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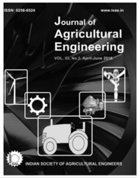

Determination of Optimum Degrees of Milling for Raw and Parboiled Basmati (PB1121) Rice Using Principal Component Analysis

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ABSTRACT

Pusa Basmati 1121 (PB1121) rice (longest milled grain in the world), raw and parboiled, was dehusked and milled at 6 different degrees of milling (DOM) varied from 5-10 per cent. Head rice yield decreased up to 10% with increased DOM in both raw and parboiled rice. However, parboiling increased the yield of marketable rice by 18.68 per cent. DOM significantly (α=0.05) affected cooking and textural qualities of raw and parboiled rice. Mineral composition of raw and parboiled rice indicated that P, K, Mg and S constituted the major portion, about 97% of the mineral composition of PB1121 rice. DOM adversely affected the mineral content of rice, but this effect was less severe in parboiled rice. Principal component analysis (PCA) performed for selected quality characteristics of PB1121 rice indicated that optimum DOM (%) for raw and parboiled PB1121 rice would be 7% and 8%, respectively.

Keywords: Basmati, DOM, cooking qualities, mineral composition, PCA

Edible rice is obtained through milling operation. Milling involves removal of husk and bran from the gain. Amount of bran removed from the grain during milling is termed as degree of milling (DOM). Usually, DOM affects the consumer preferences for rice. Majority of the consumers prefer well-milled white rice with little to no bran on endosperm. In Indian sub-continent, well-milled rice is preferred, while in Japan well-milled sticky rice is preferred. In America, semi-milled or brown rice is preferred by the consumers (Batres-Marquez *et al*., 2009).

Bran constitutes 5-7% of the total weight of brown rice. Ideally, only bran layer should be removed from the grain to obtain white rice. But commercially 10%, or even higher, DOM is frequently achieved. Mohapatra and Bal (2007) determined optimum DOM for three rice varieties, Pusa Basmati (long and slender variety), Swarna (medium grain variety) and ADT37 (short and round grain variety) as 10%, 12% and 13%, respectively; using specific energy consumption, grain colour and cooking qualities as basis. However, as per Rice Milling Industry (Regulation) Act 1958, rice should be milled only up to 4% (Puri *et al*., 2014). Rice loses nutritional value when milled at ≥10% DOM. The major reason behind over milling of raw rice is its rough surface. Brown rice kernel surface is undulating, making uniform and complete removal of bran from the grain surface difficult (Mohapatra and Bal, 2007). Even after ≥75% of the bran is removed from the surface, some streaks of bran are still left in the furrows (Mohapatra and Bal, 2007). Therefore, to produce a silky-white grain, raw rice is over-milled. Such over-milling (>5-7% DOM) removes the bran completely and also removes some portion of endosperm, which in turn leads to increase in the grain breakage.

In rice grain, outer layers of endosperm and bran layers contain major portion of nutrients like minerals, proteins, vitamins, etc. (Oghbaei and Prakash, 2016). During milling, these layers are removed from the grain, thus reducing the nutritive value of rice. Hansen *et al.* (2012) reported that considerable amount of iron is lost during milling as iron is mainly confined to the outer layers of rice grain. Adverse effects of over-milling on rice constituents like fat, ash, thiamine, phosphate and pigments that are mainly concentrated in the outer bran layers, have also been reported by different studies (Roy *et al*., 2008; Hansen *et al*., 2012). Hence, it is very crucial to know the optimum DOM level of every rice variety.

Milling induced losses of rice can be reduced using parboiling technique. Parboiling fills the void spaces and cracks within the grain and makes grain harder, thereby reducing the milling breakage. During soaking stage of parboiling, some of the micronutrients present in outer layers of grain leaches into the starchy endosperm, whereas during steaming step endosperm becomes amorphous compact mass and prevents the reverse flow of these nutrients, thus increasing the nutritional value of parboiled milled rice (Fofana *et al*., 2011; Ayamdoo *et al*., 2013; Kale *et al*., 2015; Kale *et al*., 2017; Kale *et al*., 2017a).

Information on effects of different DOMs on rice quality is essential to produce rice with better quality. Moreover, information on optimum DOM for raw and parboiled rice would be beneficial to the rice millers to produce rice with better quality and minimum breakage. Literature revealed that almost no reported information is available on determination of optimum DOM for raw and parboiled Pusa Basmati 1121 (PB1121) rice. Hence, an attempt was made to mill the raw and parboiled PB1121rice at six different DOM, and to evaluate the effects of DOM on head rice yield, cooking qualities, textural properties and mineral composition of raw and parboiled rice. Study was aimed at determining the optimum DOM for raw and parboiled PB1121 rice based on the cooking qualities, textural properties and mineral composition of rice samples.

MATERIALS AND METHODS

Freshly harvested one quintal of PB1121 paddy, one of the most popular Indian basmati variety of present times, was procured from the field of ICAR-Indian Agricultural Research Institute, New Delhi, India. Paddy was cleaned, screened, dried and used in study. Moisture content of paddy was 13.77% (d.b.). The study was conducted at the Division of Food Science and Technology, Indian Agricultural Research Institute, New Delhi, during the year 2013.

