Soaking effects on physical characteristics of basmati (*Pusa Basmati 1121*) rice

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Abstract: PB1121 paddy was soaked in water at seven different temperatures (40°C-80°C) till it achieved desired moisture. Soaking showed significant effect on physical characteristics of PB1121 rice. Soaking altered the length, breadth, thickness volume, surface area, equivalent diameter and sphericity of paddy grain. Un-soaked grains had bulk and true density as 508.60 and 1138.8 kg m^{-3}, respectively, whereas that of soaked grains varied from 511-527 and 1188-1238 kg m^{-3}, respectively. Head rice yield (HRY) of un-soaked rice was 42.12% whereas that of soaked rice varied from 50.21%-53.05%. Soaked grains were harder than the un-soaked grains. Un-soaked rice had lightness and redness values as 60.26 and 6.47, respectively but, with soaking temperature, lightness decreased (9.56%-16.23%) whereas redness increased (9.58%-25.50%). Soaking imparted reddish color to the grain, but not yellowness. Based on grain color, hardness and HRY, it was inferred that 65°C to 70°C temperatures would be appropriate for soaking of PB1121 paddy.

Keywords: basmati, soaking temperature, physical characteristics, HRY, hardness

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1 Introduction

Rice (*Oryza sativa* L.) is one of the most consumed cereal crops of the world. It is considered to be the staple food for more than half of the world's population (Ashfaq et al., 2015; Thilakarathna et al., 2015). Prior to its consumption, rice passes through number of processing operations. Freshly harvested paddy, also called as rough rice, is cleaned, dried and further processed to produce edible milled rice. However, brown or semi-milled rice is also consumed in some parts of the world (Mir and Bosco, 2013). Edible rice is obtained after various processing steps which include cleaning, drying, parboiling, dehusking, milling, grading, packing etc. Reports show that the type of processing operation and its severity affects quality of the end product (Sareepuang et al., 2008; Anand, 2012; Oludare et al., 2012; Mir and Bosco, 2013). Hence, information on the effects of various unit operations on rice quality characteristics is very useful to produce rice with better quality.

Among various operations, soaking is found to be more common practice, usually followed during parboiling, flaking and puffing of rice (Thakur and Gupta, 2006; Kale et al., 2013). Sometimes, soaking is also necessary to soften the grains prior to wet milling and cooking. Parboiling, a pre-milling treatment, has acquired more popularity due to its numerous well proven advantages. Report shows that parboiling is applied to about half of the Indian and one fourth of the world paddy produce (Kar et al., 1999). Soaking is extensively used during parboiling process. Moreover, without soaking step, complete parboiling cannot be achieved. Therefore, soaking is considered to be the most important as well as critical step of parboiling. During soaking, paddy is steeped in water to raise its moisture content (up to 40%-45%, db), essential for gelatinization of starch (Bhattacharya, 1985). In traditional parboiling methods,

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soaking is carried out at room temperature which takes one to two days or even more time. However, in modern parboiling methods, it is carried out at temperatures higher than the room temperature in order to reduce process time as water diffusion during soaking is a temperature dependent process (Igathinathane et al., 2005; Kale et al., 2013). Although, soaking at higher temperature reduces process time considerably, it may cause husk splitting as well as excessive leaching of the grain constitutes. Therefore, it is necessary to soak the paddy at optimum temperature. Various studies suggested the optimum temperature for soaking of different varieties of paddy in the range of 60ºC to 80ºC (Sridhar and Manohar, 2003; Akhter et al., 2014; Kale et al., 2015).

Even though soaking is an essential operation in rice milling industry, it affects quality characteristics of paddy which include physical characteristics, milling qualities, chemical composition, starch characteristics, cooking qualities etc. Important physical characteristics like axial dimensions, bulk density, true density, grain color, grain hardness, head rice yield (HRY) etc. are found to be affected by the severity of soaking (Bakshi and Singh, 1980; Ahromrit et al., 2006; Kashaninejad et al., 2007; Sareepuang et al., 2008). Grain dimensions, shape and densities are found important during grain handing, drying, storage etc. Also, color and length of milled rice provides visual assessment about its quality. In India, usually, light colored, long, slender grain is preferred over darker and short grain. Harder grain considered to be safe during storage. Also, harder grain possesses better milling qualities (Buggenhout et al., 2013). HRY is one of the most important quality parameter of rice. Rice milling efficiency is mostly quantified by HRY. All parboiling methods are intended to maximize HRY and to minimize the milling breakage. Therefore, information on effects of soaking on axial dimensions, shape, densities, grain color, hardness, HRY etc. of rice is very useful to the millers.

