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Physical characteristics of some of the paddy varieties as affected by shelling and milling operations

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ABSTRACT

Properties of material play crux role in process optimization design strategies for the development of equipments for handling, conveying, processing and storage. The improperly developed machinery if applied in any process line results in undesirable effect. Low recovery of quality milled white rice from paddy may thus also be influenced by the process of hulling and milling. The effect of shelling and milling on physical and optical properties of promising Indian long paddy varieties PUSA 1121, Muchhal, Sugandha, Shabnam and Usha were evaluated. The initial level of moisture content of selected paddy varieties was in the range of 11.6 to 13.2% (dry basis). Computer vision as a rapid, consistent and objective evaluation method has been successfully applied in the verification of dimensional properties. Dimensional comparison showed that PUSA 1121 kernel was longest and Usha as shortest rice variety. The result shows significant difference in milling characteristics and PUSA 1121 was found most affected paddy cultivars being longest grain rice variety.

Key words: *rice, paddy, milling, engineering properties, Oryza sativa*

Rice milling is a most gigantic industry in India and estimated to have about 1.36 lakh rice mills in India having 66 % huller mills and 25 % modern rice mills (Anon., 2013). Rice is used as a source of nourishment for over half of the world's population, thus, making it as second most important cereal grain (Bhatia *et al*., 2009). Apart from milled raw and parboiled rice, small amount of rough rice is used for making products like expanded, flaked, popped rice (Deepa and Singh, 2011; Singh and Prasad, 2012) and to a greater extent the broken are used for making rice flour (Prasad *et. al.,* 2012). The rough rice is made edible after removing the husk, bran layer and germ are further removed through the milling process to make the rice palatable, digestible, storable and easy to cook (Deepa and Singh, 2010). No rice variety can commercially be successful unless it possesses high quantity of head rice with minimum breakage of endosperms on milling (Marchezan, 1991; Owens, 2001). Head rice is three quarter or more in length of the whole milled kernels separated from the total milled rice (USDA, 1990). The extent of breakage for extra long rice kernels are much higher and thus the degree of milling affects the head rice recovery. White rice is predominantly a starchy cereal comprised of endosperm portion. About 90% of dry matter of milled rice is starch and the rest are non-starch components like protein, lipids and ash (Juliano 1992) with considerable amount of vitamins like thiamine, niacin, pantothenic acid and some of the important minerals. Rice being invaluable alternative source of carbohydrate is easily digestible and has rare allergic reactions (Prasad *et al.,* 2013). Absence of gluten provides additional benefit and makes rice particularly suitable as an alternative either in full form or as replacement of wheat in bakery products especially suitable for the celiac subjects (Prasad *et al.,* 2010b).

The knowledge of the engineering properties of the agricultural products like cereals, pulses is of fundamental importance for the proper storage procedure and for design facet, manufacturing and operating different equipments used in main processing operations (Silva and Correa, 2000). The physical properties such as dimensional (shape, size, volume and surface area), gravimetric (bulk density, true density and porosity) and frictional properties (angle of repose and static coefficient of friction on different surfaces) for different grains are important (Sahay and Singh, 1994; Ghadge and Prasad, 2012). Studies on engineering properties of various seed grains have been reported by several researchers for rough rice (Arora, 1991), milled rice (Correa *et al*., 2007; Morita and Singh, 1979; Muramatsu *et al*., 2007; Singh *et al.*, 2005) and parboiled rice (Reddy and Chakraverty, 2004). Gravimetric property like true density of raw and processed paddy find applications in the pneumatic handling of material and in the separation of undesirable materials during cleaning process. The static coefficient of friction is used to determine to achieve consistent flow of materials through the chute which is useful to find motor requirements for grain handling and transportation (Ghasemi *et al*., 2008). The angle of repose is important for designing of packaging and storage structure (Guner, 2007).

Information about the effect of hulling and milling on physical properties of rice are limited for Indian rice cultivars (Bhattacharya, 2006). Taking into account the data shortage in the scientific literature in the particular area, therefore aim of this research was considered to evaluate the influence of shelling and milling on physico-optical properties of promising Indian long grain rice cultivars.