Paddy Processing

Parboiling of paddy

A sample of 200±0.5g of paddy was soaked in 500 ml distilled water at 65^{o}C for 345 min in a water bath (MAC, MSW-275, Micro Scientific Works (R), Delhi, India; temperature range: 5 - 100°C; internal dimensions (L x B x D)275 x 275 x 150 mm) till it achieved critical moisture content (approximately 42%, d.b.) of soaking as determined by Kale *et al.*(2013). Soaking water was drained, and paddy was immediately steamed in an autoclave (Horizontal Autoclave, Tradevel Scientific Industries, New Delhi, India; Operating pressure:0.1 – 2.0 kg.cm^{-2}) at 1.5 kg.cm^{-2} of pressure for 20 min (Kale *et al*., 2017). Thickness of paddy layer was kept at 10 mm during steaming. Steamed paddy was then dried to 13.21% (d.b.) moisture content under shed (at 20 - 30^{o}C) for 3 days, and subsequently used for further study. During drying, paddy layer thickness was maintained at 10- 15 mm.

Milling of raw and parboiled paddy

Both raw and parboiled paddy was dehusked using rubber roll sheller (Ambala Associates, Ambala, India; laboratory model, maximum capacity: 40 – 45 kg.h^{-1}) to produce brown rice. After dehusking, brown rice, brokens and un-husked grains were separated, weighed and expressed as percent of initial paddy weight. Brown rice was then milled using abrasive polisher (Ambala Associates, Ambala, India) to obtain milled rice with 5%, 6%, 7%, 8%, 9% and 10% DOM. One hundred grams of brown rice was placed in an abrasive polisher (sample capacity: 800 g; operating voltage: 220 v, 50 Hz, AC). Milling was carried out for 1 min. Sample was removed and weights of whole grains and bran were measured. The weight of germ (1-2% of grain weight) was deducted from the bran weight to get actual weight of the bran. Rice sample was again placed in the polisher and further milling was carried out for 15 s, followed by weighing the sample and bran. This process continued till the desired percent of bran was removed from the sample. Degree of milling (DOM, %), or percent bran, was determined as the bran weight divided by the initial weight of brown rice. Time required to achieve desired DOM was also noted.

Quality Parameters

Head rice yield (HRY) and brokens

HRY (%) was determined as weight of whole grains (≥3/4th of the grain length) divided by initial weight of the sample. Brokens obtained during dehusking and milling were collected and categorized into three classes, namely very fine (≤ 14 mesh size), fine (>14 mesh but < 1/4th of grain length) and coarse (≥1/4th of grain length but < 3/4th of grain length).

Cooking qualities of raw and parboiled rice

Optimum cooking time

Optimum cooking time of rice samples was determined using Ranghino test as suggested by Juliano and Bechtel (1985). One hundred ml of distilled water was taken in a 250 ml beaker and boiled at about 98±1°C. Five grams of rice grain was put into a beaker. After 10 min, and every minute thereafter, 10 grains of rice were removed from the beaker and pressed between two clean glass plates. Cooking time was recorded when at least 90% of the grains was not opaque with un-cooked centres or white bellies. Rice was then allowed to simmer for about another 2 min to ensure that the core of all grains had been gelatinized. Optimum cooking time included the additional 2 min of simmer.

Volume expansion ratio, length expansion ratio, water uptake ratio, gruel solid loss

Volume expansion ratio (VER), length expansion ratio (LER), water uptake ratio (WUR) and gruel solid loss (GSL, %) were determined using the methods suggested by Juliano and Bechtel (1985), Mohapatra and Bal (2006), Fofana *et al.* (2011), and Singh *et al*. (2011).

VER, LER and WUR were determined by cooking 1 g of head rice in 20 ml boiling water till optimum cooking time. LER was calculated as ratio of the length of cooked grain to that of un-cooked grain. Lengths of the raw and cooked rice grains was measured using a digital vernier caliper (Brand: Mitutoyo; measuring range: 0-150 mm; resolution: 0.01 mm).

VER was measured using toluene displacement method, and calculated as the ratio of the volume of cooked rice to the initial volume of un-cooked rice. Weights of the samples were measured using a digital weighing balance (Mettler Toledo™ MS-TS Analytical Balances; electrical requirements: 100-240V, ±10%, 50/60Hz, 0.3A, capacity: 320 g, readability: 0.1 mg).

WUR was calculated as the ratio of water absorbed during cooking to the weight of un-cooked rice. One g of rice was cooked in 20 ml distilled water till optimum cooking time. Grains were then removed from the water, surface water was wiped out, and weight of the cooked rice was measured. Water absorbed by the grains during cooking was determined by subtracting the weight of un-cooked grains (1 g) from the weight of cooked grains.