Rice varieties are mostly categorized on the basis of their length/shape (long, medium, short or round), aroma (aromatic or non-aromatic) and amylose content (waxy or non-waxy) (Araullo et al., 1976). In India, rice varieties are generally categorised as basmati and non-basmati varieties based on their aroma as well as length. In terms of consumer preference, basmati varieties are found to be superior over most of the non-basmati varieties. Basmati rice is a unique varietal group having long, slender grain, excessive elongation after cooking, soft and fluffy texture of cooked rice and pleasant aroma. These all characteristics, together, determine the uniqueness of basmati rice. Among various basmati varieties of India, Pusa Basmati 1121 (PB1121) variety is found more popular in domestic as well as international market. Paddy grain length (13-15 mm) and milled grain length (8-8.3 mm) of PB1121 rice found to be higher than almost all the traditional as well as improved basmati varieties (Anand, 2012; Patel et al., 2013). Also, its elongation (17-18 mm) after cooking has imparted it a unique status in the market. However, its milling breakage is more due to higher length. Therefore, in order to increase the HRY, this variety needs to be parboiled. Although, parboiling of basmati varieties is not desirable due to its adverse effect on aroma, increase in HRY with improvements in cooking qualities along with nutritional content can compensate such loss. Since last few years, some of the rice mills in India have started to parboil the basmati rice (Marie-Vivien et al., 2005; Srinivasa et al., 2013). Some studies have also been conducted to parboil the selected Pakistani basmati varieties which encourage the parboiling of PB1121 rice (Saeed et al., 2011; Akhter et al., 2014). Moreover, aroma is found to be less important parameter in case of PB1121 rice, compared to other basmati varieties which further encourages its parboiling (Anand, 2012).

Volumes of literatures are available on parboiling of non-basmati varieties of rice. Attempts have also been made to evaluate the effects of soaking alone on quality characteristics of different rice varieties. However, very limited information is available on the effects of soaking step on quality characteristics of basmati varieties of rice. In our previous study, soaking induced alterations in chemical composition, starch characteristics and glycemic index of PB1121 rice was determined (Kale et al., 2015). But, the soaking effects on physical characteristics of PB1121 rice are yet to be studied. Therefore, present study was undertaken to evaluate the effects on variable soaking on selected physical characteristics of this variety.

Severity of soaking parameters (soaking temperature and time) during parboiling can be decided if one knows the various changes occurred in the soaked grains.

2 Materials and methods

2.1 Un-soaked paddy

Freshly harvested paddy (PB1121) grains were obtained from the field of ICAR-Indian Agricultural Research Institute, New Delhi, India. Grains were cleaned and screened to get samples of uniform size. Paddy grains were further dried and stored at room temperature (20°C-35°C) till the experiment was conducted. Grains used for the experiment were at average moisture content of 13.77% (db).

2.2 Soaking of paddy

Paddy samples (200±0.5g) were soaked in 500 mL of distilled water at different seven levels of temperatures 40°C, 50°C, 60°C, 65°C, 70°C, 75°C and 80°C in a water bath (MAC, MSW-275, Micro Scientific Works (R), Delhi, India) with temperature control facility. Each sample was soaked till it achieved critical moisture content (CMC) of soaking, approximately 42% (db), as determined in our previous study (Kale et al., 2013). The time required for attaining CMC at 40°C, 50°C, 60°C, 65°C, 70°C, 75°C and 80°C was 810, 480, 390, 345, 232.5, 157.5 and 97.5 min, respectively. Soaked paddy grains were then used for further analysis.

2.3 Axial dimensions, shape, volume and density characteristics of paddy

Surface moisture of soaked paddy grains was removed using blotting paper and soaked as well as un-soaked paddy grains were subsequently evaluated for various physical characteristics using standard methods as previously used by Reddy and Chakraverty (2004) and Varnamkhasti et al. (2007). Axial dimensions were measured using digital vernier calliper having resolution of 0.01 mm (Mitutoyo Corporation, Japan). True density was determined by toluene displacement method (Garnayak et al., 2008). Porosity, equivalent diameter, volume, surface area and sphericity were calculated using following formulae (Varnamkhasti et al., 2007). Slenderness ratio was calculated using related Equations (1)-(6) (Firouzi et al., 2010).

$$\text{Porosity } (\varepsilon) = \frac{\rho_t - \rho_b}{\rho_b} \times 100 \tag{1}$$

where, ρ_t is true density and ρ_b is bulk density of grains.

