensional parameters, the mean length of paddy varied from 6.87 mm (*Mushki Tujan*) to 8.57 mm (*Naaz Bar*), and in case of rice it ranged from 5.06 mm (*Mushki Budgi*) to 5.88 mm (*Tel zag*). The variation in width ranged from 2.89 mm (*Gull-zag*) to 3.92 mm (*Kaw quder*) for the paddy, and from 2.46 mm (*Gull Zag*) to 3.25 mm (*Kaw quder*) for rice respectively. The thickness of the paddy varied from 2.02 mm (*Gull Zag*) to 2.44 mm (*Koshkari*), while that of the brown rice ranged from 1.78 mm (*Gull Zag*) to 2.20 mm in case of *Koshkari*. The mean lengths of the analyzed traditional paddy cultivars at the given moisture range were found to be lower than the improved paddy rice varieties including FARO55, FARO44, FARO52, FARO49 and NERICA L34 as reported by Abdul-Rasaq et al. 2011, but the width of these improved paddy varieties were found to lower than that of the given paddy cultivars. However the mean length of these traditional rice cultivars was observed to be lesser than that of the rice variety, IR-64 as reported by Chitra et al. (2010).

Seeds can be graded homogenously according to size, which give increased harvesting yield by ensuring uniform germination. Effective grading according to width occurs when the particles lie along the axis perpendicular to the surface of the sieve vibrating vertically. However grading is satisfactory even on sieves vibrating horizontally. These principal dimensions of paddy and rice grains are useful in grading of grains by selecting sieve separators. These are also used to calculate surface area, sphericity, equivalent diameter and volume of kernels, which are used in modeling of grain drying, aeration, heating, cooling and designing of equipments (Mohsenin 1986; Varnamkhasti et al. 2008). Wide range of grain dimensions have also been reported by different investigators during their experiments with different grains (Correa et al. 2007). The mean and equivalent diameters of paddy varied from 3.61 mm (*Mushki Tujan*) to 4.17 mm (*Kaw quder*) and 3.65 mm (*Mushki Tujan*) to 4.25 mm (*Kaw quder*), while in case of brown rice mean diameter varied from 2.78 mm (*Mushki Tujan*) to 3.39 mm (*Kaw quder*) and equivalent diameter ranged from 2.98 mm (*Gull Zag*) to 3.27 (*Tel Zag*

Table 1 Dimensional characteristics of various traditional paddy cultivars of temperate region

