Effect of degree of milling on physicochemical, structural, pasting and cooking properties of short and long grain *Indica* rice cultivars

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Abstract

The effects of degree of milling (DOM) between 0 and 8% on physico-chemical, structural, pasting and cooking properties of short and long grain *Indica* rice cultivars were studied. Ash, protein, lipids and minerals decreased while blue value and crystallinity increased with increase in DOM. The colour parameters (*a**, *b**) and cooking time (CT) decreased while *L**(lightness) increased with increase in DOM. Elongation ratio (ER), gruel solid loss (GSL), length/breadth (L/B) and paste viscosities during cooking increased with increase in DOM. Short grain rice contained lower ash, protein, lipids, Mn, K, Ca, CT and GSL than long grain while the later showed higher crystallinity, Mn, P, K, Ca and ER. Paste and dough characteristics measured using Rheometer and Mixolab, respectively correlated well and differed with cultivar and DOM. Short and long grain cultivars showed variation in loss of different chemical constituents during varied DOM causing variation in cooking characteristics.

Keywords: Cooking; Degree of milling; Mixolab; Pasting; Rice

1. Introduction

The paddy after harvesting contains husk, bran, embryo and endosperm. It is dehusked to get brown rice (BR) which undergoes whitening process to remove the bran. The nature and composition of bran changes with rice cultivar, pre-milling treatment, type of milling, level/ degree of milling (DOM), soil environment (Saunders, 1985). He further explained bran in three different layers, viz. outermost layer of bran as pericarp layer, middle layer as testa and innermost layer as aleurone layer. The branny layers are removed to get white milled rice (MR). The rice from various cultivars is milled to different DOM depending upon the thickness of branny layer for removal of bran, germ/embryo and some part of endosperm to get milled white rice. The extent of milling (removal of bran) is termed as DOM which not only determines the level of whiteness of rice but also affects their physicochemical and nutritional properties as various nutrients (proteins, lipids, vitamins and minerals) are concentrated in the outer layer of the rice grain (Itani, Tamaki, Arai, & Horino, 2002; Monks et al., 2013). The concentration of these nutrients in the MR is reduced with increase in DOM as these are removed gradually at every stage of milling. In addition, DOM also affects head rice recovery, starch gelatinization, resistance to insect infestation and sensory quality (Champagne, Marshall, & Goynes, 1990; Mohapatra & Bal, 2007).

Cooking quality of rice is considered as one of the main quality attributes which is influenced by the genetic factors, cultivation techniques, post-harvest practices and cooking methods (Mestres, Ribeyre, Pons, Fallet, & Matencio, 2011; Singh, Pal, Mahajan, Singh, & Shevkani, 2011). Most consumers prefer well-milled white rice with little or no bran remaining on the endosperm due to its better palatability and have better cooking properties than BR; however, recently the trend is shifting towards the rice rich in both nutritional and cooking qualities. Hence emphasis needs to be given to the removal of minimum portion of bran so that rice with acceptable cooking qualities (minimum cooking time, higher water uptake ratio, expansion ratio, etc.) can be obtained. The cooking and nutritional properties of BR can also be improved by germination process (Pal, Singh, Kaur, Kaur, Virdi, & Parmar, 2016)

A number of rice cultivars are grown in India. Amongst these, PR113, a short grain cultivar, is preferred due to high yield and low cost while PUSA1121, long grain cultivar, finds a number of customers because of its aroma, texture and cooking properties. PUSA1121 was also proved to be a better cultivar to produce germinated BR taking into account better changes brought in it during germination process that includes increase in protein, ash, amino acid and phenolic contents (Pal et al., 2016). The effect of DOM on physicochemical, cooking and textural properties of rice has been evaluated in the past by a number of researchers (Adu-Kwarteng, Ellis, Oduro, & Manful, 2003; Mohapatra & Bal, 2007; Lamberts et al., 2007; Monks *et al*., 2013). Adu-Kwarteng et al. (2003) compared new and local Ghana rice varieties for physical, chemical and milling properties and showed significant differences in these properties amongst different varieties. Similarly, Mohapatra & Bal, (2007) investigated the effect of degree of milling on the milling energy requirement and cooking properties of aromatic long slender rice variety. Lamberts et al., (2007) and Fernandes Monks *et al*. (2013) also investigated the effect of milling on the colour, nutritional value and cooking properties of rice and showed significant effect of milling on these properties of Brazilian and Belgium long grain rice varieties. However, the comparative effect of DOM on structural, rheological and cooking quality aspects of long and short grain rice cultivars is still needed to be evaluated. Hence, the present work was undertaken to investigate the effect of varying DOM on physicochemical, structural, rheological (pasting and dough mixolab properties) and cooking properties and to establish a relationship among pasting and Mixolab rheological properties of short and long grain *Indica* rice cultivars.

2. Materials and methods

2.1. Materials

Freshly harvested PR113 (short and round; rice blue value = 0.196) and PUSA1121 (aromatic, long and slender; rice blue value = 0.161) were purchased from a seed collection and breeding center (Partap Seeds, Batala, India). The paddy was cleaned manually to remove impurities and BR was obtain after shelling (0 % DOM) using a McGill sheller (Rapsco, Brookshire, TX, USA). BR yield of 77.1% and 75.9%, respectively for PR113 and PUSA1121 was obtained. BR was milled to varying DOM (2%, 4%, 6% and 8%) using a McGill polisher (Rapsco, Brookshire, TX, USA) as described earlier (Singh, Singh, Kaur, & Bakshi, 2000). Briefly, BR grains (150 g) were separated from the brokens and milled in triplicate to get 2%, 4%, 6% and 8% bran. The pressure on the rice during milling was controlled by placing a weight (660 g) on the mill lever arm. The weight was placed at a distance of 21.5 cm from the centre of the saddle to the centre of weight. The mill was thoroughly cleaned after each milling interval by brushing the bran and broken rice kernels from the screen and rotor. DOM i.e. percent bran removed by milling; was calculated from the weight of rice before and after milling. The percent loss in weight (due to removal of bran) will correspond to that DOM. Both BR as well as MR were sealed in air tight zip-lock pouches and stored at 5 °C in a refrigerator until analyzed.

2.2. Methods

2.2.1. Physicochemical properties

Milling time of a particular DOM is the time required to achieve that DOM from previous DOM by removal of bran. Head rice yield after each DOM was evaluated following the method described by Kaur, Pal, Virdi, Kaur, Singh, & Mahajan (2016). Length (L), breadth (B), their ratio (L/B), thousand grain weight (TGW) and bulk density (BD) of BR and MR were determined by the methods of Singh, Kaur, Sodhi, & Sekhon (2005). Rice kernels were ground in a Super Mill (Newport, Australia) to pass all through a 60 mesh sieve to obtain flour which was evaluated for proximate (moisture, lipids, protein: nitrogen × 5.95 and ash content) and mineral composition i.e. calcium (Ca), manganese (Mn), phosphorous (P), zinc (Zn), potassium (K), magnesium (Mg), sodium (Na) following AACC Method 08-01 (AACC, 2000).

