CHAPTER – 2

SELECTION AND CHARACTERIZATION OF PADDY VARIETY

2.1 INTRODUCTION

Paddy (*Oryza sativa* L.) is a widely cultivated cereal crop of the family Gramineae. The paddy production in India has witnessed more than three folds increase in past 50 years and contributing more than one fifth of total paddy production in world. The present production figure of paddy in India is 152.6 MMT (FAO, 2013). Among 23 recognized species of *Oryza* in the world, *sativa* is widely cultivated mainly due to economic reasons with limited cultivation of *glaberrima* on ritual context specifically grown in West Africa. Also, the desired attributes such as disease and insect resistances with higher climatic adaptability of other wild species have been explored to transfer the desired characteristics to cultivated species through inter breeding for the development of diverse improved paddy variants. The diversities among cultivars existed for kernel size, shape, cooking, color, flavor, milling, nutritive value and their ability to make different rice products. Apart from calorie and protein, rice being staple food also supply to some extent vitamins and minerals in the poor-man’s diet.

Paddy undergoes different level of processing prior to its conversion into usable form (Singh and Prasad, 2012) for various products preparations (Prasad *et al.*, 2013). The knowledge of physical properties comprised of dimensional, gravimetric and frictional characteristics are thus necessary in the design of equipment for their effective implementation in various operations (Mohsenin, 1980; Sahay and Singh, 1994; Ghadge and Prasad, 2012) starting from harvesting till their conversion into
edible form mainly as white rice or rice powder (Prasad et al., 2012). Genetic diversity is one of the important tools to qualify genetic variability in both cross and self-pollinated crops. The obtained data on opto-physical properties may be utilized in the development of equipments related to direct seeded rice (DSR) technology in order to have an associated potential benefits of labour, water (20-25%), and cost of cultivation (Kamboj et al., 2012).

Multivariate statistical methods have been applied for the classification of paddy genotypes based on coherent physical and optical characteristics in order to reduce dimensionality problems. Principal component analysis (PCA) and cluster analysis (CA) as multivariate statistics are often employed purposely (Kara, 2009) to get the relationships among parameters of the original data matrix (Kosa et al., 2001). The multivariate analysis has successfully been applied by the author in characterization of okra genotypes (Sharma and Prasad, 2010a; Prasad and Sharma, 2012).

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).

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.

Comparative characteristics of Indian promising paddy varieties for their classification based on physical and optical properties are yet not available. Information about the effect of hulling and milling on physical properties of rice is limited for Indian rice cultivars (Bhattacharya et al., 2006). Hence, this research objective was undertaken with the following sub-heads:

1. To determine the physical and optical properties of paddy in order to classify it based on the chemo-metric approach supported by clustering technique of multivariate analysis.

2. To evaluate the influence of shelling and milling on physico-optical properties of promising Indian long grain paddy cultivars.

2.2 MATERIALS AND METHODS

Twenty two cultivars of paddy kernels were procured from different agro climatic regions of India (Table 2.1). The acquired cultivars of paddy were cleaned in an air classifier to remove the foreign matter, broken and immature kernels. The initial moisture content of paddy cultivars was determined as per standard method
(AOAC, 1990) and found to vary between 7.89±0.37 to 14.15±0.28% (dry weight basis).

The identified separate cluster formed by the long grain paddy varieties (Pusa 1121, Muchhal, Sugandha, Shabnam and Usha) in multivariate analysis were selected for further evaluating the influence of shelling and milling on physico-optical properties. The initial moisture content of the selected paddy kernels were in the range of 11.6 - 13.2% (db) (AOAC, 2000). Before subjecting the kernels for shelling and milling, they 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, 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.
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<td>Usha</td>
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2.2.1 Physical Properties

The dimensional characteristics were evaluated for three major perpendicular dimensions, length (L), breadth (B) and thickness (T). The dimensions were measured manually using dial type vernier caliper (Mitutoyo Corporation, Japan) with least count of 0.02 mm.