$$\text{Equivalent diameter } (D_p) = \left[4L\left(\frac{W+T}{4}\right)^2\right]^{1/3} \tag{2}$$

$$\text{Volume } (V) = 0.25\left[\left(\frac{\pi}{6}\right)L(W+T)^2\right] \tag{3}$$

$$\text{Surface area } (S) = \frac{\pi B L^2}{2L - B} \tag{4}$$

where, $B = \sqrt{WT}$.

$$\text{Sphericity } (\phi) = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{5}$$

$$\text{Slenderness ratio } (sr) = \frac{L}{W} \tag{6}$$

2.4 Head rice yield

Soaked paddy grains were dried under shed to achieve 13.64% (db) moisture content, approximately equal to that of un-soaked paddy. Both un-soaked as well as soaked (dried) paddy grains were dehusked using rubber roll sheller (Ambala Associates, Ambala, India) to obtain brown rice, husk, broken and un-husked grains and these components were expressed as a percentage of paddy weight. Brown rice was polished using abrasive polisher (Ambala Associates, Ambala, India) to produce milled/polished rice with 8% degrees of milling. Milled rice, broken and bran obtained during milling were expressed as a percentage of brown rice. Percent brown rice (on paddy basis) and percent milled rice (on brown rice basis) were used to determine the head rice yield (on paddy basis) of un-soaked and soaked grains.

2.5 Grain hardness

Hardness of un-soaked and soaked milled grains (about 8% degrees of milling) was determined using Texture analyzer (Model *TA+Di*, Stable Micro Systems, UK) and by applying three-point bending concept. During measurement, grain was kept horizontal on two parallel walls of platform such that only ends of the grain rested and remaining body could not touch platform (Figure 1). Grain was considered as simply supported beam and a point load was applied at the centre of the grain using spherical probe (P/5 S, diameter 5 mm). Force required to fracture the grain was considered as the grain hardness and its values were obtained in Newton (N).

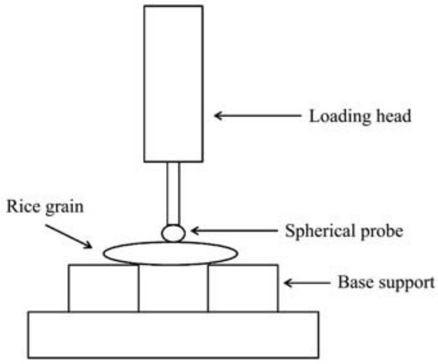

Figure 1 Three-point bending measurement of rice grain

2.6 Grain color

Color of milled grains (about 8% degrees of milling) was determined as per CIE L^*, a^*, and b^* color system, where L^* was lightness, a^* was redness and b^* was yellowness. Hunter color Lab (LX 17760, LabScan XE, Hunter Associates Laboratory Inc, USA) was used to determine the color coordinates L^*, a^*, and b^*. The total color difference (ΔE) was calculated using Equation (7).

$$\Delta E = \sqrt{(L^*_{sample} - L^*_{ref})^2 + (a^*_{sample} - a^*_{ref})^2 + (b^*_{sample} - b^*_{ref})^2} \quad (7)$$

The unsoaked grains were used as a reference (called as “ref”) sample.

2.7 Statistical analysis

Linear dimensions, equivalent diameter, volume, surface area, sphericity, slenderness ratio and hardness were replicated twenty times whereas bulk density, true density, porosity, color and HRY were determined in triplicate and the means were reported. Duncan's multiple range test was performed to test the statistical differences in these characteristics. SPSS software (version 16.0) was used to conduct the tests. The significance was accepted at 5% levels of significance ($\alpha = 0.05$).

Correlations and regressions between different variables were determined using Addin software XLSTAT (version 2014.5.03). In present study, seven soaking temperatures were used for soaking of paddy, hence, number of observations (n value) was 7. Correlations among variables were represented by Pearson correlation coefficient, r (ranged from –1 to 1) whereas regression between dependent variables (physical characteristics) and independent variable (soaking temperature) was represented by coefficient of determination, R^2 (ranged from 0 to 1).

Principal component analysis (PCA) was performed to determine the relationships between various physical characteristics as well as their association with soaking treatment. Addin software XLSTAT (version 2014.5.03) was used to perform PCA.

3 Results and discussion

Moisture required for complete gelatinization of starch is raised through soaking step of parboiling. However, on moisture absorption, paddy grain changes its physical characteristics. Such changes in physical characteristics of paddy are more pronounced after soaking, compared to steaming step of parboiling.