Blue value was calculated using absorbance measured at 680 nm with a spectrophotometer (Lambda Bio 35, Perkin Elmer, Norwalk, CT, U.S.A.) following the method of Yu, S., Ma, Y., Menager, L., & Sun, D. W. (2012). Rice flour (100 mg) was suspended in 1.0 mL of ethanol and 9.0 mL of 1.0 M NaOH, followed by heating in a boiling water bath for 10 min with intermittent shaking to completely dissolve the starch. The suspension pH was adjusted to 6.5 with 1.0M HCl, and it was diluted to 100 mL with distilled water. Diluted solution (5 mL) was mixed with 1 mL of 0.2% iodine solution, and final volume was raised to 100 mL with distilled water. The mixture was kept at room temperature for 15 min before measuring absorbance at 680 nm and Blue value (BV) was calculated according to the following equation:

$BV = 4 * A_{680} / C$.

Where A_{680}: absorbance at 680 nm and C: concentration of starch or flour in the solution.

The flours were also evaluated for colour parameters (*L**, *a** and *b** values) using a colour meter (Hunter Associates Laboratory Inc., U.S.A.) following the method described elsewhere (Shevkani, Singh, Rana, & Kaur, 2014).

2.2.2. X-ray diffraction

X-ray diffraction pattern of hydrated (stored at 100% RH for 72 h) rice flours were analyzed using X-ray diffractometer (Bruker AXS, Karlsruhe, Germany). Accelerating voltage, current and scan rate were 30 kV, 30 mA, and 1 degree/min, respectively. The diffractograms were recorded from 4 to 40° 2θ with step size of 0.02.

2.2.3. Pasting properties

Pasting properties of flour obtained from BR milled to varying DOM were measured using a Rheometer (MCR-301, Anton Paar, Austria) equipped with starch cell (C-ETD 160) and stirrer probe (ST 24-2D/2 V/2 V-30). Briefly, rice flour suspensions (10 %) were held at 50 °C for 1 min then heated from 50 to 95 °C at a rate of 12.16 °C/min, held at 95 °C for 2.5 min, cooled from 95 to 50 °C at a rate of 11.84 °C/min, and held at 50 °C for 2 min. Parameters recorded were pasting temperature (PT), peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BDV), final viscosity (FV), and setback viscosity (SBV) (Kaur, Shevkani, Singh, Sharma, & Kaur, 2015).

2.2.4. Mixolab analysis

Mixolab (Chopin Technologies, Paris, France) was also used to analyze pasting behavior of rice flour dough using the method of Xie, Chen, Tang, Luo, Jiao, & Hu (2011). Dough (90 g) made from flour containing 60% water (14% wb) was evaluated. The temperature settings were 8 min at 30 °C for the initial mixing, increased at 4 °C/min to 90 °C and held for 7 min, and then decreased at 4 °C/min to 50 °C and held for 10 min. The mixing speed during the entire assay was 120 rpm. Parameters of recorded were C1 i.e. initial consistency; C2, minimum torque; C3, peak torque; C4, minimum torque during heating period; and C5 (torque obtained after cooling to 50 °C). Cb and Cs were also calculated as C3-C4, and C5-C4, respectively.

2.2.5. Cooking properties

Cooking time (CT), elongation ratio (ER), gruel solid loss (GSL) and cooked length/breadth (C-L/B) were determined following the methods described by Singh et al., (2005).

2.2.6. Statistical analysis

The data reported is mean of triplicate observations. The data was subjected to ANOVA and principal component analysis (PCA) using Minitab Statistical Software (Minitab Inc., State College, PA, USA).

3. Results and discussion

3.1. Milling characteristics

3.1.1. Milling time

Both short and long grain cultivars showed different milling time to achieve DOM of 2, 4, 6 and 8%. Milling time required for PR113 and PUSA1121 was 54.33 s and 73.67 s, respectively to achieve 8% DOM (Table 1). Milling time required for each successive stage of milling increased significantly with the removal of soft outer branny layer and was 13.3 s and 54.33 s respectively, for 2% and 8% DOM from BR for PR113 whereas PUSA1121 required 14 s and 73.57 s to achieve similar DOM. The short grain cultivar required less time than long grain cultivar for a particular level of DOM. Singh et al. (2000) also reported variations in milling behavior (including milling) time amongst different rice cultivars attributed to differences in shape and hardness of grain. Therefore, it was likely that relatively round grains of PR113 with less harder structure got abraded more easily during milling and required lesser milling time to achieve a particular DOM as compared to PUSA1121 with slender grains.

3.1.2. Head Rice Yield

The effect of DOM on Head Rice Yield (HRY) of PR113 and PUSA1121 is shown in Table 1. PR113 showed higher HRY than PUSA1121 which significantly decreased in both the cultivars with each successive DOM. The HRY after 8% DOM was 56.3% and 49.4%, respectively, for PR113 and PUSA1121. A total loss in HRY was 26.0% and 34.9% for PR113 and PUSA1121, respectively, at 8% DOM was observed. PUSA1121 showed higher loss than PR113 which may be due to greater length and thinner width of PUSA1121 which made it more prone to breakage. This loss was higher during initial milling stage in both the cultivars and PR113 showed more loss than PUSA1121 at 2% DOM. PUSA1121 showed 8-9% loss in HRY at each successive milling stage whereas PR113 showed maximum loss in HRY at 2% DOM. HRY at 2%, 4%, 6% and 8% DOM was 10.42%, 7.06%, 5.36% and 4.15%, respectively for PR113 against 8.73%, 8.88%, 8.97% and 8.34%, respectively for PUSA1121.This variation may be attributed to difference in genetic makeup as well as grain structure and bindings between the granules. Falade & Christopher (2015) also reported that milling recovery varied from 45.74% to

68.24% for six Nigerian rice cultivars. Adu-Kwarteng et al. (2003) reported a total milling recovery of 63.5% for Ghana rice varieties. They also reported that a recovery equal to or less than 50% is undesirable.