The geometric mean dimension (GMD) and aspect ratio (AR) of sample were assessed using the relationship given by Mohsenin (1980) as:

\[ GMD = (LBT)^{1/3} \quad (2.1) \]

\[ AR = \frac{B}{L} \times 100 \quad (2.2) \]

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

\[ SPH = \left(\frac{LBT}{L}\right)^{1/3} \times 100 \quad (2.3) \]

The surface area (SA) of paddy kernel was evaluated using the relationship given by McCabe et al., (1986) as:

\[ SA = \pi(GMD)^2 \quad (2.4) \]

The weight of paddy samples was recorded using electronic balance (Ishida Co. Ltd., Japan) to an accuracy of 0.001 g. The bulk density (BD) of the seed sample was evaluated using the methods suggested by Williams et al., (1983). The true density (TD) was determined using liquid displacement technique (Shepherd and Bhardwaj, 1986). Toluene as liquid was used in spite of water, to prevent absorption and also to get the benefit of low surface tension (Ogut, 1998). The porosity (POR) of seeds was computed from the values of true density and bulk density using the following relationship by Mohsenin (1980):
The angle of repose (AOR) was determined using the relationship:

\[
AOR = \tan^{-1} \frac{(2H)}{D}
\]  

(2.6)

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

The static coefficient of friction (COF) was determined for four frictional surfaces namely glass (COFG), galvanized iron sheet (COFGI), plywood surfaces with horizontal movement (COFPAR) and vertical movement (COFPER). 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 nearly 100 g sample. The cylinder was raised slightly to avoid touching the surface. The structural surface with material filled cylinder on it was inclined gradually, until the cylinder just started to slide.

2.2.2 Optical Properties

The optical characteristics of the paddy samples were evaluated using the Hunter Colorimeter (Gretag Macbeth, Model No. i5, USA) in terms of l, a, b and \( \Delta E \) values, where, l corresponds to the luminance or brightness and a, b to the chromaticity. ‘a’ value particularly represents (Figure 2.1) the red - green component from positive to negative values; ‘b’ value represents the yellow - blue component in similar ways (Prasad et al., 2010a; Prasad et al., 2010b). Total color difference (\( \Delta E \)) is the measure of modulus of the distance vector between the reference color values and the actual color coordinates. The total color difference indicates the color difference from the standard plate or the reference sample color (Rhim et al., 1999), which was evaluated as:

\[
\Delta E = \sqrt{(l_0 - l)^2 + (a_0 - a)^2 + (b_0 - b)^2}
\]  

(2.7)

Where, \( l_0, a_0 \) and \( b_0 \) represented the least observed color values among the selected paddy cultivars. The total color difference can be used for the analytical
classification on optical basis as small (1.5 < ∆E), distinct (1.5 < ∆E < 3) and very distinct (∆E > 3) color difference (Adekunte et al., 2010).

![Hunter color lab space](image)

**Figure 2.1** Hunter color lab space

### 2.2.3 Statistical analysis

In order to determine any statistically significant effects prevailed due to paddy cultivars, analysis of variance (ANOVA) was carried out and critical difference (CD) at P≤0.05 was determined using SPSS 16.0 software with five replications. The data were presented as mean ± standard deviation. Descriptive statistics including the means of each attributes were determined and represented graphically for assessing the varietal performance and dependent separations.

Principal components analysis (PCA) and hierarchical cluster analysis (CA) for multivariate data were statistically analysed using MINITAB v 13.2 and Microsoft Excel v 2000. The principal component and hierarchical cluster analyses provided the characteristic patterns to classify the selected 22 paddy cultivars. Clustering of the
samples was done according to Ward (1963) based on minimizing the loss of information from joining two clusters (Sharma and Prasad, 2010a; Sharma and Prasad, 2010b).

2.3 RESULTS AND DISCUSSION

2.3.1 Physical Properties

The comparative characteristic variability of selected twenty two paddy cultivars (Figure 2.2) with their overall individual response with respect to their mean is presented in Figures 2.3 and 2.4. The analysis of variance (ANOVA) revealed that the differences in selected cultivars were significant for all the attributes indicating the presence of associated variability among them (p≤0.05).

Figure 2.2 Charged coupled device snapshot showing selected paddy cultivars
The length (L), breadth (B) and thickness (T) of paddy cultivars varied from 8.10±0.40 to 11.83±0.40 mm, 2.19±0.08 to 3.06±0.19 mm and 1.77±0.11 to 2.20±0.06 mm, respectively (Figure 2.3). The comparison of dimensional data with existing work on paddy can play a vital role in machine design and thus be sufficient in making symmetrical projections towards process equipment adaptation (Mohsenin, 1980). The geometric mean diameter (GMD) integrates three major dimensional parameters, found to vary from 3.46±0.01 to 3.85±0.14 mm. The aspect ratio (AR) and sphericity (SPH) of the samples varied in the range of 18.92±0.00 to 36.154±0.68% and 31.16±0.58 to 45.48±0.92%, respectively (Figure 2.3). Lower values of sphericity with intermediate value of aspect ratio suggest that the paddy tend towards a cylindrical shape rather spherical. Thus indicate a likely difficulty in getting the kernel to roll than sliding on surface. This tendency of sliding is necessary in the design of hoppers or sowing equipment. As evident the surface area (SA) of the paddy kernels ranged from 37.68±0.28 to 46.67±3.43 mm$^2$, is a relevant tool in determining the material shape (Figure 2.3). The dimensional characteristics of the selected paddy cultivars significantly differ (p≤0.05) to each other, support the results reported by Reddy and Chakraverty (2004).