MATERIALS AND METHODS

Five paddy varieties namely, Pusa 1121, Muchhal, Sugandha, Shabnam and Usha (Crop year: 2011) were procured from Chaudhary Charan Singh Haryana Agricultural University, Hisar, with an initial moisture content of 11.6 - 13.2% (d.b) (AOAC, 2000). These samples were cleaned to remove stones, dust, iron filings and other unwanted materials and these were stored at refrigerated temperature in polyethylene bags. Rice husker (THU-34A, Satake Co. Ltd. Tokyo, Japan) was used in shelling. About one kilogram paddy in each lot was brought to room temperature and shelled to get the brown rice.

The brown rice kernels (100 g) were milled to an extent of 5% degree of milling in triplicates for selected paddy varieties using single pass rice pearler (BS08A Satake Co. Ltd. Tokyo, Japan) with an automatic timer set to 60 seconds. The rice pearler was thoroughly cleaned after each milling operation by removing the bran and broken rice kernels from the screen and rotor. The polished rice thus obtained was brought to room temperature and subjected to rice grader (Indosaw Industries (P) Ltd., Ambala, India) for separation of head and broken rice. The other powdery portion was considered as bran. Before further analysis, the milled rice was stored in cold room. All these samples were kept in polyethylene bags and stored under refrigerated condition. The samples were weighed just after filling and again prior to analysis in order to insure about negligible moisture migration during storage.

The procedure for the determination of physical properties was adopted as described by Prasad *et al*. (2010c) for chickpea. The linear dimensions of the samples were measured by using three major perpendicular dimensions, length (L), breadth (B) and thickness (T). The physical dimension were also measured manually using dial type vernier caliper (Mitutoyo Corporation, Japan) having least count 0.02 mm. Verification of dimensional characteristics of the samples was carried out using image analysis (Prasad, 2010a; Prasad *et al*., 2012) to ten times higher accuracy and represented at the level of third decimal place.

The geometric mean dimension (D_e) and aspect ratio (R_a) of sample was calculated using the relationship given by Mohsenin (1980) as:

$$D_e = (LBT)^{1/3} \qquad (1)$$

$$R_a = \frac{B}{L} \times 100 \qquad (2)$$

The criteria used to describe the shape of the seed are the sphericity and aspect ratio. Thus, the sphericity (S_p) was accordingly computed (Mohsenin, 1980) as:

$$S_p = \frac{(LBT)^{1/3}}{L} \times 100 \qquad (3)$$

The surface area (S_a) of grains was calculated using the relationship given by McCabe *et al*., (1986) as:

$$S_a = \pi D_e^2 \qquad (4)$$

The weights of the samples were recorded using electronic balance (Ishida Co. Ltd., Japan) to an accuracy of 0.001 g. The bulk density ($\tilde{n}_b$) of the seed sample was evaluated using the methods suggested by Williams *et al*. (1983). The true density ($\tilde{n}_t$) was determined using liquid displacement technique (Shepherd and Bhardwaj, 1986). Toluene was used as liquid in spite of water so as to prevent the absorption during measurement and also to get the benefit of low surface tension of selected solvent (Ogut, 1998). The porosity (å) of seeds was computed from the values of true density ($\tilde{n}_t$) and bulk density ($\tilde{n}_b$) using the following relationship by Mohsenin (1980):

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (5)$$

The angle of repose (ö) was determined using the relationship:

$$\varphi = \tan^{-1}\frac{(2H)}{D} \quad (6)$$

Where, H and D are the height and diameter of the heap in mm.

The static coefficient of friction (ì) was determined for four frictional materials namely glass, galvanized iron sheet, plywood parallel and plywood perpendicular. A plastic cylinder of 50 mm diameter and 60 mm height was placed on an adjustable tilting flat plate faced with the test surface and filled with the sample of about 100 g. The cylinder was raised slightly to avoid touching the surface. The structural surface with the cylinder resting on it was inclined gradually, until the cylinder just started to slide down.