Varieties	Dimensional characteristics						
	Length (mm)	Width (mm)	Thickness (mm)	Equivalent diameter (mm)	Mean diameter (mm)	Aspect ratio	Angle of repose (°)
Kamad	8.13 ± 0.20 ^{ac}	3.29 ± 0.78 ^b	2.26 ± 0.08 ^{ac}	3.97 ± 0.10 ^b	3.92 ± 0.11 ^b	0.405 ± 0.01 ^{fghj}	34.63 ± 0.67 ^b
Mushki budgi	7.28 ± 0.13 ^{dg}	3.39 ± 0.20 ^{be}	2.19 ± 0.17 ^{ae}	3.84 ± 0.15 ^{bf}	3.78 ± 0.15 ^b	0.466 ± 0.03 ^{af}	40.79 ± 1.03 ^{cde}
Koshkari	7.38 ± 0.54 ^{bcd}	3.51 ± 0.17 ^b	2.44 ± 0.01 ^a	4.03 ± 0.16 ^{ab}	3.98 ± 0.15 ^b	0.477 ± 0.02 ^{ae}	38.64 ± 0.95 ^{eg}
Zag	7.170 ± 0.292 ^{di}	3.30 ± 0.17 ^{bg}	2.13 ± 0.27 ^{bcd}	3.74 ± 0.13 ^{bi}	3.68 ± 0.14 ^b	0.461 ± 0.41 ^{ag}	38.65 ± 0.95 ^{ef}
Mushki tujan	6.87 ± 0.188 ^{efghi}	3.22 ± 0.24 ^{bj}	2.16 ± 0.07 ^{bcd}	3.65 ± 0.12 ^{cdefghi}	3.61 ± 0.11 ^b	0.479 ± 0.05 ^{ac}	34.97 ± 1.04 ^b
Naaz bar	8.57 ± 0.48 ^a	3.13 ± 0.11 ^{cdefghijk}	2.12 ± 0.01 ^{cde}	3.90 ± 0.10 ^{bd}	3.85 ± 0.09 ^b	0.366 ± 0.02 ^{ij}	33.67 ± 1.07 ^b
Gull zag	8.173 ± 0.15 ^{ab}	2.89 ± 0.05 ^k	2.02 ± 0.02 ^{cde}	3.67 ± 0.03 ^{cdefghi}	3.63 ± 0.03 ^b	0.353 ± 0.01 ^{ij}	42.59 ± 1.01 ^{bd}
Tcheri bar	7.54 ± 0.27 ^{bcd}	3.31 ± 0.27 ^{bf}	2.14 ± 0.14 ^{bcd}	3.83 ± 0.23 ^{bh}	3.77 ± 0.22 ^b	0.437 ± 0.02 ^{ah}	35.67 ± 2.46 ^b
Kaw kareed	7.26 ± 0.93 ^{dh}	3.44 ± 0.05 ^{bc}	2.17 ± 0.07 ^{bcd}	3.84 ± 0.17 ^{be}	3.77 ± 0.17 ^b	0.482 ± 0.08 ^{ab}	42.60 ± 1.00 ^{bc}
Kaw quder	7.73 ± 0.32 ^{bcd}	3.92 ± 0.11 ^a	2.40 ± 0.10 ^{ab}	4.25 ± 0.07 ^a	4.17 ± 0.073 ^{ab}	0.507 ± 0.03 ^a	44.98 ± 0.93 ^{ab}
Tel zag	7.91 ± 0.18 ^{ad}	3.27 ± 0.16 ^{bi}	2.23 ± 0.22 ^{ad}	3.91 ± 0.18 ^{bc}	3.92 ± 0.19 ^b	0.412 ± 0.01 ^{cdefghi}	46.10 ± 0.89 ^a
Shel kew	7.16 ± 0.325 ^{dj}	3.42 ± 0.13 ^{bd}	2.17 ± 0.16 ^{bcd}	3.83 ± 0.17 ^{bg}	3.76 ± 0.17 ^b	0.478 ± 0.01 ^{ad}	36.20 ± 1.84 ^{fgh}

Values are expressed as mean ± SD

Means having different letters within the same column differ significantly at $p \leq 0.05$

Values in triplicates were taken