3.2. Physicochemical properties

BR from PR113 and PUSA1121 showed TGW of 24.2 g and16.4 g, respectively which decreased gradually with increase in DOM. TGW of 21.9 g and 15.4 g, respectively at 8% DOM for PR113 and PUSA1121was observed (Table 1). With each successive DOM, 1.5-2.5% reduction in TGW for both cultivars was observed. This decrease was due to the removal of bran during each stage of milling. PR113 and PUSA1121 showed L/B ratio of 2.68 and 4.18, respectively for BR, against 2.91 and 4.48, respectively for MR (Table 1). The increase in L/B ratio on successive milling may be due to decrease in grain width during milling whereas average length remained the same. PR113 had higher BD as compared to PUSA1121 which gradually increased from 0.78 to 0.90 g/ml for PR113 and from 0.69 to 0.80 g/ml for PUSA1121 with increase in DOM from 0 to 8% (Table 1). This gradual increase in BD may be attributed to the removal of branny layers rich in lipids with lower specific gravity than starch and proteins which were main constituents of endosperm. L/B ratio is an important parameter for classification and grading of MR from different cultivars whereas BD provides an indication of grain soundness. However, higher BD for PR113 than PUSA1121 may also be attributable to its lower L/B ratio owing to rounder shape and compact structure (Falade & Christopher, 2015).

Blue value, ash, protein and lipids content varied amongst cultivars and DOM (Table 1). PUSA1121 showed higher ash, protein and lipids content and lower blue value than PR113. Ash, protein and lipids content were 1.8%, 7.9% and 4.14%, respectively for BR from PR113 against 2.2%, 8.2% and 5.5%, respectively for those from PUSA1121. Each milling stage led to a decrease in ash, protein and lipids content and an increase in blue value in both the cultivars (Table 1). The increase in blue value with extended DOM may be attributed to increase in starch content which consequently increased amylose content in the system, as starch is concentrated more in the endosperm than in brany layers. Baek & Lee (2014) also reported higher ash, protein and lipids content for BR than white MR. Ash content decreased by 10.11% and 9.22%, respectively for PR113 and PUSA1121 at 2% DOM. Ash content decreased to the extent of 5.62%, 21.91%, and 19.66% for PR113 against 4.15%, 17.97% and 27.65% for PUSA1121 at 4%, 6% and 8% DOM, respectively. Above results depicted that the highest proportion of ash content was removed at 6% and 8% DOM. This indicated that testa and aleurone layer (middle and innermost layer of bran) which were concentrated in inorganic mineral matter were removed at 6-8% DOM in both the cultivars. The highest decrease of 2.20% to 2.65% respectively in protein content for PR113 and PUSA1121 at 2% DOM was observed. Further, extending DOM to 4, 6 and 8% caused a decrease of 1.39%, 1.26% and 0.51%, respectively in protein content for PR113. However, PUSA1121 showed uniform decrease of 1.10% protein content upon each successive increase in DOM from 4 to 8%. The above results reflected that 2% DOM caused maximum loss in protein for both the cultivars. This reflected that the highest concentration of proteins might be present in the pericarp layer (outermost layer of bran) in both the cultivars which got removed at 2% DOM. Lipids removal also showed a similar reduction with increase in DOM as observed for proteins. Lipids content reduced to extent of 29.47%, 28.99%, 17.87% and 12.80%, respectively for PR113 against 30.24%, 20.77%, 15.66% and 14.57%, respectively for PUSA1121 when milled to 2%, 4%, 6% and 8% DOM. These results reflected that maximum loss of lipids was observed after 2% DOM indicating the highest concentration of lipids were present in the pericarp followed by testa and aleurone layer in both the cultivars. The results also reflected that the concentration of ash, protein and lipids in both the cultivars varied among different branny layers.

Mineral composition of MR as a function of varying DOM is presented in Fig. 1. BR from PR113 had higher content of Zn, Mg and Na than PUSA1121. On the other hand Mn, P, K and Ca were higher in PUSA1121. BR from both cultivars contained significantly higher content of Ca, Mn, P, Zn, K, Mg and Na as compared to MR and their concentration decreased gradually with increase in DOM. These observations were in agreement with Lamberts et al. (2007), who observed a decrease in the mineral content up to 15% DOM after which constant levels were observed. From the results it can be predicted that the highest reduction in Zn, K, Mg and Ca (12.19%, 30.58%, 28.64% and 41.52%, respectively) was observed at 2% DOM. On the other hand, maximum reduction of 35.13% and 21.45%, respectively for P and Mn was observed at 8% DOM. However, the highest loss in Na content was observed at intermediate level of DOM, therefore 35.43% reduction in Na was observed when milled to 6% DOM. The distribution of different minerals in different layers of bran may be responsible for the variation of amount of mineral removal after each DOM. These results showing maximum loss at 2%, 6% and 8% for various minerals in PR113 indicated Zn, K, Mg and Ca may be highly concentrated in the pericarp, Na seems to be concentrated in testa and aleurone layers while higher concentration of P and Mn may be present in the aleurone layer.PUSA1121 showed the highest loss of Zn, K and Ca at 2% DOM (9.76, 19.34and 49.17 % respectively) while the highest loss in Mn and Na content (14.03 and 31.56% respectively) at 4% DOM. The maximum reduction in P and Mg content (31.76% and 18.68 %, respectively) was observed at 8% DOM. The percent loss after each DOM indicated that Zn, K and Ca were concentrated more in pericarp while Mn and Na probably in testa and P and Mg might be in the aleurone layer of the PUSA1121. The results also reflected that higher concentration of different minerals in different layers of bran also varied for both the cultivars. Juliano (1985) also supported that P was the major mineral present in rice bran and DOM have direct effect on mineral concentration. Lombi, Scheckel, Pallon, Carey, Zhu, & Meharg (2009) also found similar distribution of Mn, P and Zn among different layers of bran and embryo of rice grain.

Both the cultivars differed significantly in colour characteristics (*L**, *a** and *b** values). Both BR and MR from PR113 showed significantly higher lightness (*L**) and lower redness (*a**) and yellowness (*b**) than PUSA1121 (Table 1). These differences might be attributed to lower content of proteins and mineral matter in PR113 compared to PUSA1121. Contribution of constituents like proteins and minerals to yellowness and redness in cereal flours has been reported earlier (Jamin & Flores, 1998; Singh, Shevkani, Kaur, Thakur, Parmar, & Virdi, 2014). BR from PR113 had *L**, *a** and *b** values of 74.52, 1.55 and 11.26 against 73.09, 1.87 and 12.05, respectively for PUSA1121. Expectedly, the removal of branny layers increased *L** and decreased *a** and *b** for both cultivars wherein the extent of the change of lightness and redness was the highest at 8% DOM for both cultivars. Zhong, Liu, Xu, Liu, & Tu (2014) also reported similar trends of *L**, *a** and *b** values of Chinese rice cultivars with varying DOM. PCA also supported this relation as *L** related negatively while *a** and *b** positively to protein, ash and lipids content (Fig. 2).