3.1 Effect of soaking on axial dimensions paddy

In present study, un-soaked paddy had 13.77% (db) moisture content whereas soaked paddy had about 42% (db), which indicated that soaking increased the moisture content of paddy by almost 28%-29%. Axial dimensions of paddy grains were found to be significantly ($\alpha = 0.05$) affected by soaking process. Moisture gain during soaking was the major reason behind dimensional change. Starch granules present in the endosperm swell after water absorption and cause the dimensional change. Another reason is the filling and subsequent widening of cracks present in the grain during soaking (Ahromrit et al., 2006). It is evident from Table 1 that statistical difference ($\alpha = 0.05$) was observed between length (L) and thickness (T) of un-soaked and soaked paddy. However, no significant change was observed in grain breadth (B) after soaking. Results also revealed that length, breadth and thickness did not show any correlation with each other. Pearson correlation coefficient (r) for length and breadth was 0.45 whereas for length and thickness, it was found as –0.30 and for breadth and thickness as 0.47 (Table 4).

Table 1 also indicates that soaking induced increase was found higher (7.63% to 11.37%) in grain thickness, compared to length and breadth. Highest variation in grain thickness in comparison to length and breadth is also shown by principal component analysis (Table 9) which indicated that grain thickness was associated with Principal Component 1 (65.05% variance explained) and had highest loading value (0.9951) whereas length and breadth were found to be associated with Principal Component 2 (16.45% variance explained) and had loading values as 0.8555 and 0.7366, respectively thereby indicating that thickness was more important variable than length and breadth. Generally, milled rice grain has tendency to expand along the length, like its elongation during cooking. Because, cell arrangement in the longitudinal direction of milled rice grain is different than that in the transverse direction which causes preferential breakdown of the endosperm cell walls in a lengthwise direction. But, present study revealed that paddy expanded more along the thickness as compared to length. Thus, it can be inferred that in case of milled rice, grain is free to expand lengthwise, however, in case of paddy grain, husk provides obstruction to the grain to swell and expand lengthwise. This might be the reason behind more increase in paddy grain thickness compared to length and breadth. Unlike length, breadth and thickness exhibited linear relationship (R^2=0.68 and 0.89, respectively) with soaking temperature.

Table 1 Axial dimensions of un-soaked and soaked paddy

Treatment	Length (L), mm	Breadth (B), mm	Thickness (T), mm	Increase in T, %
Un-soaked	12.70±0.63c	2.36±0.08a	1.85±0.07a	-
40°C	12.61±0.43bc	2.28±0.45a	1.99±0.08b	7.63
50°C	12.63±0.66bc	2.38±0.14a	1.99±0.06b	7.88
60°C	12.72±0.46bc	2.43±0.10a	2.00±0.06b	8.20
65°C	12.44±0.48a	2.43±0.11a	2.03±0.07b	9.72
70°C	12.63±0.47ab	2.39±0.09a	2.04±0.09b	10.28
75°C	12.61±0.63ab	2.43±0.13a	2.05±0.07b	10.80
80°C	12.67±0.50bc	2.44±0.11a	2.06±0.21b	11.37

Note: Values followed by same letter in a column do not differ significantly (α=0.05).

3.2 Effect of soaking on shape and volume characteristics

Volume (V), surface area (S), equivalent diameter (D_p), sphericity (ϕ) and slenderness ratio (R_a) of un-soaked paddy grain were found significantly (α=0.05) different than that of soaked paddy grain (Table 2). Volume, surface area, equivalent diameter and sphericity of paddy grain increased whereas slenderness ratio was found to be decreased after soaking. Volume of single un-soaked paddy grain was 29.35 mm^3 and it increased (4.94%-14.62%) with soaking temperature. Highest increase (14.62%) in grain volume was observed at 80°C. Values of surface area, equivalent diameter, sphericity and slenderness ratio of un-soaked paddy grain were 45.28 mm^2, 3.83 mm, 0.30 and 5.40, respectively. However, on soaking, surface area, equivalent diameter and sphericity increased by 1.88%-7.88%, 1.57%-4.44% and 3.33%-6.67%, respectively whereas slenderness ratio decreased by 1.48%-5.19%. Slenderness ratio decreased with soaking temperature up to 70°C but again increased at 75°C and 80°C.

Increase in volume, surface area, equivalent diameter and sphericity of paddy grain after soaking might be attributed to increase in grain thickness on water absorption. However, decrease in slenderness ratio (i.e. length to breadth ratio) after soaking might be due to more increase in breadth (up to 3.65%) as compared to length (up to 0.20%) during soaking. Correlation matrix (Table 4) shows that volume, surface area and equivalent diameter were positively correlated (r>0.98) to each other and change in one was associated with change in other two characteristics.