Table 2 Physical characteristics of various traditional paddy cultivars of temperate region

Varieties	Physical characteristics						
	Sphericity (%)	Volume (mm ³)	Surface area (mm ²)	Thousand kernel weight	Bulk density (kg/m ³)	True density (kg/m ³)	Porosity (%)
Kamad	0.48 ± 0.01 ^{aj}	32.83 ± 2.74 ^{bc}	5.14 ± 0.15 ^{bg}	28.56 ± 0.30 ^{bc}	620.98 ± 5.53 ^a	1428.3 ± 15.27 ^d	50.24 ± 6.28 ^{hi}
Mushki budgi	0.52 ± 0.03 ^{ag}	29.78 ± 3.46 ^{bf}	5.28 ± 0.47 ^{be}	20.93 ± 1.33 ^h	542.73 ± 4.03 ^{fg}	1090 ± 10 ^h	50.20 ± 0.71 ^{hi}
Koshkari	0.54 ± 0.02 ^{ab}	34.34 ± 4.11 ^b	5.74 ± 0.12 ^{ab}	28.57 ± 5.69 ^{bd}	551.15 ± 1.71 ^e	1561 ± 56.19 ^b	62.20 ± 5.58 ^{bcd}
Zag	0.51 ± 0.41 ^{ah}	27.66 ± 2.94 ^{cdefgh}	5.12 ± 0.55 ^{bh}	24.76 ± 0.05 ^{efg}	542.80 ± 3.30 ^{fg}	1213.3 ± 50.57 ^g	53.91 ± 2.41 ^{efgh}
Mushki tujan	0.54 ± 0.03 ^{ad}	25.73 ± 2.61 ^{defgh}	5.17 ± 0.36 ^{bf}	25.90 ± 0.30 ^{cdefg}	544 ± 3.89 ^{eg}	1295 ± 15 ^{ef}	58.75 ± 1.58 ^{de}
Naaz bar	0.45 ± 0.02 ^{cdefghij}	31.12 ± 2.37 ^{be}	4.77 ± 0.11 ^{cdefghij}	28.03 ± 0.15 ^{be}	582.27 ± 6.05 ^c	1401.7 ± 7.63 ^d	58.45 ± 0.64 ^{df}
Gull zag	0.44 ± 0.01 ^{bcddefghij}	25.79 ± 0.83 ^{defgh}	4.45 ± 0.05 ^j	25.40 ± 0.20 ^{cdefg}	596.03 ± 4.80 ^b	1270 ± 10 ^{df}	53.08 ± 0.52 ^{gi}
Tcheri bar	0.49 ± 0.01 ^{ai}	29.54 ± 5.26 ^{bg}	5.07 ± 0.40 ^{cdefghi}	26.70 ± 0.70 ^{bf}	550.30 ± 1.61 ^{ef}	1335 ± 35 ^e	59.08 ± 0.89 ^d
Kaw kareed	0.53 ± 0.06 ^{ae}	27.37 ± 2.12 ^{cdefgh}	5.32 ± 0.34 ^{bc}	26.00 ± 0.79 ^{cdef}	478.02 ± 1.70 ^j	1300 ± 39.68 ^{cd}	64.21 ± 2.08 ^{ac}
Kaw quder	0.54 ± 0.02 ^{ac}	40.43 ± 1.90 ^a	6.01 ± 0.30 ^a	32.50 ± 0.98 ^a	531.80 ± 2.17 ^h	1625 ± 49.24 ^a	67.15 ± 0.54 ^a
Tel zag	0.64 ± 0.26 ^a	31.47 ± 4.51 ^{bd}	5.11 ± 0.37 ^{bi}	29.67 ± 0.15 ^{ab}	506.17 ± 3.56 ⁱ	1493.3 ± 10.41 ^c	66.09 ± 0.15 ^{ab}
Shel kew	0.52 ± 0.02 ^{af}	29.47 ± 3.79 ^{bh}	5.29 ± 0.33 ^{bd}	26.63 ± 0.15 ^{bg}	573.37 ± 3.22 ^d	1335 ± 13.23 ^e	57.46 ± 0.83 ^{dg}