The significant (p≤0.05) difference in bulk density (BD) 323.86±2.28 to 612.13±11.71 kg/m$^3$ and true density (TD) 756.53±3.10 to 1521.74±3.07 kg/m$^3$ (Figure 2.3) have been found also evident from the work of Correa et al., (2007); Muramatsu et al., (2007) and Singh et al., (2005). Higher level of porosity (POR) ranged from 46.42±1.68 to 75.17±0.08% has indicated the dependency on bulk and true densities of material. The frictional characteristics for paddy cultivars found to have significant difference. The experimental values of angle of repose (AOR) ranged from 30.56±0.29° to 43.81±2.79° (Figure 2.4).
Figure 2.3 Dimensional and gravimetric properties of selected paddy cultivars
Figure 2.4  Frictional and optical properties of selected paddy cultivars
Similar trends have been reported by Ghasemi et al., (2008) for emptying angle of repose for rough rice. The coefficient of friction (COF) was found to be minimum for glass surface (COFG) and maximum for plywood surface vertically aligned (Figure 2.4). The differences in the values may be due to the fact that the roughness of the material used for determining the coefficient of friction (Correa et al., 2007). The frictional characteristics are thus having imperative role in the food grain processing, particularly in the designing of the hopper and sowing equipment applied for the purpose of direct seeded rice technology.

2.3.2 Optical Properties

The optical properties, l, a and b values of the samples lie in the range 55.33±2.08 to 68.67±5.13, 4.00±2.92 to 10.24±0.11 and 20.87±0.29 to 31.33±2.31, respectively (Figure 2.4). As the value of total color difference (ΔE) varied from 12.23±4.86 to 22.13±4.64 further confirms the existence of very distinct color difference (Adekunte et al., 2010) with variety specific associated characteristic variability (p≤0.05) in distinguishing on the basis of considered parameter.

2.3.3 Multivariate analysis

The correlation matrix of physical and optical characteristics spread over dimensional (seven), gravimetric (three), frictional (five) and optical (four) attributes are shown in Table 2.2. Nearly, 80 % of the correlation coefficients in the matrix are over 0.20 (Table 2.2). Kernel length was observed having positive significant correlation with optical parameters (l, a, ΔE) whereas negative correlation with dimensional (breadth, sphericity, aspect ratio, thickness), optical (b value) and frictional (Angle of Repose, AOR) attributes.
### Table 2.2  Correlation matrix of variable properties of paddy cultivars

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<tr>
<th>Variables</th>
<th>B</th>
<th>T</th>
<th>GMD</th>
<th>SA</th>
<th>AR</th>
<th>SPH</th>
<th>BD</th>
<th>TD</th>
<th>POR</th>
<th>COFG</th>
<th>COFPER</th>
<th>COFPAR</th>
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<th>l</th>
<th>a</th>
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<td>0.24</td>
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<tr>
<td>AOR</td>
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<td>-0.21</td>
<td>0.36</td>
<td>-0.11</td>
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<td>l</td>
<td>-0.23</td>
<td>-0.33</td>
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<tr>
<td>a</td>
<td>-0.49</td>
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</table>
The strong correlation is indicative for the cultivar associative character towards longer kernel length and the feeble correlation vice-versa. The results are in agreement with the physical properties of white rice reported elsewhere (Bhatia et al., 2009).

The data set of the observed measurements was subjected to principal component analysis (PCA), which has eliminated the prevailed variations of highly inter-correlated nature. The initial statistics of Eigen analysis is given in Table 2.3. It can be seen that three principal components (PCs) appeared to account for 79.36% of the total variance in the data. According to Kaiser Criterion (Kaiser, 1960), only the first four PCs could be retained because the Eigen values of more than one to reduced dimensionality descriptor space to four. The descriptors were represented graphically in form of loading plot for three components (Figure 2.5).