Table 2 Volume (V), surface area (S), equivalent diameter (D_p), sphericity (ϕ) and slenderness ratio of un-soaked and soaked paddy grain

Treatment	Volume (V), mm^3	Surface area (S), mm^2	Equivalent Diameter (D_p), mm	Sphericity (ϕ)	Slenderness ratio (sr)
Un-soaked	29.35±1.91a	45.28±2.37a	3.83±0.08a	0.30±0.01a	5.40±0.34b
40°C	30.80±2.31ab	46.13±2.32ab	3.89±0.10ab	0.32±0.01b	5.17±0.26a
50°C	31.67±3.12ab	47.27±3.28ab	3.92±0.13ab	0.31±0.01ab	5.32±0.37b
60°C	32.62±2.03ab	48.14±2.06b	3.96±0.08ab	0.31±0.01ab	5.25±0.31a
65°C	32.42±2.42ab	47.63±2.24ab	3.95±0.10ab	0.32±0.01b	5.12±0.32a
70°C	31.40±2.20ab	46.56±2.14ab	3.91±0.09a	0.32±0.01b	5.12±0.29a
75°C	33.07±2.94ab	48.39±2.90ab	3.98±0.12ab	0.32±0.01b	5.21±0.37a
80°C	33.64±4.11b	48.85±3.48b	4.00±0.15b	0.32±0.01b	5.20±0.27a

Note: Values followed by same letter in a column do not differ significantly (α=0.05).

3.3 Effect of soaking on density characteristics

Bulk and true densities are important physical characteristics of paddy and found useful during grain handling, storage etc. Bulk density is also required during determination of water requirement for soaking of paddy in bulk. In present study, Table 3 presents the bulk density, true density and porosity of PB1121 paddy. Table 3 shows that soaking temperature significantly (α=0.05) affected the bulk and true densities of soaked paddy. Un-soaked grains had bulk and true density as 508.60 and 1138.8 kg m^{-3}, respectively and increase in soaking temperature caused the corresponding increase in bulk (0.57% to 3.78%) and true (4.37% to 8.74%) densities. Although, volume of grains increased after soaking at all temperatures (Table 2), still increase in bulk and true densities was observed. This might be attributed to less increase in volume of grains as compared to corresponding increase in weight of the grain due to moisture gain (Kashaninejad et al., 2007). Increase in bulk density (by 3.61%) and true density (by 4.14%) of milled rice (Var. Tarom Mahali) after soaking have also been reported by Kashaninejad et al. (2007). Correlation matrix (Table 4) indicates that bulk density and true density were positively correlated (r=0.92) and increase in one was associated with increase in other. Both bulk and true densities were found to be exhibited a linear relationship (R^2=0.84 and 0.93, respectively) with soaking temperature.

Table 3 Bulk density, true density and porosity of un-soaked and soaked paddy

Treatment	Bulk density, kg m^{-3}	True density, kg m^{-3}	Porosity, %
Un-soaked	508±6.08a	1138±6.79a	55.34±0.38a
40°C	512±6.12d	1188±8.49c	56.87±0.21b
50°C	511±6.08bcd	1192±5.95c	57.10±0.30b
60°C	516±2.03cd	1202±8.71c	57.04±0.15b
65°C	521±5.99abcd	1220±1.94c	57.27±0.46b
70°C	527±5.24abcd	1232±10.09b	57.23±0.25b
75°C	523±6.43ab	1232±10.06b	57.50±0.20b
80°C	527±6.08abc	1238±6.57b	57.38±0.62b

Note: Values followed by same alphabet in a column do not differ significantly (α=0.05).

Table 4 Correlation matrix of physical characteristics of paddy

Variables	L	B	T	V	S	D_p	ϕ	AR	Bulk density	True density	Porosity
L	**1**										
B	0.45	**1**									
T	–0.30	0.47	**1**								
V	0.20	**0.74**	**0.86**	**1**							
S	0.35	**0.78**	**0.78**	**0.99**	**1**						
D_p	0.20	**0.73**	**0.86**	**1.00**	**0.99**	**1**					
ϕ	–0.60	0.14	**0.89**	0.62	0.49	0.62	**1**				
AR	**0.72**	–0.14	**–0.80**	–0.48	–0.34	–0.49	**–0.92**	**1**			
Bulk density	–0.29	0.61	**0.83**	**0.71**	0.62	**0.71**	**0.75**	**–0.73**	**1**		
True density	–0.28	0.58	**0.98**	**0.86**	**0.77**	**0.86**	**0.86**	**–0.78**	**0.92**	**1**	
Porosity	–0.26	0.44	**0.98**	**0.86**	**0.78**	**0.85**	**0.84**	**–0.73**	**0.71**	**0.93**	**1**

Note: Values in bold are different from 0 with a significance level of α=0.05.