Values are expressed as mean ± SD

Means having different letters within the same column differ significantly at $p \leq 0.05$

Values in triplicates were taken

Table 3 Dimensional characteristics of various traditional brown rice cultivars of temperate region

Varieties	Dimensional characteristics						
	Length (mm)	Width (mm)	Thickness (mm)	Equivalent diameter (mm)	Mean diameter (mm)	Aspect ratio	Angle of repose
Kamad	5.8 ± 0.27 ^a	2.81 ± 0.05 ^{bg}	2.03 ± 0.09 ^{bc}	3.24 ± 0.10 ^{bc}	3.21 ± 0.11 ^{aghi}	0.485 ± 0.02 ^{bcd}	29.52 ± 1.18 ^{efgh}
Mushki budgi	5.06 ± 0.23 ^{de}	2.87 ± 0.18 ^{be}	1.90 ± 0.16 ^{cdefghij}	3.07 ± 0.12 ^{bcg}	3.02 ± 0.13 ^{bcd}	0.569 ± 0.05 ^a	34.19 ± 1.27 ^{ab}
Koshkari	5.15 ± 0.17 ^{bcd}	3.02 ± 0.28 ^b	2.203 ± 0.17 ^a	3.27 ± 0.17 ^{ac}	3.24 ± 0.15 ^{ab}	0.588 ± 0.07 ^a	31.85 ± 1.72 ^{bcdg}
Zag	5.91 ± 0.23 ^a	2.77 ± 0.02 ^{bi}	1.91 ± 0.01 ^{cdefghi}	3.18 ± 0.03 ^{bc}	3.15 ± 0.03 ^{ae}	0.470 ± 0.02 ^{dg}	31.97 ± 0.72 ^{bcd}
Mushki tujan	5.74 ± 0.85 ^{ab}	2.75 ± 0.07 ^{cdefghi}	2.01 ± 0.05 ^{be}	3.19 ± 0.19 ^{bc}	2.78 ± 0.46 ^{ghij}	0.484 ± 0.05 ^{bcd}	29.52 ± 1.18 ^{efgh}
Naaz bar	5.80 ± 0.15 ^a	2.63 ± 0.133 ^{efghij}	1.88 ± 0.041 ^{cdefghk}	3.08 ± 0.63 ^{bee}	3.06 ± 0.06 ^{cdefg}	0.453 ± 0.03 ^{dh}	29.02 ± 1.83 ^{fgh}
Gull Zag	5.87 ± 0.14 ^a	2.46 ± 0.65 ^j	1.78 ± 0.04 ^{ijk}	2.98 ± 0.02 ^{defg}	2.95 ± 0.03 ^{cdefj}	0.420 ± 0.02 ^{efgh}	33.67 ± 1.07 ^{ac}
Tcheri bar	5.49 ± 0.19 ^{ad}	2.86 ± 0.85 ^{bf}	2.02 ± 0.06 ^{bd}	3.19 ± 0.03 ^{bc}	3.15 ± 0.02 ^{ad}	0.521 ± 0.02 ^{ad}	28.53 ± 1.82 ^{fgh}
Kaw kareed	5.07 ± 0.06 ^{de}	2.78 ± 0.17 ^{bh}	2.01 ± 0.10 ^{bf}	3.07 ± 0.04 ^{bcd}	3.04 ± 0.04 ^{bcd}	0.547 ± 0.63 ^{ab}	30.94 ± 1.37 ^{bcdh}
Kaw quder	5.72 ± 0.38 ^{ac}	3.25 ± 0.159 ^a	2.11 ± 0.01 ^{ab}	3.45 ± 0.14 ^a	3.39 ± 0.12 ^a	0.570 ± 0.03 ^a	36.20 ± 1.84 ^a
Tel zag	5.88 ± 0.24 ^a	2.90 ± 0.08 ^{bd}	1.98 ± 0.03 ^{bh}	3.27 ± 0.09 ^{ab}	3.23 ± 0.08 ^{ac}	0.493 ± 0.01 ^{bcd}	32.59 ± 1.32 ^{bcd}
Shel kew	5.37 ± 0.30 ^{ae}	2.91 ± 0.09 ^{bc}	1.99 ± 0.03 ^{bg}	3.18 ± 0.10 ^{bcd}	3.14 ± 0.09 ^{af}	0.542 ± 0.01 ^{ac}	33.11 ± 1.98 ^{ad}