3.3. X-Ray diffraction pattern

X-ray diffractograms from PR113 and PUSA1121 with varying DOM are shown in Fig. 3. Both cultivars showed “A” type X-ray diffraction pattern which was expected for rice flour with crystalline peaks at approximately 15, 17, 18 and 23° 2θ, as reported earlier for starches from different rice cultivars (Singh, Nakaura, Inouchi, & Nishinari, 2007; Singh et al., 2011). A small crystalline peak at 2θ approximately 20°, attributing to amylose-lipid complexes (Zobel, 1988), was also observed for both cultivars. PR113 showed lower crystalinity as measured by intensities of various peaks compared to PUSA1121 (Fig.3) likely due to higher blue value indicating higher amylose content. Similar difference in crystallinity due to difference in amylose content among different *Indica* rice cultivars has also been reported by Singh et al., (2007). Crystallinity in starches and flours was primarily attributed to the double helical arrangement of long amylopectin chains within the granule, while the amorphousness was due to amylose, less-ordered amylopectin and branch points connecting double helices (Waterschoot, Gomand, Fierens & Delcour, 2015). In addition, non-starch constituents i.e. proteins and lipids may have contributed to amorphous structure as intensities of peaks increased increased gradually with increase in removal of branny layers indicating increase in crystalline structure (Fig. 3). Contrarily, the intensity at 20° 2θ peak decreased with increased DOM due to removal of lipids. Increase in intensities of crystalline peaks, except of peak attributing to amylose-lipid complexes, with successive purification of corn starch and flour has also been reported earlier (Singh et al., 2014).

3.4. Pasting properties

The effect of DOM on pasting properties of PR113 and PUSA1121 are shown in Table 2. Paste viscosities (PV, FV, SBV and BDV) differed amongst cultivars and were lower for BR than MR from both cultivars. PV, FV, SBV and BVD for BR from PR113 were 1640, 1550, 40 and 130 cP, respectively, against 820, 1740, 1032 and 112 cP, respectively for PUSA1121. Paste viscosities, for both cultivars, increased significantly with increase in DOM. Paste viscosity is generally considered to be the property of starches, particularly amylose content (Noda, Nishiba, Sato, & Suda, 2003); therefore, increase in starch concentration upon successive DOM due to removal of proteins and lipids might partly attributed to higher paste viscosities of MR than BR flour of both the cultivars. PCA loading plot also highlighted a negative relationship between paste viscosities and proteins, lipids and ash content (Fig. 2). MR from PR113 with 8% DOM showed significantly higher paste viscosities (PV, FV and SBV of 2264, 4250 and 2150 cP, respectively) than counterpart from PUSA1121 (967, 2060 and 1292 cP, respectively). BDV for PR113 was lower (164 cP) than PUSA1121 (199 cP) when milled to 8% DOM. This might be due to higher amylose content in PR113 which provided stability to the swollen granules at elevated temperature. FV indicated the ability of flour to form a viscous mass as a result of starch retrogradation. MR with 8% DOM from PR113 showed almost double FV as compared to

PUSA1121 indicating greater susceptibility towards retrogradation possibly due to higher amylose content. The retrogradation in starch gels during cooling was also attributed to the reassociation of amylose molecules as the temperature decreases (Singh, Singh, Kaur, Sodhi, & Gill, 2003). However, BR from PR113 showed lower FV than that from PUSA 1121 (Table 2), which was possibly due to the differences in the properties of the rice bran proteins amongst the two cultivars. Earlier, the paste viscosities of rice flour were reported to be decreased with the incorporation of proteins from two different types of cowpeas depending on the protein characteristics and the level of incorporation (Shevkani, Kaur, Kumar, & Singh, 2015). MR and BR from PR113 showed a lower PT (65.0 to 69.1 °C) than PUSA1121 (65.5 to 71.7 °C) possibly due to lesser crystallinity in the former as observed by XRD results. Higher crystallinity of PUSA1121 increased the resistance of starch towards gelatinization and delayed the absorption of water in the granules during cooking and swelling. However, PT of both cultivars decreased gradually with increase in DOM (Table 2), further highlighting the contribution of non-starch constituents (lipids and proteins), which might have delayed the initiation of the gelatinization process. Proteins and lipids present in rice and other cereals have been reported to increase the resistance of starch granules towards gelatinization and swelling (Singh *et. al.*, 2014). Furthermore, the decrease in PT of flours might also be due to the decreased amylose-lipid complexes (as evident from decreased 20° 2θ diffraction peak) that can increase granular integrity, leading to higher PT and retardation of granular swelling and lower paste viscosities (Shevkani, Singh, Singh, Singh, & Ahlawat, 2011).

3.5. Mixolab properties

Mixolab measures pasting behavior of starch in dough system which can be effectively used to predict eating quality of different rice cultivars (Marco & Rosell, 2008; Xie *et. al.*, 2011). Flours from rice with varying DOM from both cultivars showed typical Mixolab curve with an abrupt increase in torque during initial mixing (C1) followed by a decrease during continuous mixing stage (C2), a starch gelatinization-derived peak during heating (C3), a decline to a value i.e. C4 during temperature hold (Cb), and an increase to a value i.e. C5 upon cooling (Cs) (Table 2). C1 and C2 indicated resistance to mixing while C3, C4, and C5 represented starch gelatinization, stability of gelatinized starch granules, and retrogradation, respectively (Heo, Lee, Shim, Yoo, & Lee, 2013). BR and MR from PR113 showed higher C3, C4 and C5 but lower Cb and Cs than PUSA1121 consistent to pasting properties measured with Rheometer. DOM significantly affected Mixolab properties of both cultivars. MR at 8% DOM showed higher values of C3, C4 and C5. PCA analysis also revealed that C1 decreased while C2, C3, C4, C5 and Cb increased with increasing DOM (Fig.2). This could be explained by the reduction in non-starch constituents (ash, lipids and proteins) with each successive removal of branny layers. PCA also showed that C3, C4 and C5 related positively to PV and FV and negatively to non-starch constituents. Xie et al. (2011) also observed positive correlations of C4 and C5 with hot paste viscosity and final viscosity, respectively measured using rapid visco-analyzer. Hence, the variability in the Mixolab properties may be attributed to the same factors discussed above for pasting properties.