<table>
<thead>
<tr>
<th>No.</th>
<th>Eigen value</th>
<th>Individual Percent</th>
<th>Cumulative Percent</th>
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<tr>
<td>1</td>
<td>7.524</td>
<td>39.60</td>
<td>39.60</td>
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<td>2</td>
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<td>3</td>
<td>2.075</td>
<td>10.92</td>
<td>79.36</td>
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<tr>
<td>4</td>
<td>1.252</td>
<td>6.59</td>
<td>85.96</td>
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<tr>
<td>5</td>
<td>0.722</td>
<td>3.80</td>
<td>89.75</td>
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<td>0.663</td>
<td>3.49</td>
<td>93.25</td>
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<td>7</td>
<td>0.447</td>
<td>2.35</td>
<td>95.60</td>
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<tr>
<td>8</td>
<td>0.330</td>
<td>1.74</td>
<td>97.33</td>
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<tr>
<td>9</td>
<td>0.228</td>
<td>1.20</td>
<td>98.53</td>
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<tr>
<td>10</td>
<td>0.152</td>
<td>0.80</td>
<td>99.33</td>
</tr>
<tr>
<td>11</td>
<td>0.083</td>
<td>0.44</td>
<td>99.77</td>
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<tr>
<td>12</td>
<td>0.021</td>
<td>0.11</td>
<td>99.88</td>
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<tr>
<td>13</td>
<td>0.010</td>
<td>0.05</td>
<td>99.93</td>
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<tr>
<td>14</td>
<td>0.006</td>
<td>0.03</td>
<td>99.97</td>
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<tr>
<td>15</td>
<td>0.004</td>
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<td>17</td>
<td>0.000</td>
<td>0.00</td>
<td>100.00</td>
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<tr>
<td>18</td>
<td>0.000</td>
<td>0.00</td>
<td>100.00</td>
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</tbody>
</table>
The loading of components on principal axes indicated the presence of variability among the selected paddy cultivars (Figure 2.5). To study the prevailed pattern for the measured attributes and to categorize factors that are substantively meaningful, chemo-metric approach was applied. It can be seen that the first component explaining 39.60% of variance is highly correlated both positively (porosity) and negatively (dimensional properties, coefficient of friction and other gravimetric properties). Thus, it classifies and distinguishes the score of paddy cultivars on the basis of these components. The second principal component explaining 28.84% of total variance is highly correlated with most of the observed parameters leaving the gravimetric attributes. While, the third component has explained only 10.92% of total variance and is loaded with mainly the optical attributes and the mass per unit volume occupied by different paddy cultivars as represented in terms of true density (Figure 2.3).

Figure 2.5 illustrates the biplot of scores and loadings on the three principal components for the observed parameters of paddy cultivars. The biplot of principal component 1 (PC1) and principal component 2 (PC2) shows the separation of the paddy cultivars according to their respective scores. First quadrant of the plot contains samples having positive PC1 and PC2 scores. The cultivars forming a distinct cluster with five cultivars namely Muchhal (11), Pusa 1121 (14), Shabnam (17), Sugandha (21) and Usha (22) are found loaded with the length and color difference (ΔE) attributes (Figure 2.5). Another distinct cluster formed by cultivars Jehlum (10), Shalimar 1 (18), Shalimar 2 (19) and Shalimar 3 (20), the short bold rice kernel characteristics and occupied their position in third quadrant in principal space (Figure 2.5). The remaining 13 cultivars have formed a separate cluster and occupied their place in the fourth quadrant in principal space (Figure 2.5).
Figure 2.5  Biplot for paddy cultivars on principal axes 1, 2 and 3

A graphical depiction of classification based on measured characteristics of selected paddy cultivars was obtained by means of cluster analysis (CA) of standardized compositions using Ward’s method (Ward, 1963) as an amalgamation rule and squared Euclidean distances as the measure of proximity between samples. A
dendogram is shown in Figure 2.6. As a result of applying CA to the principal component score matrix, the paddy cultivars were grouped into three different clusters (Table 2.4) supporting the findings obtained using principal component analysis. It was revealed that clusters I, II and III have 5, 4 and 13 cultivars, respectively. The formed first cluster represents mainly the long grain rice varieties (Singh and Prasad, 2013a) and thus found susceptible to breakage during milling (Singh and Prasad, 2012). Clustering pattern of paddy cultivars reveals considerable characteristic diversity among themselves pertaining basically on the attributes of dimensional and total color difference characteristics by occupying three clusters. Thus the above characterizations of paddy cultivars on the basis of dissimilarity in scores with respect to extracted principal components justify the existence of variability and may thus be used varietal improvement program with the development of equipment pertaining to the processing and agricultural purposes.