The optical properties of the paddy grain samples were evaluated using the Hunter Colorimeter in terms of L (luminance or brightness), a [red (+) - green (-)] and b [yellow (+) - blue (-)] values.

The physical properties of all paddy varieties as affected by shelling and milling were evaluated by 2-way ANOVA using SPSS 16.0 software with five replications. The least significant difference of milling, variety and interactions was calculated at $P<0.05$.

RESULTS AND DISCUSSION

The brown rice yield from paddy varieties, Pusa 1121, Muchhal, Sughanda, Shabnam and Usha was 78.91±1.20, 78.26±0.72, 77.88±0.98, 77.63±1.04 and 78.98±0.95 %, respectively (Table 1). The overall recovery of milled rice ranged from 72.30±1.29 to 73.16±1.00 %, while the husk and bran obtained as 21.02±0.95 to 22.37±1.04 % and 05.25±0.28 to 05.97±0.37 %, respectively. The obtained results found for milling of paddy are in agreement with the findings of Chauhan *et al.,* (1994).

The variety wise pictorial representation of paddy, brown rice and white rice. Fig. 1 depicts the comparative variations in dimensional characteristics as affected by shelling and milling for the selected paddy varieties. The length, breadth and thickness of rice varieties at different shelling and milling levels varied from 7.128 to 11.831mm, 1.894 to 2.503 mm and 1.603 to 2.043mm from milled rice to paddy grain, respectively (Table 2). PUSA 1121 white rice was found to be the longest kernel length, while milled rice of Usha variety was found to be shortest (7.128±0.197 mm). The significant difference in characteristic of different rice varieties was noticed as affected by shelling and milling. The findings of dimensional characteristics support variety specific dimension changes (Konak *et al*., 2002; Aydin, 2002). Similar findings with lower magnitude in the breadth and thickness characteristics are reflected

Table 1. Hulling and milling characteristics in per cent for five Indian paddy varieties

Milling Parameters (%)	Paddy Variety				
	Pusa 1121	Muchhal	Sugandha	Shabnam	Usha
Brown Rice	78.91±1.20	78.26±0.72	77.88±0.98	77.63±1.04	78.98±0.95
Husk	21.09±1.20	21.74±0.72	22.12±0.98	22.37±1.04	21.02±0.95
White Head Rice	60.19±0.91	60.61±1.23	60.80±1.41	60.46±0.90	60.86±0.74
Brokens	12.74±0.66	12.40±0.58	11.76±0.58	11.84±0.59	12.30±0.47
Bran	05.97±0.37	05.25±0.28	05.32±0.45	05.34±0.28	05.82±0.41
Hulling Recovery	78.91±1.20	78.26±0.72	77.88±0.98	77.63±1.04	78.98±0.95
Overall Recovery	72.93±1.11	73.01±0.81	72.56±1.17	72.30±1.29	73.16±1.00

(Table 2). The geometric mean diameter ranged from 2.878 to 3.811mm. Aspect ratio reflects the relationship between breadth and length of the kernel, found to be varied from 18.919 - 24.574, 22.436 - 30.433 and 22.997 - 32.149 % for paddy, brown rice and white rice, respectively. The sphericity of the paddy grain varied from 31.211 to 43.807%. Surface area was found to be decreased on milling of paddy as the process of milling removed the different layers (Fig. 1).