Values are expressed as mean ± SD

Means having different letters within the same column differ significantly at $p \leq 0.05$

Values in triplicates were taken

Table 4 Physical characteristics of various traditional brown rice cultivars of temperate region

Varieties	Physical characteristics					Hunter color lab values		
	Sphericity (%)	Volume (mm ³)	Surface area (mm ²)	Thousand kernel weight (g)	Bulk density (kg/m ³)	True density (kg/m ³)	Porosity (%)	L* A* B*
Kamad	0.55 ± 0.01 ^{ag}	17.86 ± 1.68 ^b	4.73 ± 0.12 ^{bcd}	23.67 ± 0.23 ^{cd}	786.97 ± 16.73 ^c	1342.57 ± 5.73 ^b	41.61 ± 1.71 ^{ef}	62.79 ± 1.73 ^{ac} 2.97 ± 1.24 ^c 18.78 ± 0.53 ^{bd}
Mushki budgi	0.59 ± 0.04 ^{ac}	15.16 ± 1.87 ^{hi}	4.48 ± 0.92 ^{cdeg}	19.00 ± 0.80 ^f	856.24 ± 1.08 ^{ab}	1276.8 ± 3.35 ^{ef}	32.93 ± 0.10 ^{hi}	64.52 ± 2.12 ^a 4.97 ± 0.84 ^c 20.26 ± 0.58 ^b
Koshkari	0.63 ± 0.05 ^a	18.44 ± 2.63 ^b	5.41 ± 0.70 ^a	26.90 ± 1.01 ^a	817.80 ± 8.74 ^d	1341.7 ± 7.67 ^{bc}	39.04 ± 0.85 ^{fg}	60.38 ± 1.49 ^{af} 4.85 ± 0.26 ^c 18.98 ± 0.53 ^b
Zag	0.53 ± 0.01 ^{gh}	16.95 ± 0.59 ^{be}	4.49 ± 0.54 ^{cdef}	23.00 ± 2.43 ^{de}	754.63 ± 6.26 ^f	1350.3 ± 8.28 ^b	43.85 ± 4.52 ^{bc}	62.96 ± 1.52 ^{ab} 8.83 ± 0.73 ^c 11.95 ± 0.63 ^b
Mushki tujan	0.49 ± 0.14 ^{gh}	17.14 ± 3.23 ^{bc}	4.66 ± 0.15 ^{cde}	21.60 ± 0.17 ⁱ	750.27 ± 1.21 ^f	1443.3 ± 10 ^a	48.01 ± 0.44 ^a	56.26 ± 1.84 ^{fg} 7.86 ± 0.39 ^b 21.81 ± 1.24 ^a
Naaz Bar	0.53 ± 0.52 ^{gh}	15.45 ± 0.96 ^{bg}	4.32 ± 0.18 ^{cdeh}	23.10 ± 0.26 ^{de}	754.10 ± 24.43 ^f	1320 ± 4.36 ^{bd}	42.87 ± 1.21 ^{bc}	62.20 ± 3.11 ^{ae} 3.28 ± 0.47 ^c 18.14 ± 1.59 ^{cde}
Gull Zag	0.50 ± 0.01 ^{gh}	13.87 ± 0.27 ^{hi}	4.01 ± 0.28 ^{gh}	21.30 ± 0.55 ^{hi}	839.05 ± 2.616 ^c	1428.39 ± 1.71 ^a	40.88 ± 1.46 ^{eg}	64.44 ± 3.49 ^a 3.83 ± 1.69 ^c 18.71 ± 0.77 ^{bc}
Tcheri Bar	0.57 ± 0.02 ^{af}	17.11 ± 0.62 ^{bd}	4.83 ± 0.15 ^{ad}	21.80 ± 0.20 ^{eh}	820.38 ± 11.94 ^{cd}	1443.3 ± 3.3 ^a	42.09 ± 1.19 ^{bd}	54.75 ± 1.29 ^g 2.91 ± 1.26 ^c 17.10 ± 0.76 ^{de}
Kaw kareed	0.60 ± 0.14 ^{ab}	15.18 ± 0.66 ^{gh}	4.78 ± 0.13 ^{ae}	22.00 ± 0.20 ^g	803.57 ± 10.78 ^{de}	1464.77 ± 1.35 ^a	45.19 ± 0.83 ^{ab}	59.11 ± 0.71 ^{bc} 3.65 ± 0.03 ^c 18.08 ± 0.86 ^{cd}
Kaw quder	0.59 ± 0.02 ^{ad}	21.46 ± 2.41 ^a	5.34 ± 0.14 ^{ab}	26.33 ± 0.15 ^{ab}	846.00 ± 9.92 ^b	1313.33 ± 2.88 ^{bc}	35.74 ± 0.61 ^h	47.23 ± 0.74 ^b 10.76 ± 1.65 ^a 11.96 ± 0.65 ^f
Tel Zag	0.55 ± 0.01 ^{ab}	18.39 ± 1.52 ^{ab}	4.72 ± 0.08 ^{bcd}	24.96 ± 0.49 ^{bc}	845.63 ± 8.73 ^b	1262.66 ± 2.51 ^f	31.87 ± 0.85 ⁱ	62.71 ± 4.85 ^{ad} 4.69 ± 1.19 ^c 19.11 ± 1.11 ^{bc}
Shel kew	0.58 ± 0.01 ^{ae}	16.89 ± 1.63 ^{bf}	4.87 ± 0.04 ^{ac}	22.43 ± 0.15 ^{ef}	872.03 ± 6.25 ^a	1277.01 ± 2.90 ^{bf}	32.17 ± 0.37 ⁱ	43.60 ± 3.11 ^b 9.31 ± 2.91 ^a 11.83 ± 1.64 ^f

Values are expressed as mean ± SD

Means having different letters within the same column differ significantly at $p \leq 0.05$

Values in triplicates were taken

and *Koshkari*). The mean and equivalent diameter had been reported to have an important role in determining the diameter of pores in a sieve (Simonyan et al. 2007)

Aspect ratio and sphericity

Aspect ratio of paddy varied from 0.35 (*Gull Zag*) to 0.51 (*Kaw Kuder*) and in case of brown rice it ranged from 0.42 (*Gull Zag*) to 0.57 (*Kaw Kuder*). Aspect ratio is related to the kernel width and length, and determines whether the grains will slide or roll on their flat surfaces. Grains with higher aspect ratio will slide rather than roll (Al-Mahasneh and Rababah 2007). Sphericity of paddy varied from 0.44 (*Gull Zag*) to 0.64 (*Tel Zag*) and that of brown rice varied from 0.49 (*Mushki Tujan*) to 0.63 (*Koshkari*). The results for sphericity (0.32–1) agreed with that reported by Mohsenin (1986) for most agricultural materials, but were found to be higher than the improved paddy rice varieties of Nigeria (Abdul-Rasaq et al. 2011). As sphericity is inversely proportional to length, the sphericity of brown rice was higher than their respective paddy cultivars. The justification for these results is due to the presence of awns or pointed ends of paddy, which increases the length of paddy as compared to rice grains having rounded ends (Thakur and Gupta 2007). The sphericity of brown rice of *Mushki-Tujan* is lower than its respective paddy. This might be due to its lesser difference between paddy and rice kernel length of this variety as compared to others cultivars. Sphericity gives an indication of how the shape of a grain deviates from a sphere and is thus useful in depicting the drying behaviour of grains by considering the sphericity value with the shape of grain, as the sphericity values for rounded grains are higher than cylindrical shaped grains. The lower sphericity values indicate that the paddy or rice kernels would slide rather than roll on the surface thus play essential role in the designing of grain hoppers (Al-Mahasneh and Rababah 2007).