**Figure 2.6**  Dendogram of Cluster Analysis for selected paddy cultivars
Table 2.4  Distribution of 22 paddy cultivars into three clusters

<table>
<thead>
<tr>
<th>Cluster No.</th>
<th>Paddy cultivars in different cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Muchhal (11), Pusa 1121 (14), Shabnam (17), Sugandha (21) and Usha (22)</td>
</tr>
<tr>
<td>II</td>
<td>Jehlum (10), Shalimar 1 (18), Shalimar 2 (19) and Shalimar 3 (20)</td>
</tr>
<tr>
<td>III</td>
<td>BR 4-10 (1), CSR 10 (2), Haryana Mahak 11 (3), HBC 19 (4), HKR 95-157 (5), HKR 95-407 (6), HKR 99-66 (7), HKR H7 (8), IR 64 (9), Palman 579 (12), PAU 201 (13), Pusa Basmati (15) and Pusa Sugandh (16)</td>
</tr>
</tbody>
</table>

2.3.4 Hulling and milling characteristics

Table 2.5 represents the brown rice yield of five selected long grain paddy varieties, Pusa 1121, Muchhal, Sughanda, Shabnam and Usha as 78.91±1.20, 78.26±0.72, 77.88±0.98, 77.63±1.04 and 78.98±0.95 %, respectively. 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.

Table 2.5  Hulling and milling characteristics for five Indian paddy varieties

<table>
<thead>
<tr>
<th>Milling Parameters (%)</th>
<th>Paddy Variety</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pusa 1121</td>
</tr>
<tr>
<td>Brown Rice</td>
<td>78.91±1.20</td>
</tr>
<tr>
<td>Husk</td>
<td>21.09±1.20</td>
</tr>
<tr>
<td>White Head Rice</td>
<td>60.19±0.91</td>
</tr>
<tr>
<td>Brokens</td>
<td>12.74±0.66</td>
</tr>
<tr>
<td>Bran</td>
<td>05.97±0.37</td>
</tr>
<tr>
<td>Hulling Recovery</td>
<td>78.91±1.20</td>
</tr>
<tr>
<td>Overall Recovery</td>
<td>72.93±1.11</td>
</tr>
</tbody>
</table>
2.3.5 Effect of milling on physico-optical characteristics

Figure 2.7 shows the variety wise pictorial representation of paddy, brown rice and white rice. Figure 2.8 depicts the comparative variations in dimensional characteristics as affected by shelling and milling for the selected paddy varieties.

![Figure 2.7 Image of five Indian paddy varieties](image)

The length, breadth and thickness of rice varieties at different shelling and milling levels varied from 7.13 to 11.83 mm, 1.89 to 2.50 mm and 1.60 to 2.04 mm from milled rice to paddy grain, respectively (Table 2.6). Pusa 1121 white rice was found to be the longest kernel length, while milled rice of Usha variety was found to be shortest (7.13±0.19 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 2.6). The geometric mean diameter ranged from 2.88 to 3.81 mm. Aspect ratio reflects the relationship between breadth and length of the kernel, found to be varied from 18.92 to 24.57, 22.44 to 30.43 and
22.99 to 32.15 % for paddy, brown rice and white rice, respectively. The sphericity of the paddy grain varied from 31.21 to 43.81 %. Surface area was found to be decreased on milling of paddy as the process of milling removed the different layers (Figure 2.8). The significant increase in bulk density (Table 2.6) 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 (Figure 2.8), 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 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; 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 2.6).

The experimental value of angle of repose was ranged from 30.55 to 35.49, 32.22 to 38.47, 35.77 to 44.84, 36.66 to 40.44 and 33.65 to 44.35° for Pusa 1121, Muchhal, Sughanda, Shabnam and Usha, respectively (Table 2.6). 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 2.7). The resemble trend of static friction with 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.
Table 2.6  Physical characteristics of five Indian paddy varieties