Porosity of PB1121 paddy was not affected significantly (α=0.05) by soaking temperature. Its value for un-soaked paddy was 55.30%, whereas, it varied from 56.87% to 57.50% after soaking at 40°C to 80°C. Almost constant porosity value (approximately 57%) of soaked grain might be due to simultaneous increase in bulk and true densities of paddy with soaking temperature. Such simultaneous increase in bulk and true densities might be due to the expansion and swelling of grains, coupled with more uptake of moisture (Kibar et al., 2010).

Biplot (Figure 3) obtained during PCA indicates that thickness, bulk density, true density and porosity were located on the right side of the Principal Component 1 (65.05% variance explained) and found to be correlated (grouped) to each other. Therefore, it can be inferred that densities were affected more by grain thickness, compared to length and breadth.

Though, statistical differences were observed among values of axial dimensions, shape, volume and density characteristics of paddy soaked at different temperatures, from a practical standpoint, these differences were very little to not significant. However, considerable difference was observed between above characteristics of un-soaked and soaked (at any temperature in the range of 40°C to 80°C) paddy grains.

3.4 Milling analysis of un-soaked and soaked paddy

Head rice yield (HRY) is one of the most important characteristics with commercial point of view. Almost all the parboiling methods are aimed to increase the HRY. In present study, results (Table 5) revealed that soaking made dehusking easier. Percent brown rice obtained from soaked paddy was found significantly (α=0.05) higher (13.00%-14.84%) than that obtained from un-soaked paddy. Breakage during dehusking was much higher in case of un-soaked paddy (15.96% broken) as compared to soaked paddy (9.11%-11.74% broken). Table 5 also indicates that PB1121 paddy contains about 26%-27% husks. The husk content of other rice varieties has been reported in the range of 20%-25% of the paddy weight (Champagne et al., 2004; Delcour and Hoseney, 2010).

It is evident from Figure 2 and Table 5 that soaking increased the HRY (paddy basis) significantly (α=0.05). HRY of un-soaked rice was found as 42.12%, whereas, that of soaked rice varied from 50.21% to 53.05%. Such increase in HRY after soaking (at all the temperatures) might be due to loosening of husk and hardening of rice grain during soaking (Sridhar and Manohar, 2003; Mohapatra and Bal, 2006). Increase in HRY (brown rice basis) of KDML105 variety from 50.92% to 59.22%, 82.98% and 84.46% after soaking at 40°C, 50°C and 60°C, respectively has also been reported by Sareepuang et al. (2008). In present study, HRY exhibited almost linear relationship (R^2=0.78) with soaking temperature. HRY was lowest at 40°C (50.21%) and found to be increased with soaking temperature. Such soaking induced increase in HRY might be due to partial gelatinization of starch at higher temperatures, thereby increase in grain hardness and hence the HRY (Bhattacharya, 1985; Mohapatra and Bal, 2006).

Table 5 Head rice yield of un-soaked and soaked paddy

Treatment	Dehusking				Polishing			HRY on paddy basis, %
	BR, %	Broken, %	Husk, %	Un-husked paddy, %	WR, %	Broken, %	Bran, %	
Un-soaked	52.23	15.96	23.21	7.25	80.64	12.6	6.76	42.12±2.13a
40°C	59.85	9.11	25.25	4.78	83.89	8.93	6.18	50.21±3.11b
50°C	59.96	9.44	25.82	4.02	84.49	8.71	6.41	50.66±3.32b
60°C	59.12	10.09	25.92	3.81	86.15	8.58	6.16	50.93±2.15b
65°C	59.34	9.67	24.92	3.75	87.01	7.87	5.9	51.63±4.22c
70°C	59.99	11.16	24.93	3.31	87.31	7.06	6.52	52.38±3.21cd
75°C	59.62	11.25	25.44	3.46	88.19	5.99	6.11	52.58±5.11cd
80°C	59.6	11.74	25.57	2.6	89.01	5.09	6.09	53.05±2.14d

Note: Values followed by same alphabet in a column do not differ significantly (α=0.05).Values for dehusking are based on paddy basis whereas values for polishing are based on brown rice basis.