Table 2. Physical characteristics of five Indian paddy varieties

ProcessingLevel (P)	Variety (V)					CD (P > 0.05)		
	Pusa 1121	Muchhal	Sugandha	Shabnam	Usha			
Length (L), mm								
Paddy	11.458±0.451[b]	11.831±0.326[a]	11.159±0.308[bc]	10.903±0.301[c]	9.921±0.274[d]	P	-	0.118
Brown Rice	8.833±0.481[e]	8.706±0.24[ef]	8.328±0.230[fg]	7.908±0.218[hi]	7.558±0.208[i]	V	-	0.152
White Rice	8.680±0.164[ef]	7.991±0.22[gh]	8.179±0.225[gh]	7.797±0.215[hi]	7.128±0.197[j]	P×V	-	0.265
Breadth (B), mm								
Paddy	2.503±0.116[a]	2.238±0.062[bc]	2.281±0.063[b]	2.192±0.06[cd]	2.438±0.067[a]	P	-	0.022
Brown Rice	1.976±0.050[e]	2.010±0.055[e]	2.046±0.056[e]	2.140±0.059[d]	2.300±0.064[b]	V	-	0.028
White Rice	1.995±0.015[e]	1.987±0.057[e]	2.024±0.053[e]	1.894±0.052[f]	2.292±0.060[b]	P×V	-	0.049
Thickness (T), mm								
Paddy	1.932±0.040[b]	1.901±0.075[b]	1.914±0.022[b]	1.768±0.097[d]	2.043±0.060[a]	P	-	0.037
Brown Rice	1.639±0.016[efg]	1.714±0.022[def]	1.787±0.115[cd]	1.638±0.035[efg]	2.030±0.090[a]	V	-	0.047
White Rice	1.603±0.052[g]	1.699±0.048[defg]	1.733±0.041[de]	1.614±0.058[fg]	1.867±0.155[bc]	P×V	-	0.083
Geometric mean diameter, mm								
Paddy	3.811±0.078[a]	3.692±0.093[b]	3.652±0.080[b]	3.482±0.107[c]	3.670±0.099[b]	P	-	0.031
Brown Rice	3.057±0.044[ef]	3.107±0.068[ef]	3.121±0.070[e]	3.026±0.070[ef]	3.279±0.103[d]	V	-	0.040
White Rice	3.028±0.041[ef]	2.999±0.070[f]	3.061±0.055[ef]	2.878±0.084[g]	3.123±0.132[e]	P×V	-	0.069
Aspect ratio, %								
Paddy	21.865±1.286[f]	18.919±1.342[h]	20.436±1.749[g]	20.103±1.142[g]	24.574±1.784[d]	P	-	0.302
Brown Rice	22.436±1.537[ef]	23.083±1.026[e]	24.566±1.223[d]	27.057±1.195[c]	30.433±1.863[b]	V	-	0.390
White Rice	22.997±0.531[e]	24.870±0.996[d]	24.745±1.978[d]	24.296±1.447[d]	32.149±0.751[a]	P×V	-	0.676
Sphericity, %								
Paddy	33.284±0.861[f]	31.211±0.429[h]	32.730±0.201[fg]	31.936±0.545[gh]	36.987±0.212[c]	P	-	0.358
Brown Rice	34.678±1.487[e]	35.686±0.216[d]	37.487±0.993[bc]	38.273±0.291[b]	43.390±0.416[a]	V	-	0.462
White Rice	34.886±0.520[de]	37.532±0.389[bc]	37.431±0.503[bc]	36.908±0.252[c]	43.807±0.964[a]	P×V	-	0.802
Surface area, mm^2								
Paddy	45.642±1.873[a]	42.847±2.133[b]	41.915±1.831[b]	38.118±2.308[c]	42.328±2.258[b]	P	-	0.650
Brown Rice	29.373±0.852[e]	30.331±1.332[e]	30.611±1.382[e]	28.785±1.324[e]	33.814±2.095[d]	V	-	0.839
White Rice	28.800±0.784[e]	28.265±1.309[e]	29.440±1.057[e]	26.033±1.501[f]	30.688±2.608[e]	P×V	-	1.453
Bulk density, kg m^{-3}								
Paddy	496.29±5.88[h]	347.81±7.37[k]	473.44±4.35[i]	441.60±5.78[j]	550.15±11.46[g]	P	-	5.246
Brown Rice	728.63±2.41[b]	725.12±12.24[b]	702.94±14.96[de]	710.54±13.36[cd]	772.35±11.60[a]	V	-	6.772
White Rice	709.21±1.53[cde]	707.51±14.36[cde]	680.77±8.88[f]	696.98±7.03[e]	719.81±9.39[bc]	P×V	-	11.731
True density, kg m^{-3}								
Paddy	919.27±17.84[i]	1179.74±69.47[g]	1022.22±49.69[h]	1151.96±61.68[g]	1194.44±76.07[g]	P	-	32.130
Brown Rice	2005.13±8.14[b]	1463.09±45.58[e]	1472.53±60.19[e]	1467.08±38.53[e]	1390.45±52.16[f]	V	-	41.480
White Rice	2171.76±24.05[a]	1698.97±67.76[c]	1727.27±82.99[c]	1696.97±66.16[c]	1615.39±70.22[d]	P×V	-	71.846
Porosity, %								
Paddy	45.990±1.532[i]	70.428±2.006[a]	53.596±2.320[fg]	61.591±1.811[cd]	53.784±3.222[fg]	P	-	1.093
Brown Rice	63.661±0.159[c]	50.179±0.944[h]	52.180±2.667[gh]	51.558±0.650[gh]	44.375±2.726[i]	V	-	1.412
White Rice	67.341±0.364[b]	58.251±1.963[e]	60.519±1.844[de]	58.866±1.951[e]	55.392±1.380[f]	P×V	-	2.446
Angle of repose, degree								
Paddy	30.552±0.226[j]	32.215±0.179[i]	35.769±0.145[g]	36.656±0.189[f]	33.653±0.166[h]	P	-	0.166
Brown Rice	33.351±0.260[h]	36.985±0.202[f]	38.337±0.133[e]	39.365±0.146[d]	40.527±0.146[c]	V	-	0.214
White Rice	35.490±0.963[g]	38.474±0.131[e]	44.836±0.110[a]	40.436±0.108[c]	44.350±0.118[b]	P×V	-	0.372