Volume and surface area

The volume and surface area of paddy and rice grains were found to be significantly different ($p < 0.05$). The volume of paddy grains varied from 25.73 mm³ (*Mushki Tujan*) to 40.43 mm³ (*Kaw Quder*) and that of rice from 15.16 mm³ (*Mushki Budgi*) to 21.46 mm³ (*Kaw Quder*). The surface area for paddy ranged from 4.45 to 6.01 mm² for *Gull Zag* and *Kaw Quder* and of rice was observed to range from 4.01 to 5.41 mm² for *Gull Zag* and *Koshkari*. The surface area to volume ratio can be used for calculating drying time and energy requirements, as the rate of heat and mass transfer increases with increase in surface to volume ratio (Zareiforouh et al. 2011). The volume to surface area called as characteristic length, is an important criterion in

determine the handling of different grains. The volume to surface ratio has an important role in the designing of grain cleaners, aspirators, pneumatic separators and fluidised bed dryers, as it determines the projected area of the grains suspended in turbulent air stream.

Temperature has a significant effect on the physical properties of paddy and rice grains. The transfer of heat into the grain as in case of drying, milling and storage causes simultaneous diffusion of water from the grains to the surrounding air, thereby resulting in different physical properties of grains. Heat transfer at higher temperature leads to the shrinkage of the rice grain and results in internal cracking of the rice kernels. Shrinkage of grains also had a significant effect on reduction of the geometric dimensions of the grains and thus on the volume and surface area of the grains. Among the two types on shrinkages, that are isotropic and anisotropic, it is usually isotropic shrinkage (uniform shrinkage of all the geometric dimensions) that is observed in the paddy and rice grains (Kim and Lee 2012).

Thousand kernel weight, bulk density, true density and porosity

The thousand kernel weight ranged from 20.93 g of (*Mushki Budgi*) to 32.50 g of (*Kaw quder*) for paddy, whereas in brown rice the values ranged from 19.00 to 26.90 g for *Mushki Budgi* and *Koshkari* brown rice cultivars, respectively. Values below 20 g indicates the presence of damaged, immature and shriveled grains, which in turn results in poor milling yield due to breakage. The cultivars having highest equivalent diameter (ED) possess higher values of thousand kernel weight as compared to the cultivars having lesser values of ED (Iraj et al. 2013). The thousand kernel weight showed a decreasing trend with the level of processing from paddy to brown rice (Ozguven and Kubilay 2004).

The bulk density values varied from 620.98 to 478.02 kg/m³ and 750.27 to 872.03 kg/m³ for paddy and brown rice cultivars, respectively. In paddy the highest value was found for *Kamad* and the lowest in *Kaw Kareed*. In case of brown rice, the maximum bulk density was obtained in *Shel Kew* and minimum in *Mushki Tujan*. The internal void space between the husk and the caryopsis is filled with air in case of dry grains, for this reason, the bulk density values of paddy is lower than corresponding brown rice. The low bulk density of *Mushki Budgi*, *Mushki Tujan* and *Kaw Kareed* may be due to the presence of long awns possessed by these cultivars which are bulky and occupies space by keeping paddy grains distant from each other that results in the reduction in the total mass per unit volume occupied by the grains (Alizadeh et al. 2006). The bulk density of the given rice cultivars except *Shel Kew* were

found to be lower than the brown rice variety, *Jyoti* (860 kg/m^3) as reported previously by Pandey et al. (2016). This could be attributed to the greater length (6.7 mm) and thickness (2.2 mm) of the *Jyoti* rice variety as compared to the given rice cultivars. The higher bulk density of *Shel Kew* might be due to greater width (2.91 mm) of its grain. The bulk density of grains is useful in the design of silos and storage bins (Nalladulai et al. 2002).