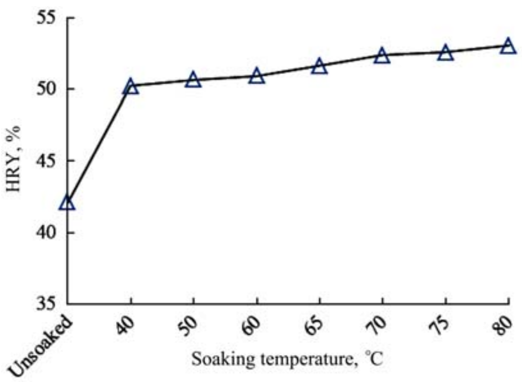

Figure 2 HRY (%) of un-soaked and soaked paddy

3.5 Effect of soaking on grain hardness and color

Grain hardness is very important quality parameter and can be related with HRY, cooking qualities, storage life etc. In present study, grain hardness was found to be affected significantly (α=0.05) by soaking temperature (Table 6). Higher soaking temperature imparted more hardness to the grains. Un-soaked grains had hardness as 8.08 N. However, it varied from 16.14 to 24.95 N when soaking temperature varied from 40°C to 80°C. Such soaking induced increase in hardness might be due to partial gelatinization of starch and thereby hardening of the grains (Bhattacharya, 1985). Swelling of starch after soaking completely heals the cracks and chalkiness of rice grain and improves its hardness (Mohapatra and Bal, 2006). Hardness showed a linear relationship with soaking temperature (R^2=0.94). Increase in grain hardness with increasing soaking temperature (from 60°C to 80°C) has also been reported by Mir and Bosco (2013). Results also revealed that hardness showed positive correlation (r=0.94) with HRY. In other words, hardness and HRY found to be increased simultaneously, which is true theoretically also. However, hardness values were not found to be differed considerably in case of grains soaked at 40°C to 75°C. The difference of 1 to 4 N is not considerable from practical point of view but hardness (8 N) of un-soaked grains and that of soaked grains (16-24 N) differed considerably which ultimately brought the difference in HRY.

Table 6 Hardness and color of un-soaked and soaked rice

Treatment	Hardness, N	L^*	a^*	b^*	ΔE
Un-soaked	8.08±2.53a	60.26±0.10d	6.47±0.11a	23.21±0.39a	0.00
40°C	16.14±3.38b	54.50±0.35c	7.34±0.18bc	23.14±0.06a	5.83a
50°C	18.11±3.24bc	52.49±0.33b	7.77±0.05bc	22.87±0.04a	7.89b
60°C	17.05±2.31bc	52.52±0.49b	7.09±0.21ab	21.90±1.02a	7.87d
65°C	20.15±2.90bcd	54.09±0.67c	7.64±0.11bc	23.17±0.09a	6.28b
70°C	20.71±4.43cd	52.69±0.82b	7.35±0.72bc	23.00±1.55a	7.62c
75°C	20.38±2.63bc	50.69±0.25a	7.62±0.27bc	22.05±0.46a	9.71e
80°C	24.95±4.18d	50.48±0.77a	8.12±0.38c	23.00±0.35a	9.92e

Note: Values followed by same alphabet in a column do not differ significantly (α=0.05).

Grain color is very important quality characteristic of rice as most of the consumers select rice on the basis of its color also. In present study, grain color was found to be affected significantly (α=0.05) by soaking temperature. Table 6 indicates that un-soaked rice had lightness (L^*) value as 60.26 but it decreased (9.56%-16.23%) with soaking temperature indicating that higher temperature imparted darker color to the grain. Redness (a^*) of un-soaked grains was 6.47 and it increased (9.58% –25.50%) with soaking temperature, might be due to non-enzymatic browning caused by hydrothermal treatment (Bello et al., 2007). However, soaking temperature had no significant (α=0.05) effect on yellowness (b^*) of the grains. Like a^*, total color difference (ΔE) also increased (from 5.83 to 9.92) with soaking temperature. Such increase in ΔE might be due to the non-enzymatic browning of rice and diffusion of color pigments from husk and bran to the grain (Dutta and Mahanta, 2012). In present study, visual observations of grain color suggested that increase in ΔE up to 7.62 (corresponds to 70°C) would be acceptable.

Results indicated that L^* and a^* as well as L^* and ΔE showed negative correlation (r=–0.84 and –1, respectively) whereas a* and ΔE showed positive correlation (r=0.84). However, b^* possessed weak correlation (r<±0.5) with L^*, a^* and ΔE. Thus, strong correlation between a^* and ΔE on one hand, while weak correlation between b^* and ΔE on the other hand indicated that change in grain color after soaking was mainly due to redness as compared to yellowness. Similar results are also represented by PCA (Table 7 and Figure 3) which indicates that Principal Component 1 (65.05% variance explained) was associated with a^* and ΔE in one direction whereas L^* in opposite direction. Thus, L^*, a^* and ΔE were found to be more important variables than b^*. PCA (Figure 3) also shows that a^* and ΔE were located close to each other and hence found to be highly correlated whereas b^* was located at a considerable distance from a^* and ΔE. Therefore, from results, it can be inferred that soaking imparted reddish or brownish color to the grain. However, it did not impart yellowness to the grains which is commonly found in parboiled rice.