3.6. Cooking properties

The cooking properties (CT, ER, C L/B and GSL) of BR and MR varied significantly with cultivars and DOM (Table 3). BR from PR113 showed higher CT (16.59 min) and lower ER (1.39) than PUSA1121 (13.43 min and 1.43, respectively) (Table 3). Optimum CT were reported to range from 12 to 19 min for Japonica and 9.5 to 19.0 min for Indica rice cultivars (Mestres et al., 2011 & Singh et al., 2011). The optimum CT of rice depends on rate of moisture diffusion (Juliano, 1985); the higher values of CT for PR113 may be attributed to its round shape (lesser specific surface area than the slender grains of PUSA1121). Lesser surface area slowed slower moisture diffusion in grains resulting in longer CT (Mohapatra & Bal, 2006). The extended DOM decreased CT and increased ER for both cultivars though the increase in elongation was higher for PUSA1121. The milling of PR113 and PUSA1121 to 2% DOM decreased CT by 29 s and 20 s, respectively in comparison to BR. CT of MR further decreased by 32 s, 37 s and 75 s for PR113 and 14 s, 57 s and 8 s for PUSA1121 upon 4, 6 and 8% DOM. Therefore, maximum decrease in CT for PR113 was observed at 8% DOM whereas PUSA1121 showed the highest decrease at 6 % DOM. This might be due to the difference in the concentration of various constituents in different layers for both the cultivars that leads to maximum removal of constituents affecting CT at different DOM. High grain elongation during cooking has been reported to be a characteristic of long and slender basmati rice (Kamath et al., 2008), while the non-basmati PR113 rice might have shown lesser elongation due to higher gelatinization temperature as a result of greater starch crystallinity (Kaur, Panesar, & Bera, 2011). The increase in ER of MR by 3.60% and 4.90% for PR113 and PUSA1121 respectively at 2% DOM in comparison to BR was observed. It further increased to 5.04, 4.32 and 7.19% for PR113 and 2.80, 8.39 and 11.19% for PUSA1121 when milled to 4, 6 and 8 % DOM, respectively. The results revealed that maximum variation in ER was observed at 8% DOM for both the rice cultivars. ER showed negative relation with protein, ash and lipids content and positive to DOM, Mixolab parameters (C3, C4 and C5) and paste viscosities (Fig. 2). This clearly highlighted that MR in the absence of branny layers cooked faster and elongated more due to rapid diffusion of water and more swelling of the starch granules. The C-L/B for PR113 was lesser than that of PUSA1121 at different stages of DOM. Cooked BR and MR of PR113 showed L/B of 3.41 and 3.64 whereas PUSA1121 showed 4.6 and 5.12, respectively. A constant increase of 1.5-2.0% in C-L/B ratio of PR113 grains was observed with each succeeding DOM. On the other hand, maximum increase (3.77 %) in C-L/B for PUSA1121 was observed upon 2 % DOM. GSL of BR and MR ranged from 6.34 to 7.77% for PR113 against 2.35 to 3.23% for PUSA1121 that increased gradually with increased DOM (Table 3). PCA revealed that GSL was negatively related with protein, ash and lipids content of rice (though the relation was stronger with protein content) and positively with PV (Fig. 2). This suggested suppressing effect of proteins and lipids on granular swelling that might have resulted in reduced GSL. Higher GSL has been reported for rice with higher amylose content (Morris, 1990; Singh et al., 2005; Singh et al., 2011). PCA also revealed positive relation of cooking properties with Mixolab parameters (C3, C4 and C5), wherein CT and GSL had stronger relation than ER. Xie et al. (2011) also reported that Mixolab could be useful in evaluating rice cooking and pasting attributes.

4. Conclusions

Physicochemical, rheological and cooking properties of *Indica* rice varied significantly with DOM and cultivar. Lightness increased while yellowness and redness decreased gradually with increase in DOM, though the effect was prominent at > 4% DOM. Loss in the proteins, lipids and mineral content varied at each DOM and their concentration in different layers of bran also varied for both the cultivars. Milling up to 8% DOM significantly reduced the amounts of proteins, lipids and minerals to 5.8%, 87.88% and 89.13%, respectively. This variation in the distribution of various components in different layers of bran was also responsible for the difference in pasting, cooking and crystalline properties of both the cultivars. Milling up to 8% DOM significantly reduced the amounts of proteins, lipids and minerals that account 89.13% loss in lipids followed by 87.88% loss in minerals and minimum loss in protein content (5.8%). CT decreased with increase in DOM though steep decrease was observed at DOM > 4%, while ER, GSL and C L/B increased gradually. The pasting parameters measured by Rheometer and Mixolab were correlated and can be used to predict cooking quality of rice.

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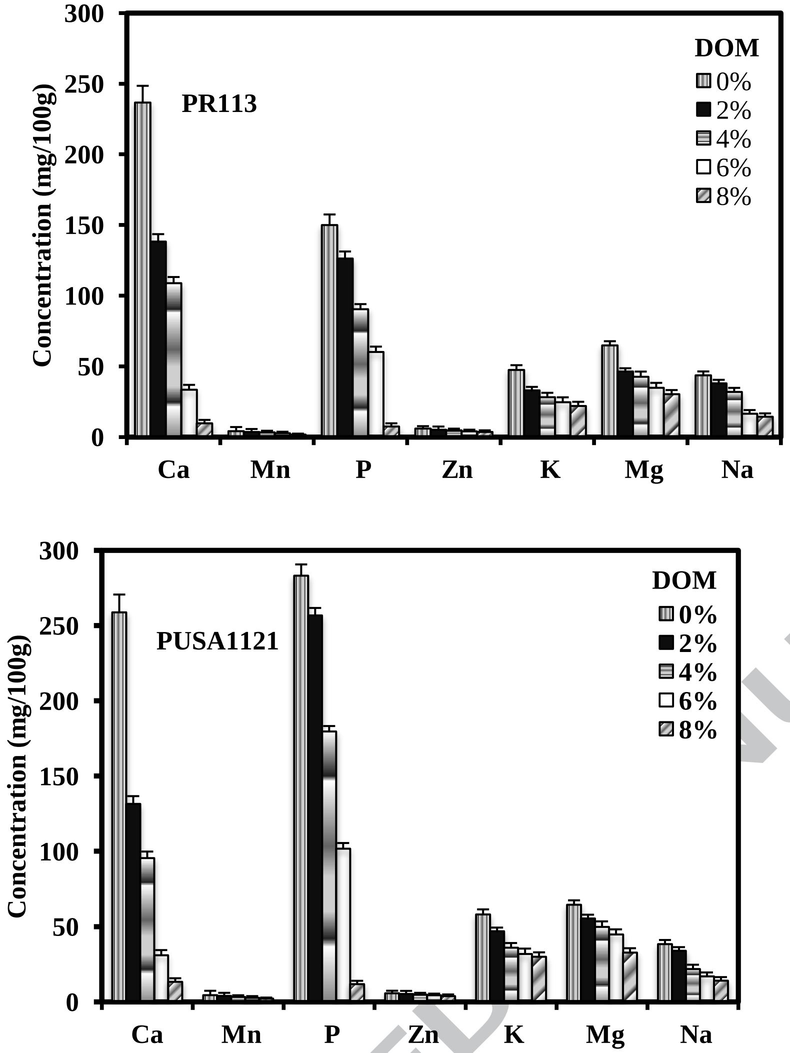
Figure captions

Fig. 1. Mineral composition of brown rice and rice milled to different DOM for PR-113 and PUSA-1121 rice cultivars. Triplicate readings were obtained from three independent experiments and data is expressed as mean values ± standard deviations of three results. Here, Ca: Calcium, Mn: Manganese, P: Phosphorous, Zn: Zinc, K: Potasium, Mg: Magnesium, Na: Sodium.