The respective values of true densities of paddy ranged from 1625 to 1090 kg/m^3 in *Kaw Quder* and *Mushki Budgi*, respectively, while in brown rice cultivars it ranged from 1262.66 to 1464.77 kg/m^3 for *Tel Zag* and *Kaw Kareed*. True density finds application in separating different cereal grains using Pneumatic separators, as seeds of various impurities differ greatly in true density among each other.

The porosity values showed significant difference among different cultivars for paddy and brown rice. Values for porosity ranged from 50.20 to 67.15 in case paddy cultivars of *Mushki Budgi* and *Kaw Quder* and from 31.87 to 48.01 in brown rice cultivars of *Mushki Tujan* and *Tel Zag*. Differences among different cultivars of paddy and brown rice in terms of true and bulk density and porosity may be due to the intrinsic characteristics of different cultivars. The porosity values were found in the same range as revealed for hybrid paddy cultivars of Kashmir but for brown rice from paddy cultivars possessing awns the values were found lesser than those of hybrid ones (Mir et al. 2013).

Angle of repose and static coefficients of friction

The mean values of angle of repose ranged from 46.10° (*Tel Zag*) to 33.67° (*Naaz Bar*) for paddy and 36.20° (*Kaw Quder*) to 28.53° (*Tcheri Bar*) for brown rice. Angle of repose of paddy cultivars was greater than that of brown rice cultivars. Statistical analysis represented significant difference in the angle of repose among different cultivars for paddy and brown rice. The standard value of angle of repose has been reported as 35.83° for paddy, therefore the mean values were greater than the reported values for Tarom, Khazar, Fajr, Nemat and Neda paddy cultivars (Iraj et al. 2013). The grains possessing higher values for the angle of repose may be due to the large size of these grains and their relatively rough surface which reduced flow of the grains on one another easily (Tunde-Akintunde and Akintunde 2007). An interesting fact was the higher angle of repose of traditional rice cultivars as compared to standard reported values due to rougher surface. The angle of repose of these traditional paddy cultivars were found to be lesser than paddy varieties, IR-64 (46°) and *Jyothi* (48°) as reported earlier by Banu et al. (2015).

The static coefficients of friction, as shown in Fig. 1, had been found to differ significantly between the cultivars

for both paddy and brown rice against three different surfaces. The highest average values of the coefficient of static friction against plywood, glass and iron sheet were 0.56, 0.45 and 0.50 for paddy grains while the lowest values were 0.39, 0.26 and 0.33, respectively. Jouki and Khazaei (2012) experimented that the paddy (*Sadri* variety) had coefficients of static friction of 0.50, 0.39 and 0.42 against plywood, glass and galvanized iron sheet surface respectively. The static coefficient of friction values for Kashmiri traditional paddy cultivars were found higher as compared to the *Sadri* variety. For brown rice higher values were observed (0.47, 0.33 and 0.39) while the lower of 0.33, 0.20 and 0.29 for plywood, glass and iron sheet, respectively were observed. The coefficient of static friction decreased from rough to brown rice in all the cultivars against different surface materials. This is justified because the grain surface becomes smoother during the milling operation (Correa et al. 2007) which affirmed that the friction and consequently its coefficient were affected mainly by the nature and type of the surface in contact. The frictional properties like the angle of repose and the coefficient of static friction have been validated by the engineers as important properties dealing with design of seed bins and other storage structures (Vilche et al. 2003).

Fig. 1 Static coefficient of friction of different traditional cultivars of Kashmir (a) paddy (b) rice

Colour characteristics

A significant difference was found in color parameters like L^* , a^* and b^* among the selected rice cultivars (Table 4). L^* values were found to be the highest for *Mushki Budgi* (64.52) and the lowest for *Shel Kew* (43.60). The brown rice of *Mushki Budgi* ($L^* = 64.52$) was found to be the lightest, followed by *Gull Zag* (64.44), whereas the *Shel Kew* ($L^* = 43.60$) was observed to be the darkest while *Kaw Quader* ($a^* = 10.76$) represent the highest values for a^* indicated deep red colored rice kernels followed by *Shel Kew* (9.31) and *Zag* (8.83). *Mushki Tujan* ($b^* = 21.81$) was found to have the highest b^* value followed by *Mushki Budgi* (20.26). The high color values are due to the pigments possessed by these cultivars. These colored cultivars possess antioxidant properties and thus act as functional foods. The difference in color of the rice kernels have been reported due to difference in composition of kernels, genetic makeup and colored pigments in pericarp (Aboubakar et al. 2008). The more colored brown rice kernel required more energy to polishing and are difficult to process to the same degree than less colored kernels (Saikia et al. 2012). Mir et al. (2013) reported the color values of different hybrid brown rice cultivars grown in Kashmir, but the a^* values of some traditional rice cultivars were found higher (twice) and b^* values lesser than that the reported ones. The high colour values are due to pigments possessed by these cultivars. The L^* values of the given rice cultivars were found to greater than that of red coloured *Jyoti* rice variety as reported by Pandey et al. (2016). It had been reported that rice milled at relatively lower temperature possessed higher L values and lower a and b values (Kim and Lee 2012).