The significant increase in bulk density (Table 2) was noticed on shelling and milling, it may be attributed to removal of different layers; the associated reduction in volume is higher than the corresponding reduction in mass of the grain during shelling and milling (Fig. 1), the magnitude of change of which is varietal specific intrinsic characteristics. The true density of measured samples at different levels of processing varied from 919.27 kg m^{-3} for paddy to 2171.76 kg/m^3 for white rice of PUSA 1121. This shows maximum

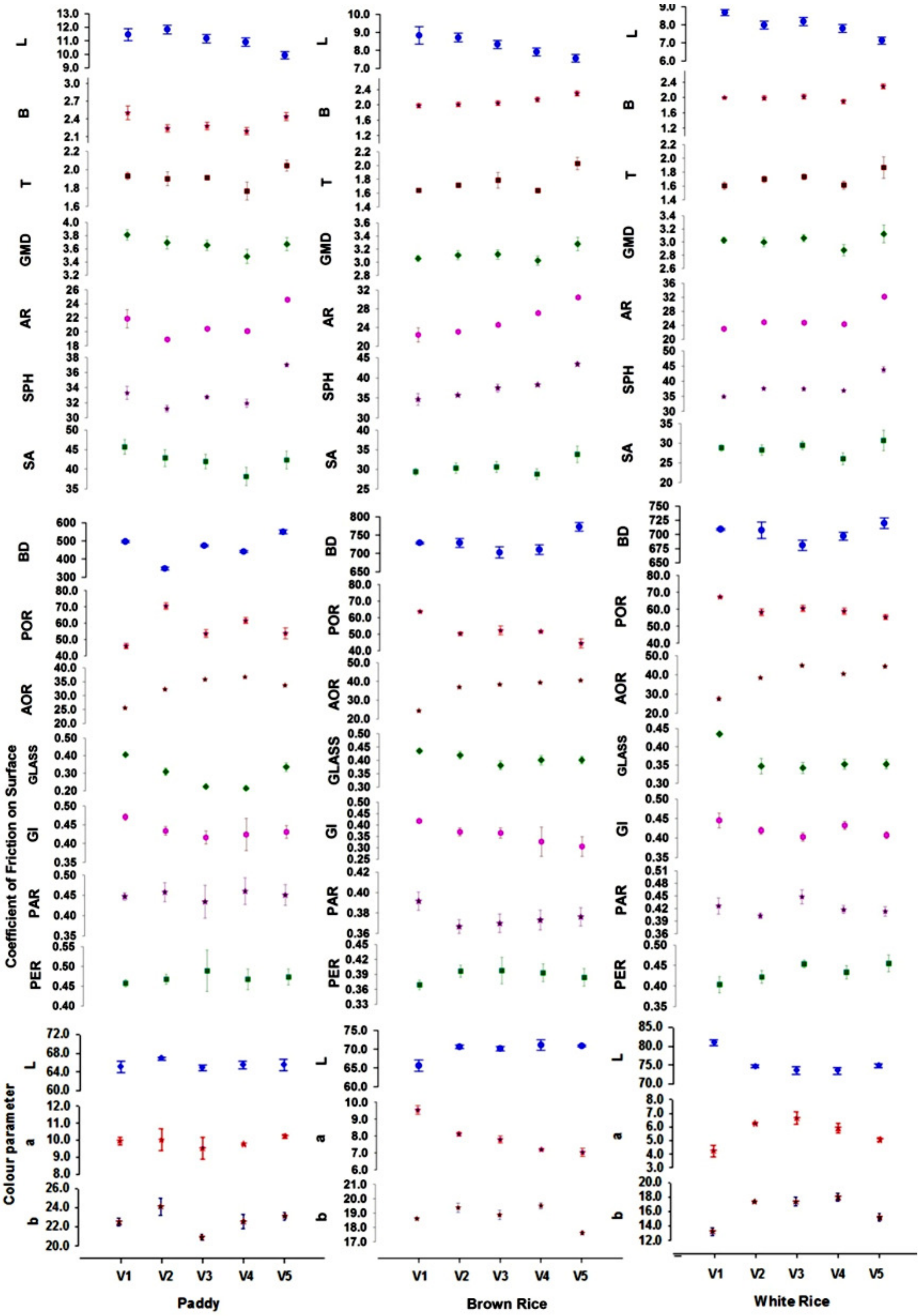

Fig. 1. **Comparative physical characteristics of five Indian paddy varieties studied**
(V1- Pusa 1121, V2-Muchhal, V3-Sugandha, V4-Shabnam, V5-Usha)

Table 3. Coefficient of friction of five Indian paddy varieties

Processing Level (P)	Variety (V)					CD at 5%		
	Pusa 1121	Muchhal	Sugandha	Shabnam	Usha			
Coefficient of friction on glass								
Paddy	0.405±0.006b	0.309±0.020e	0.224±0.012f	0.215±0.010f	0.335±0.024d	P	-	0.008
Brown Rice	0.435±0.007a	0.419±0.014ab	0.381±0.017c	0.401±0.017b	0.400±0.014b	V	-	0.010