<table>
<thead>
<tr>
<th>Processing Level (P)</th>
<th>Variety (V)</th>
<th>Length (L), mm</th>
<th>Breadth (B), mm</th>
<th>Thickness (T), mm</th>
<th>Geometric mean diameter, mm</th>
<th>Aspect ratio, %</th>
<th>Sphericity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pusa 1121</td>
<td>Muchhal</td>
<td>Sugandha</td>
<td>Shabnam</td>
<td>Usha</td>
<td>CD at 5%</td>
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<tr>
<td>Paddy</td>
<td>11.46±0.45&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.83±0.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.16±0.31&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>10.90±0.30&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.92±0.27&lt;sup&gt;d&lt;/sup&gt;</td>
<td>P - 0.118</td>
<td></td>
</tr>
<tr>
<td>Brown Rice</td>
<td>8.83±0.48&lt;sup&gt;e&lt;/sup&gt;</td>
<td>8.71±0.24&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>8.33±0.23&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>7.91±0.22&lt;sup&gt;hi&lt;/sup&gt;</td>
<td>7.56±0.21&lt;sup&gt;i&lt;/sup&gt;</td>
<td>V - 0.152</td>
<td></td>
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<tr>
<td>White Rice</td>
<td>8.68±0.16&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>7.99±0.22&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.18±0.23&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.80±0.22&lt;sup&gt;hi&lt;/sup&gt;</td>
<td>7.13±0.20&lt;sup&gt;ij&lt;/sup&gt;</td>
<td>P×V - 0.265</td>
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<tr>
<td>Paddy</td>
<td>2.50±0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.238±0.06&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>2.28±0.06&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>2.19±0.06&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>2.44±0.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P - 0.022</td>
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<tr>
<td>Brown Rice</td>
<td>1.98±0.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.010±0.05&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.05±0.06&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.14±0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.30±0.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>V - 0.028</td>
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<td>White Rice</td>
<td>1.99±0.02&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1.987±0.06&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.02±0.05&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1.89±0.05&lt;sup&gt;f&lt;/sup&gt;</td>
<td>2.29±0.06&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Paddy</td>
<td>3.81±0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.69±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>3.48±0.11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.67±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Brown Rice</td>
<td>3.06±0.04&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>3.11±0.07&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>3.12±0.07&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>3.03±0.07&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>3.28±0.10&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>White Rice</td>
<td>3.03±0.04&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>2.99±0.07&lt;sup&gt;f&lt;/sup&gt;</td>
<td>3.06±0.05&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>2.88±0.08&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>3.12±0.13&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>P×V - 0.069</td>
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<tr>
<td>Paddy</td>
<td>21.86±1.29&lt;sup&gt;f&lt;/sup&gt;</td>
<td>18.92±1.34&lt;sup&gt;h&lt;/sup&gt;</td>
<td>20.44±1.75&lt;sup&gt;g&lt;/sup&gt;</td>
<td>20.10±1.14&lt;sup&gt;g&lt;/sup&gt;</td>
<td>24.57±1.78&lt;sup&gt;d&lt;/sup&gt;</td>
<td>P - 0.302</td>
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<tr>
<td>Brown Rice</td>
<td>22.44±1.54&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>23.08±1.03&lt;sup&gt;e&lt;/sup&gt;</td>
<td>24.57±1.22&lt;sup&gt;d&lt;/sup&gt;</td>
<td>27.06±1.19&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>30.43±1.86&lt;sup&gt;b&lt;/sup&gt;</td>
<td>V - 0.390</td>
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<tr>
<td>White Rice</td>
<td>22.99±0.53&lt;sup&gt;e&lt;/sup&gt;</td>
<td>24.87±0.99&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>24.75±1.98&lt;sup&gt;d&lt;/sup&gt;</td>
<td>24.30±1.45&lt;sup&gt;d&lt;/sup&gt;</td>
<td>32.15±0.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P×V - 0.676</td>
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<tr>
<td>Paddy</td>
<td>33.28±0.86&lt;sup&gt;f&lt;/sup&gt;</td>
<td>31.21±0.43&lt;sup&gt;h&lt;/sup&gt;</td>
<td>32.73±0.20&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>31.94±0.55&lt;sup&gt;dh&lt;/sup&gt;</td>
<td>36.99±0.21&lt;sup&gt;c&lt;/sup&gt;</td>
<td>P - 0.358</td>
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<tr>
<td>Brown Rice</td>
<td>34.68±1.49&lt;sup&gt;e&lt;/sup&gt;</td>
<td>35.69±0.22&lt;sup&gt;d&lt;/sup&gt;</td>
<td>37.49±0.99&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>38.27±0.29&lt;sup&gt;b&lt;/sup&gt;</td>
<td>43.39±0.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>V - 0.462</td>
<td></td>
</tr>
<tr>
<td>White Rice</td>
<td>34.89±0.52&lt;sup&gt;de&lt;/sup&gt;</td>
<td>37.53±0.39&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>37.43±0.50&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>36.91±0.25&lt;sup&gt;c&lt;/sup&gt;</td>
<td>43.81±0.96&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P×V - 0.802</td>
<td></td>
</tr>
</tbody>
</table>