Table 7 Factor loadings for physical characteristics of un-soaked and soaked rice

Variables	Principal component 1	Principal component 2
Length	–0.2624	0.8555
Breadth	0.4798	0.7366
Thickness	0.9951	–0.0133
L^*	–0.9512	–0.1975
a^*	0.8811	–0.0527
b^*	–0.2822	–0.7202
ΔE	0.9505	0.2016
Bulk density	0.8038	0.0965
True density	0.9683	0.0641
Porosity	0.9837	0.0039
HRY	0.5913	–0.2897
Hardness	0.9756	0.0214

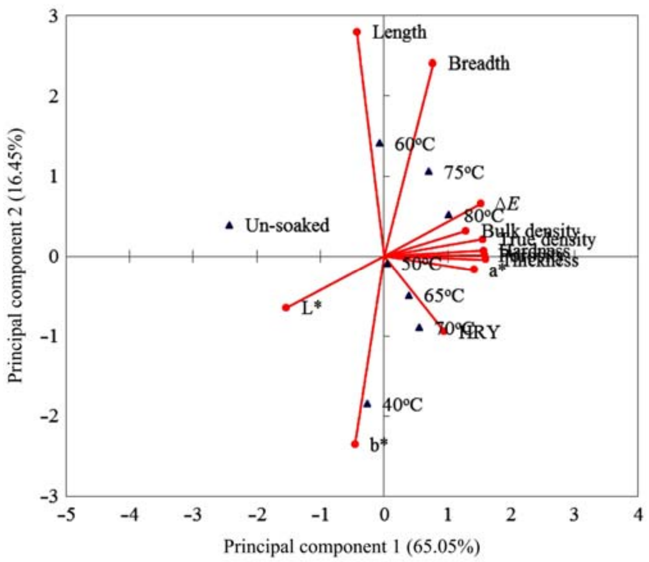

Figure 3 Scores and loadings plot of first two principal components obtained for physical characteristics of un-soaked and soaked rice

3.6 Optimum soaking treatment based on color, hardness and HRY using PCA

Soaking treatment, which brings minimum change in grain color (i.e. lower Δ*E*) and improves grain hardness and HRY, may be considered to be the optimum soaking treatment. In present study, from PCA results (Figure 3), it was observed that treatments 75°C and 80°C showed some association with grain hardness and HRY but were also found to be closely associated with Δ*E*, thereby indicating that grains soaked at these treatments were harder but were also found darker that was undesirable effect. Treatments un-soaked, 40°C and 60°C did not show any close association with grain hardness and HRY and hence could not be considered as optimum soaking treatments. However, treatments 65°C and 70°C are found to be strongly associated with HRY which is desirable effect. These treatments also showed some association with grain hardness and found to be located at considerable distance from Δ*E.* Therefore, it can be inferred that soaking of PB1121 paddy at 65°C to 70°C would be appropriate to produce rice with minimum color change and higher grain hardness along with improved HRY.

4 Conclusions

Soaking showed significant (α=0.05) effect on physical characteristics of PB1121 rice. Soaking temperature affected paddy grain length and thickness significantly (α=0.05), however, it did not affect grain breadth. Maximum increase after soaking was found in paddy grain thickness (by 7.63% to 11.37%), compared to length which further revealed that swelling of starch granules was more pronounced along the grain thickness. Volume, surface area, equivalent diameter and sphericity of paddy grain increased by 4.94%-14.62%, 1.88%-7.88%, 1.57%-4.44% and 3.33%-6.67%, respectively, whereas slenderness ratio was found to be decreased by 1.48%-5.19% after soaking. Soaking temperature affected density characteristics of PB1121 paddy significantly (α=0.05). Porosity increased after soaking but it was almost constant (approx. 57%) at all soaking temperatures, might be due to simultaneous increase in both bulk and true densities. HRY of un-soaked rice was found as 42.12%, whereas, that of soaked rice varied from 50.21% to 53.05%. Grains soaked at different temperatures were found harder and darker than the un-soaked grains. Soaking treatment affected the redness value of grain but had no effect on yellowness value. Therefore, it was inferred that soaking imparted reddish or brownish color to the grain, however, it did not impart yellowness. Based on PCA results, it was inferred that 65°C to 70°C temperatures would be appropriate for soaking of PB1121 paddy in order to produce rice with minimum color change and higher grain hardness and HRY.

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