White Rice	0.431±0.004a	0.347±0.021d	0.342±0.015d	0.352±0.014d	0.349±0.013d	P×V	-	0.019
Coefficient of friction on galvanized iron sheet								
Paddy	0.471±0.009a	0.434±0.011bc	0.416±0.017bc	0.432±0.043bc	0.431±0.017bc	P	-	0.015
Brown Rice	0.417±0.008bc	0.370±0.018de	0.365±0.023e	0.327±0.064f	0.306±0.043f	V	-	0.019
White Rice	0.445±0.019ab	0.419±0.009bc	0.402±0.011cd	0.424±0.011bc	0.407±0.008bc	P×V	-	0.034
Coefficient of friction on plywood parallel								
Paddy	0.447±0.009ab	0.458±0.024a	0.434±0.041abc	0.460±0.033a	0.451±0.026ab	P	-	0.010
Brown Rice	0.392±0.010ef	0.367±0.007f	0.370±0.009f	0.373±0.010f	0.376±0.009f	V	-	0.013
White Rice	0.426±0.019bcd	0.402±0.006de	0.448±0.017ab	0.417±0.014cde	0.413±0.011cde	P×V	-	0.024
Coefficient of friction on plywood perpendicular								
Paddy	0.458±0.009bc	0.468±0.015ab	0.489±0.053a	0.467±0.026ab	0.473±0.020ab	P	-	0.012
Brown Rice	0.369±0.011g	0.396±0.012efg	0.398±0.026efg	0.393±0.018efg	0.384±0.018fg	V	-	0.015
White Rice	0.403±0.020ef	0.422±0.015de	0.454±0.009bc	0.433±0.016cd	0.455±0.021bc	P×V	-	0.024