…….continued
### Processing Level (P) × Variety (V) × CD at 5%

<table>
<thead>
<tr>
<th>Processing Level (P)</th>
<th>Variety (V)</th>
<th>Surface area, mm²</th>
<th>Bulk density, kg m⁻³</th>
<th>True density, kg m⁻³</th>
<th>Porosity, %</th>
<th>Angle of repose, degree</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paddy</strong></td>
<td>Pusa 1121</td>
<td>45.64±1.87ᵃ</td>
<td>41.92±1.83ᵇ</td>
<td>42.33±2.26ᵇ</td>
<td>P - 0.650</td>
<td>30.55±0.23ᶠ</td>
</tr>
<tr>
<td></td>
<td>Muchhal</td>
<td>42.85±2.13ᵇ</td>
<td>38.12±2.31ᶜ</td>
<td>33.81±2.09ᵈ</td>
<td>V - 0.839</td>
<td>33.35±0.26ʰ</td>
</tr>
<tr>
<td></td>
<td>Sugandha</td>
<td>41.92±1.83ᵇ</td>
<td>38.12±2.31ᶜ</td>
<td>33.81±2.09ᵈ</td>
<td>V - 0.839</td>
<td>33.35±0.26ʰ</td>
</tr>
<tr>
<td></td>
<td>Shabnam</td>
<td>42.33±2.26ᵇ</td>
<td>33.81±2.09ᵈ</td>
<td>30.69±2.61ᵉ</td>
<td>P×V - 1.453</td>
<td>35.49±0.96ᵍ</td>
</tr>
<tr>
<td></td>
<td>Usha</td>
<td>43.66±2.19ᵃ</td>
<td>36.66±2.01ᵇ</td>
<td>33.65±0.17ʰ</td>
<td>P - 0.166</td>
<td>35.49±0.96ᵍ</td>
</tr>
</tbody>
</table>

For Brown Rice and White Rice, the tables follow a similar structure with respective values for each level and variety.
Table 2.7 Coefficient of friction of five Indian paddy varieties

<table>
<thead>
<tr>
<th>Processing Level (P)</th>
<th>Variety (V)</th>
<th>Pusa 1121</th>
<th>Muchhal</th>
<th>Sugandha</th>
<th>Shabnam</th>
<th>Usha</th>
<th>CD at 5%</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Coefficient of friction on glass</td>
<td></td>
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</tr>
<tr>
<td>Paddy</td>
<td>0.405±0.006(^b)</td>
<td>0.309±0.020(^f)</td>
<td>0.224±0.012(^f)</td>
<td>0.215±0.010(^f)</td>
<td>0.335±0.024(^d)</td>
<td>P -</td>
<td>0.008</td>
</tr>
<tr>
<td>Brown Rice</td>
<td>0.435±0.007(^a)</td>
<td>0.419±0.014(^{ab})</td>
<td>0.381±0.017(^c)</td>
<td>0.401±0.017(^b)</td>
<td>0.400±0.014(^b)</td>
<td>V -</td>
<td>0.010</td>
</tr>
<tr>
<td>White Rice</td>
<td>0.431±0.004(^a)</td>
<td>0.347±0.021(^d)</td>
<td>0.342±0.015(^d)</td>
<td>0.352±0.014(^d)</td>
<td>0.349±0.013(^d)</td>
<td>P×V -</td>
<td>0.019</td>
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<tr>
<td>Coefficient of friction on galvanized iron sheet</td>
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<td></td>
</tr>
<tr>
<td>Paddy</td>
<td>0.471±0.009(^a)</td>
<td>0.434±0.011(^{bc})</td>
<td>0.416±0.017(^{bc})</td>
<td>0.432±0.043(^{bc})</td>
<td>0.431±0.017(^{bc})</td>
<td>P -</td>
<td>0.015</td>
</tr>
<tr>
<td>Brown Rice</td>
<td>0.417±0.008(^{bc})</td>
<td>0.370±0.018(^{de})</td>
<td>0.365±0.023(^{e})</td>
<td>0.327±0.064(^{f})</td>
<td>0.306±0.043(^{f})</td>
<td>V -</td>
<td>0.019</td>
</tr>
<tr>
<td>White Rice</td>
<td>0.445±0.019(^{ab})</td>
<td>0.419±0.009(^{bc})</td>
<td>0.402±0.011(^{cd})</td>
<td>0.424±0.011(^{bc})</td>
<td>0.407±0.008(^{bc})</td>
<td>P×V -</td>
<td>0.034</td>
</tr>
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<tr>
<td>Coefficient of friction on plywood parallel</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Paddy</td>
<td>0.447±0.009(^{ab})</td>
<td>0.458±0.024(^a)</td>
<td>0.434±0.041(^{abc})</td>
<td>0.460±0.033(^a)</td>
<td>0.451±0.026(^{ab})</td>
<td>P -</td>
<td>0.010</td>
</tr>
<tr>
<td>Brown Rice</td>
<td>0.392±0.010(^{ef})</td>
<td>0.367±0.007(^{gf})</td>
<td>0.370±0.009(^{f})</td>
<td>0.373±0.010(^{f})</td>
<td>0.376±0.009(^{f})</td>
<td>V -</td>
<td>0.013</td>
</tr>
<tr>
<td>White Rice</td>
<td>0.426±0.019(^{bc})</td>
<td>0.402±0.006(^{de})</td>
<td>0.448±0.017(^{ab})</td>
<td>0.417±0.014(^{cde})</td>
<td>0.413±0.011(^{cde})</td>
<td>P×V -</td>
<td>0.024</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coefficient of friction on plywood perpendicular</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Paddy</td>
<td>0.458±0.009(^{bc})</td>
<td>0.468±0.015(^{ab})</td>
<td>0.489±0.053(^{a})</td>
<td>0.467±0.026(^{ab})</td>
<td>0.473±0.020(^{ab})</td>
<td>P -</td>
<td>0.012</td>
</tr>
<tr>
<td>Brown Rice</td>
<td>0.369±0.011(^{ef})</td>
<td>0.396±0.012(^{ed})</td>
<td>0.398±0.026(^{ef})</td>
<td>0.393±0.018(^{ef})</td>
<td>0.384±0.018(^{gf})</td>
<td>V -</td>
<td>0.015</td>
</tr>
<tr>
<td>White Rice</td>
<td>0.403±0.020(^{ef})</td>
<td>0.422±0.015(^{de})</td>
<td>0.454±0.009(^{bc})</td>
<td>0.433±0.016(^{cd})</td>
<td>0.455±0.021(^{bc})</td>
<td>P×V -</td>
<td>0.024</td>
</tr>
</tbody>
</table>
Table 2.8  
Optical properties of five Indian paddy varieties