Fig. 2. Principal component analysis (PCA) loading plot highlighting effect of degree of milling (DOM) and relationships amongst various properties of brown rice and rice milled to different DOM for PR-113 and PUSA-1121 rice cultivars. Triplicate readings were obtained from three independent experiments and data is expressed as mean values ± standard deviations of three results. Here, DOM: Degree of milling, MT: Milling time, LB: Length to breadth ratio, PV: Peak viscosity, FV: Final viscosity, SBV: Set back viscosity, BDV: Break down viscosity, PT: Peak temperature, L*: Lightness, a*: Redness, b*: Yellowness, ER: Elongation ratio, BV: Blue value, BD: Bulk density, GSL: Gruel solid loss, TGW: Thousand grain weight, CT: Cooking time, Na: Sodium, K: Potasium, P: Phosphorous, Ca: Calcium, Mg: Magnesium, Mn: Manganese, Zn: Zinc, Mc: Moisture content, LC: Lipid content, PC: Protein content, AC:Ash content,C1, C2, C3, C4, C5, Cb, Cs are Mixolab parameters

Fig. 3. XRD difractograms of brown rice and rice milled to different DOM for PR-113 and PUSA-1121 rice cultivars. Triplicate readings were obtained from three independent experiments and data is expressed as mean values ± standard deviations of three results. Here, DOM: Degree of milling.



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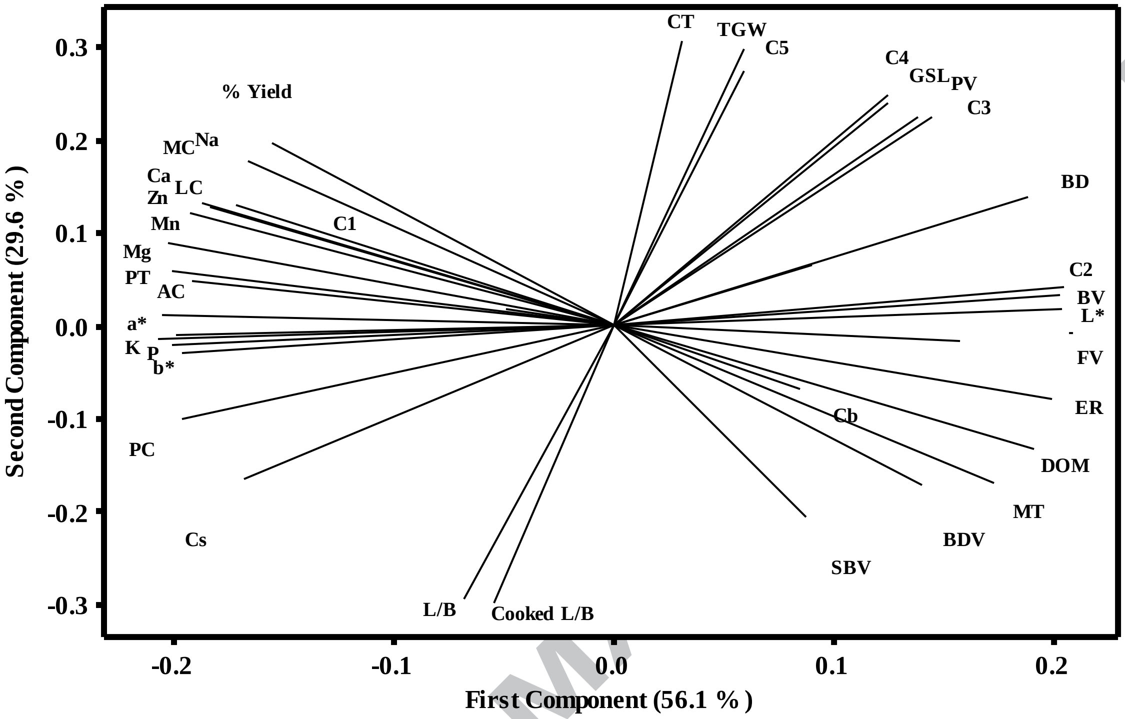

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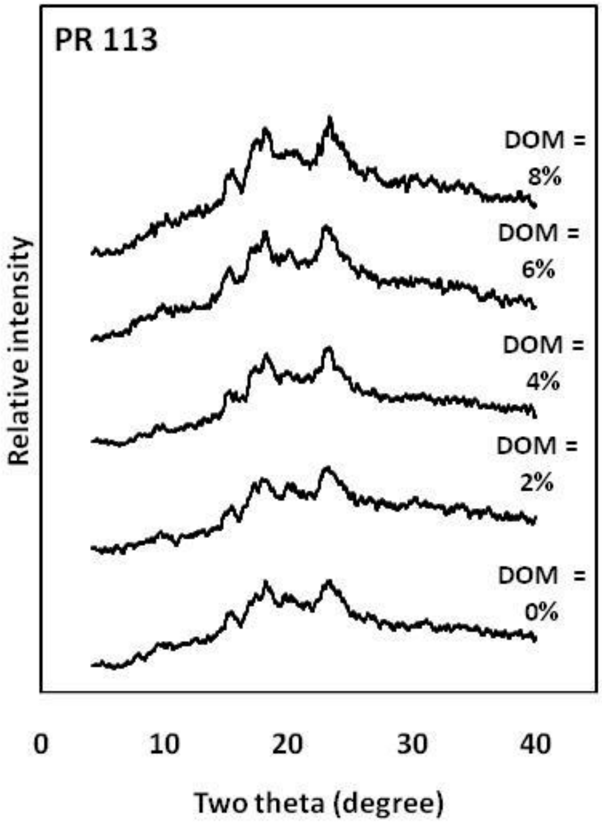
PR 113
DOM = 8%
DOM = 6%
DOM = 4%
DOM = 2%
DOM = 0%
Relative intensity
0
10
20
30
40
Two theta (degree)