difference between the true densities as affected by the shelling and milling, reflect husk and endosperm as loosely bound to each other. Similar trends were noticed for other varieties elsewhere (Correa *et al*., 2007; Muramatsu *et al*., 2007 and Singh *et al*., 2005). The porosity depends on the bulk as well as on true density and further the magnitude. It could be attributed to the spikelet feature of the rice husk, allowing more void space in the bulk grains and when processed, the void space reduced and consequently the porosity (Table 2).

The experimental value of angle of repose was ranging from 30.552 to 35.490, 32.215 to 38.474, 35.769 to 44.836, 36.656 to 40.436 and 33.653 to 44.350° for Pusa 1121, Muchhal, Sughanda, Shabnam and Usha, respectively (Table 2). Among all varieties, the angle of repose affected by the shelling and milling showed the highest angle of repose values for milled rice. The static coefficient of friction on different surfaces for rice grain was found to lie between 0.215 and 0.489 (Table 3). The resemble trend of static friction with

Table 4. Optical properties of five Indian paddy varieties

Processing Level (P)	Variety (V)					CD at 5%		
	Pusa 1121	Muchhal	Sugandha	Shabnam	Usha			
L								
Paddy	65.109±1.202e	66.857±0.285d	64.891±0.575e	65.445±0.826de	65.443±1.147de	P	-	0.598
Brown Rice	65.609±1.544de	70.651±0.445c	70.135±0.579c	71.070±1.393c	70.882±0.238c	V	-	0.773
White Rice	80.920±0.660a	74.588±0.397b	73.589±1.075b	73.481±0.837b	74.843±0.453b	P×V	-	1.339
a								
Paddy	9.951±0.236ab	10.013±0.631ab	9.523±0.651b	9.765±0.060ab	10.243±0.110a	P	-	0.247
Brown Rice	9.532±0.258b	8.115±0.116c	7.784±0.207c	7.198±0.050d	7.030±0.247d	V	-	0.319
White Rice	4.242±0.428h	6.255±0.044ef	6.646±0.435de	5.907±0.351f	5.065±0.153g	P×V	-	0.553
b								
Paddy	22.479±0.403b	24.112±0.896a	20.865±0.292c	22.541±0.765b	23.113±0.398b	P	-	0.317
Brown Rice	18.606±0.079ef	19.370±0.316de	18.875±0.324de	19.511±0.204d	17.620±0.132g	V	-	0.409
White Rice	13.240±0.516i	17.290±0.182g	17.321±0.576g	17.951±0.506fg	15.150±0.514h	P×V	-	0.709

shelling and milling (Correa *et al*., 2007; Ghasemi *et al*., 2008). This was due to the fact that the husk formed mostly of cellulosic and fibrous tissue and is covered with very hard glass-like spines.

The L, a, and b values used to represent colour of the materials was found to be ranged from 65.109±1.202 to 0.920±0.660, 4.242±0.428 to 10.243±0.110 and 13.240±0.516 to 24.112±0.896, respectively (Table 4). Significant increase in the L value reflects that on milling brightness improves with the decrease in both red and yellow colour attributes (Fig. 1).

The promising basmati rice varieties PUSA 1121 was found to be the longest grain with substantial more loss of grain during milling as compared to other rice varieties. The characteristic differences in the physico-optical characteristics for varietal dependent level of processing among paddy, brown rice and white rice exists. This may pave the way to use the physical characteristics clubbed with optical characteristics to identify the variety as well as in the development of equipments.

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