<table>
<thead>
<tr>
<th>Processing Level (P)</th>
<th>Variety (V)</th>
<th>CD at 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pusa 1121</td>
<td>Muchhal</td>
</tr>
<tr>
<td>Paddy</td>
<td>65.11±1.20</td>
<td>66.86±0.28</td>
</tr>
<tr>
<td>Brown Rice</td>
<td>65.60±1.54</td>
<td>70.65±0.45</td>
</tr>
<tr>
<td>White Rice</td>
<td>80.92±0.66</td>
<td>74.59±0.40</td>
</tr>
<tr>
<td></td>
<td>9.95±0.24</td>
<td>10.01±0.63</td>
</tr>
<tr>
<td></td>
<td>9.53±0.26</td>
<td>8.12±0.12</td>
</tr>
<tr>
<td></td>
<td>4.24±0.43</td>
<td>6.26±0.04</td>
</tr>
<tr>
<td></td>
<td>22.48±0.40</td>
<td>24.11±0.89</td>
</tr>
<tr>
<td></td>
<td>18.61±0.08</td>
<td>19.37±0.37</td>
</tr>
<tr>
<td></td>
<td>13.24±0.52</td>
<td>17.29±0.18</td>
</tr>
</tbody>
</table>
Figure 2.8  Physical and optical characteristics of five Indian paddy varieties
The l, a, and b values used to represent color of the materials was found to be ranged from 65.11±1.20 to 0.92±0.66, 4.24±0.43 to 10.24±0.11 and 13.24±0.52 to 24.11±0.89, respectively (Table 2.8). Significant increase in the l value reflects that on milling brightness improves with the decrease in both red and yellow color attributes (Figure 2.8).

2.4 CONCLUSION

Through present study efforts were made to find out variability and relationship between paddy cultivars of various economically important traits. Multivariate classification techniques were applied to determine the coherent physical and optical characteristics in order to reduce dimensionality problems. The properties heavily loaded on different components are dimensional with frictional in first principal component, dimensional and optical in second component and optical with gravimetric in third components found responsive for major variations (79.36%) in Eigen analysis of data. The observed physical and optical characteristics differ significantly and found cultivar dependent, which has paved the way for the classification of selected paddy cultivars on the basis of principal component and cluster analysis.

Characteristic variations among physical and optical properties existed among the paddy cultivars. Cultivars Muchhal, Pusa 1121, Shabnam, Sugandha and Usha showed greater potentials in terms of handling attributes as it may outperform processing as compared the other cultivars due to significant dimensional variations. Thus, indicating the usefulness multivariate analysis in identifying promising cultivars for the likely possibility to produce new recombinants with desired characters or appropriateness in the development of agricultural and processing equipments based on opto-physical characteristics.
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 promising basmati rice varieties Pusa 1121 was found to be the longest grain with substantial more loss of grain during milling as compared to selected 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.