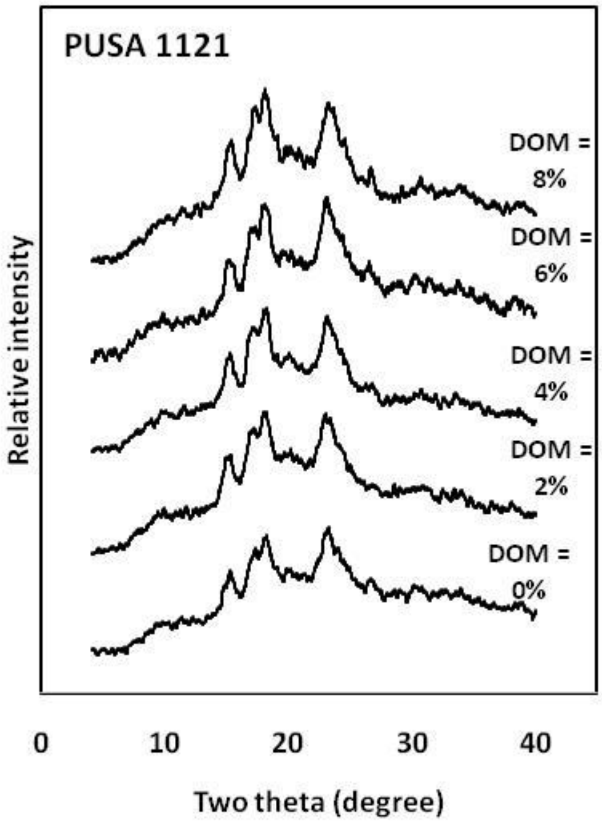
PUSA 1121
DOM = 8%
DOM = 6%
DOM = 4%
DOM = 2%
DOM = 0%
Relative intensity
0
10
20
30
40
Two theta (degree)

Fig. 3. XRD difractograms of brown rice and rice milled to different DOM for PR-113 and PUSA-1121 rice cultivars. Here DOM: Degree of milling.

Table 1.

Effect of DOM on milling and physico-chemical characteristics of PR113 and PUSA1121.

Variety	PR113					PUSA		
DOM (%)	0	2	4	6	8	0	2	4
MT (s)	0±0^{eP}	13.33±1.15^{dP}	27.33±0.58^{cP}	38.33±1.53^{bP}	54.33±1.15^{aP}	0±0^{eP}	14±1.73^{dP}	32.33±
HRY (%)	77.08±2.08^{aP}	69.05±1.24^{bP}	63.61±1.14^{cP}	59.48±1.22^{dP}	56.28±1.43^{eP}	75.94±1.97^{aP}	65.31±0.92^{bP}	62.57±
TGW (g)	24.16±1.19^{aP}	23.63±1.11^{aP}	22.99±1.00^{aP}	22.43±1.46^{aP}	21.85±1.33^{aP}	16.35±0.52^{aQ}	16.12±0.54^{aQ}	16.02±
L/B	2.68±0.15^{aP}	2.72±0.14^{aP}	2.80±0.22^{aP}	2.83±0.20^{aP}	2.91±0.10^{aP}	4.18±0.09^{bcQ}	4.31±0.02^{acQ}	4.32±
BD (g/ml)	0.78±0.02^{dP}	0.81±0.01^{cP}	0.82±0.01^{cP}	0.87±0.02^{bP}	0.90±0.01^{aP}	0.69±0.02^{cQ}	0.7±0.01^{cQ}	0.72±
MC (%)	13.45±0.16^{aP}	13.17±0.23^{abP}	13.13±0.14^{acP}	13.06±0.16^{bcP}	12.91±0.16^{bcP}	13.64±0.13^{aP}	13.19±0.22^{bP}	13.05±
BV	0.127±0.01^{cP}	0.151±0.01^{bcP}	0.172±0.02^{abP}	0.188±0.02^{aP}	0.196±0.01^{aP}	0.110±0.01^{dQ}	0.132±0.02^{bcdQ}	0.146±
AC (%)	1.78±0.18^{aP}	1.60±0.23^{aP}	1.50±0.22^{aP}	1.11±0.14^{bP}	0.76±0.11^{cP}	2.17±0.13^{aP}	1.97±0.16^{aP}	1.88±
PC (%)	7.92±0.27^{aP}	7.71±0.18^{abP}	7.60±0.23^{acP}	7.50±0.24^{adP}	7.46±0.18^{bcdP}	8.20±0.18^{aQ}	8.02±0.10^{abQ}	7.93±
LC (%)	4.14±0.30^{aP}	2.92±0.33^{bP}	1.72±0.36^{cP}	0.98±0.23^{dP}	0.45±0.24^{dP}	5.49±0.06^{aP}	3.83±0.23^{bP}	2.69±
L*	74.52±0.29^{eP}	75.06±0.15^{dP}	75.85±0.27^{cP}	76.50±0.28^{bP}	78.83±0.34^{aP}	73.09±0.12^{dQ}	73.72±0.26^{cQ}	73.95
a*	1.55±0.23^{aP}	1.39±0.14^{aP}	1.27±0.21^{abP}	0.91±0.24^{bP}	0.44±0.27^{cP}	1.87±0.27^{aQ}	1.78±0.31^{abQ}	1.63±

b*	11.26±0.24^{aP}	11.21±0.15^{aP}	11.10±0.09^{aP}	9.80±0.22^{bP}	8.26±0.21^{cP}	12.05±0.11^{aQ}	12.04±0.12^{aQ}	11.82±

DOM: degree of milling, MT: milling time, HRY: head rice yield, TGW: thousand grain weight, L/B: length to breadth ratio, BD: bulk density, MC: moisture content, BV: blue value, AC: ash content, PC: protein content, LC: lipid content, L*: lightness, a*: redness, b*: yellowness.

Results are expressed as mean values ± standard deviations of three independent experiments. Means in a row with similar superscripts (a, b, c, d, e) do not differ significantly ($p < 0.05$) with DOM. Means in row with same superscripts (P, Q) within a particular variety are not significantly different ($p < 0.05$).

Table 2.

Effect of DOM on pasting properties of PR113 and PUSA1121.