Correlations among various physical properties of paddy

Pearson correlation coefficients for relationships among various physical parameters of different paddy cultivars have been shown in Table 5. Surface area was positively correlated with width ($r = 0.96$, $p < 0.05$) and thickness ($r = 0.89$, $p < 0.05$). This is in accordance with the results reported by (Iraj et al. 2013). True density was found to be highly significant and positive correlation with Thousand Kernel Weight ($r = 0.96$, $p < 0.05$) and mean diameter ($r = 0.82$, $p < 0.05$). Similar observations regarding the correlation between true density and grain mass had been reported early. A significant ($p < 0.05$) strong correlations existed between grain width and thickness, equivalent diameter, mean diameter, volume and surface area while a significant ($p < 0.05$) negative correlations was found with bulk density. Thousand kernel weight, width, arithmetic mean diameter and equivalent diameter showed significant ($p < 0.05$) positive correlations with sphericity, surface area, volume, true density, and angle of repose; but negatively correlated with bulk density. Similar relationship had been reported for different minor millets by (Balasubramanian and Viswanathan 2010).

Conclusion

This research concluded with providing information about the physical and engineering properties of different traditional paddy and rice cultivars of high altitude regions of Kashmir (India). Significant differences were observed in the principle dimensions and physical properties among cultivars. The colour parameters of the analyzed rice

Table 5 Pearson correlation coefficients between various physical properties of paddy cultivars

Factors	L	W	T	ED	MD	ASR	SPH	V	SA	TKW	BD	TD	P	AR
L	1.00													
W	−0.33	1.00												
T	−0.12	0.80	1.00											
ED	0.27	0.80	0.84	1.00										
MD	0.32	0.74	0.84	0.99	1.00									
ASR	−0.79	0.83	0.56	0.34	0.27	1.00								
SPH	−0.39	0.43	0.47	0.25	0.33	0.49	1.00							
V	0.28	0.77	0.84	0.98	0.98	0.31	0.24	1.00						
SA	−0.43	0.96	0.89	0.74	0.70	0.86	0.50	0.73	1.00					
TKW	0.40	0.45	0.59	0.73	0.76	0.07	0.28	0.73	0.42	1.00				
BD	0.48	−0.42	−0.18	−0.09	−0.10	−0.58	−0.69	0.00	−0.41	−0.01	1.00			
TD	0.34	0.50	0.73	0.78	0.82	0.12	0.32	0.78	0.52	0.96	−0.02	1.00		
P	−0.06	0.53	0.47	0.49	0.52	0.40	0.61	0.44	0.52	0.68	−0.68	0.69	1.00	
AR	0.02	0.30	0.21	0.29	0.33	0.21	0.53	0.25	0.26	0.20	−0.59	0.20	0.48	1.00

Bold letters indicate stronger Pearson correlation coefficients between the respective parameters

L Length, W width, B breadth, T thickness, ED equivalent diameter, MD mean diameter, ASR aspect ratio, SPH sphericity, V volume, SA surface area, TKW thousand kernel weight, BD bulk density, TD true density, P porosity, AR angle of repose

cultivars were observed to be significantly different from each other. The presence of awns in some paddy cultivars was found to have a significant effect on the physical properties of these cultivars. Results indicated significant differences in the physical properties among various paddy and brown rice cultivars when compared with standard data available in the literature. Thousand kernel weight, width, arithmetic mean diameter and equivalent diameter showed significant ($p < 0.05$) positive correlations with sphericity, surface area, volume, true density, and angle of repose; but negatively correlated with bulk density. These could be helpful in the designing of appropriate processing and handling equipment in order to minimize the post harvest losses.

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