	Variety	PR113					PUSA1121				
	DOM (%)	0	2	4	6	8	0	2	4	6	8
Pasting Properties	PV (cP)	1640±19.97^{dP}	1660±27.18^{cdP}	1693±24.98^{cP}	1920±29.26^{bP}	2264±27.06^{aP}	820±22.12^{cQ}	840±16.7^{cQ}	910±22.65^{bQ}	918±14.84 ^{bQ}	967±14.57^{aQ}
	FV (cP)	1550±18.73^{eP}	1590±19.31^{dP}	1660±14.11^{cP}	2490±18.03^{bP}	4250±26.46^{aP}	1740±22.72^{dP}	1780±13.23^{cP}	1810±18.52^{cP}	1920±21.79^{bP}	2060±24.58^{aP}
	SBV (cP)	40±5.29^{eP}	68±3.61^{dP}	110±7.81^{cP}	721±9.54^{bP}	2150±18.03^{aP}	1032±7.21^{dQ}	1062±9.85^{cQ}	1074±6.56^{cQ}	1180±13.23^{bQ}	1292±7.94^{aQ}
	BDV (cP)	130±8.72^{cdP}	138±8.19^{bdP}	143±7.21^{bcP}	151±6.24^{abP}	164±7.21^{aP}	112±2.65^{dP}	122±5.57^{cP}	174±5.57^{bP}	178±4.58^{bP}	199±5.57^{aP}
	PT (^{0}C)	69.1±1.77^{aP}	68.3±0.87^{aP}	67.8±0.95^{abP}	66.9±1.08^{acP}	65.0±1.31^{bcP}	71.7±1.31^{aP}	70.3±1.93^{aP}	69.7±1.68^{aP}	66.4±2.00^{bP}	65.5±1.85^{bP}
Mixolab properties	C1 (Nm)	1.47±0.07^{aP}	1.19±0.12^{bP}	1.07±0.07^{bP}	1.11±0.1^{bP}	1.48±0.22^{aP}	1.34±0.21^{aP}	1.35±0.19^{aP}	1.37±0.17^{aP}	1.14±0.15^{aP}	1.18±0.14^{aP}
	C2 (Nm)	1.04±0.11^{abP}	0.89±0.18^{acP}	0.75±0.14^{bcdP}	0.84±0.15^{adP}	1.13±0.17^{aP}	0.49±0.09^{cP}	0.65±0.1^{cP}	1.19±0.12^{aP}	0.48±0.05^{cP}	0.95±0.16^{dP}
	C3 (Nm)	3.41±0.26^{bcP}	3.23±0.18^{cdP}	3.35±0.2^{bdP}	3.66±0.18^{bP}	4.02±0.12^{aP}	1.24±0.17^{bQ}	1.45±0.12^{bQ}	1.44±0.2^{bQ}	2.03±0.26^{aQ}	1.24±0.12^{bQ}
	C4 (Nm)	3.34±0.2^{aP}	3.18±0.15^{aP}	3.28±0.2^{aP}	3.34±0.11^{aP}	3.18±0.14^{aP}	0.81±0.12^{cdQ}	1.21±0.07^{bQ}	1.1±0.17^{bcQ}	1.98±0.28^{aQ}	0.95±0.12^{bdQ}
	C5 (Nm)	4.9±0.18^{aP}	4.43±0.18^{bP}	4.65±0.17 ^{abP}	4.57±0.13^{bP}	3.98±0.18^{cP}	3.45±0.13^{bQ}	3.37±0.14^{bQ}	3.5±0.15^{bQ}	3.61±0.14^{abQ}	3.78±0.11^{aQ}
	Cb (Nm)	0.06±0.07^{cP}	0.05±0.04^{cP}	0.07±0.06^{cP}	0.32±0.1^{bP}	0.84±0.08^{aP}	0.43±0.05^{aP}	0.24±0.09^{bP}	0.34±0.03^{bP}	0.11±0.05^{cP}	0.29±0.03^{aP}
	Cs (Nm)	1.56±0.02^{aP}	1.25±0.06^{bP}	1.37±0.16^{bP}	1.23±0.03^{bP}	0.8±0.05^{cP}	2.64±0.03^{bQ}	2.16±0.13^{eQ}	2.4±0.08^{dQ}	1.63±0.15^{cQ}	2.83±0.05^{aQ}

DOM: degree of milling, PV: peak viscosity, FV: final viscosity, SBV: set back viscosity, BDV: break down viscosity, PT: peak temperature.

Results are expressed as mean values ± standard deviations of three independent experiments. Means in a row with similar superscripts (a, b, c, d, e) do not differ significantly ($p < 0.05$) with DOM. Means in row with same superscripts (P, Q) within a particular variety are not significantly different ($p < 0.05$).

Table 3.

Effect of DOM on cooking properties of PR-113 and PUSA-1121.

Variety	PR113					PUSA1121				
DOM (%)	0	2	4	6	8	0	2	4	6	8
CT (min)	16.59 ± 0.37^{aP}	16.3 ± 0.25^{aP}	15.58 ± 0.41^{bP}	15.21 ± 0.52^{bP}	14.06 ± 0.23^{cP}	13.43 ± 0.03^{aQ}	13.23 ± 0.05^{aQ}	13.09 ± 0.04^{aQ}	12.12 ± 0.04^{bQ}	12.04 ± 0.08^{bQ}
GSL (%)	6.34 ± 0.06^{eP}	6.76 ± 0.10^{dP}	7.14 ± 0.04^{cP}	7.51 ± 0.05^{bP}	7.77 ± 0.09^{aP}	2.35 ± 0.21^{dQ}	2.74 ± 0.11^{cQ}	2.91 ± 0.09^{bcQ}	3.04 ± 0.08^{abQ}	3.23 ± 0.14^{aQ}
C-L/B	3.41 ± 0.04^{cdP}	3.47 ± 0.05^{bdP}	3.52 ± 0.06^{bcP}	3.57 ± 0.06^{abP}	3.64 ± 0.08^{aP}	4.60 ± 0.02^{cQ}	4.78 ± 0.08^{bcQ}	4.86 ± 0.09^{bQ}	4.95 ± 0.09^{abQ}	5.12 ± 0.18^{aQ}
ER	1.3 ± 0.07^{cdP}	1.48 ± 0.12^{bcP}	1.53 ± 0.14^{acdP}	1.61 ± 0.19^{abP}	1.67 ± 0.19^{aP}	1.43 ± 0.02^{bP}	1.50 ± 0.01^{bP}	1.54 ± 0.02^{bP}	1.61 ± 0.06^{abP}	1.82 ± 0.16^{aP}

CT: cooking time, GSL: gruel solid loss, C-L/B: cooked length to breadth, ER: elongation ratio.

Results are expressed as mean values ± standard deviations of three independent experiments. Means in a row with similar superscripts (a, b, c, d, e) do not differ significantly ($p < 0.05$) with DOM. Means in row with same superscripts (P, Q) within a particular variety are not significantly different ($p < 0.05$).

Highlights

- Physicochemical, rheological and cooking properties of *Indica* rice varied significantly with DOM and cultivar.
- Milling up to 8% DOM significantly reduced the amounts of proteins, lipids and minerals to 5.8%,87.88% and 89.13%,respectively.
- Concentration of various chemical constituents varied among different layers of bran for different rice cultivars.
- The pasting parameters measured by Rheometer and Mixolab were correlated and can be used to predict cooking quality of rice.