GSL (%) was determined by a method suggested by Singh *et al*. (2011). Here, weight of an PB1121empty beaker was measured, and 10 g of rice sample was cooked in 100 ml distilled water in the beaker till optimum cooking time. Further, cooked rice was removed from the water, surface water was wiped out and weight of cooked sample was measured. After removing the cooked grains, beaker was kept in a hot air oven (R B Electronic & Engineering Pvt. Ltd, Mumbai; maximum temperature: 250°C) along with water remaining in the beaker till the water was evaporated and the beaker dried. Weight of gruel solid was determined by subtracting the weight of empty beaker from the weight of beaker after drying. GSL (%) was calculated as the ratio of weight of gruel solid and weight of cooked grains multiplied by 100.

Cooking index

Cooking index (CI) is an important parameter for determining cooking quality. It combines all the characteristics viz. VER, LER, WUR and cooking time.

It was calculated using the equation (Eq.1)previously used by Mohapatra and Bal (2006).

$$\text{Cooking Index} = \frac{\text{VER} \times \text{LER} \times \text{WUR}}{\text{cooking time}} \quad \text{... (1)}$$

Textural profile analysis of cooked rice

Textural profile analysis (TPA) of raw and parboiled cooked rice was performed using texture analyser (Stable Micro Systems, UK, Model *TA+Di*, maximum force capacity: 750 kg, calibrated load cells down to 0.5 kg). Ten grams of rice sample was cooked in 200 ml distilled water at about 98±1°C for optimum cooking time. The cooked grains were then removed from water, and surface moisture was removed using blotting paper. Cooked hot rice grains were placed on the base of texture analyser (Juliano *et al*., 1984). A two-cycle compression force versus time program was used to compress the samples till 90% of the original cooked grain thickness, return to the original position and again compress (Mohapatra and Bal, 2006). A 10 mm diameter ebonite probe was used to compress 2–3 grains, with pre-test speed of 1 mm.min^{-1}, post-test speed of 2 mm.min^{-1} and test speed of 0.5 mm.min^{-1}. Parameters recorded from the test curves were hardness, fracturability, adhesiveness, cohesiveness, springiness, chewiness and gumminess. All textural analyses were replicated five times for each sample and means were recorded.

Mineral composition of milled rice

Some of the nutritionally essential minerals (K, P, S, Ca, Mg, Mn, Fe, Cu and Zn) in the raw and parboiled PB1121 rice were determined using di-acid digestion method. P and S were quantified using a colorimetric method with the help of a Spectrophotometer (Jasco, USA, Model: V-670; includes a double monochromator for exceptional resolution with extremely low stray light of 0.00008%; photometric range: up to 8 AU), K using a Flame photometer (Systronics India Limited, India, Flame Photometer 128, Microcontroller controlled automation, 20-character, 4-line alphanumeric LCD readout); while remaining minerals were quantified using an Atomic Absorption Spectrophotometer (Electronics Corporation of India Limited, India, AAS 4141, High resolution Ebert type Monochromator with 330 mm focal length and dual blaze grating operates over the wave length range 190 to 930 nm).

Determination of Optimum DOM

Optimization of the process parameters of a technological process is frequently done using response surface methodology and Box-Behenken design. But these methods have limitations as they do not incorporate all levels of variables (Tarko *et al*., 2017). On the contrary, principal component analysis (PCA) accommodates all levels of variables that influence the process. Main advantage of PCA is that it allows simultaneous analysis of several variables (Tarko *et al*., 2017). Reports indicate that, during optimization of technological processes, PCA isa useful tool to indicate the variables that have impact on the process (Rodríguez-Delgado *et al*., 2002; Liang *et al*., 2013; Tarko *et al*., 2017).

PCA is a multivariate approach developed for multi-correlated data. It projects the information available in the original variables into small number of new variables, called principal components (PCs). PCs are linear combinations of original variables. They are used as new axes in a plot of treatments (score plot) and a corresponding plot of variables (loading plot). They are orthogonal to each other and indicate the best description of the variability in the data in decreasing order. Thus, PC1 has highest score (value indicated in the bracket of loading plot, and projects the maximum variability in the original data and vice versa). Loading plots of PCA make it easy to get an overview of the original data and to determine which properties are related as well as which properties are most important in distinguishing between the treatments (Aamodt *et al*., 2003; Osella *et al*., 2008; Tarko *et al*., 2017; Alvarez *et al*., 2018).

In the present study, PCA was performed to determine the relationships between quality parameters of rice samples determined during study. Add in software XLSTAT (version 2014.5.03) was used to perform PCA. Optimum DOM for raw and parboiled rice samples was determined on the basis of PCA results.

Statistical Analysis

HRY, cooking qualities and textural properties of cooked rice were replicated five times, whereas, minerals were estimated in triplicate.

Duncan's multiple range test was performed to test the statistical differences in these properties as affected by DOM. SPSS statistical software version 16.0 (SPSS, INC., Chicago, USA) was used to conduct the tests. The significance was accepted at 5% level of significance (α=0.05).

RESULTS AND DISCUSSION

Dehusking of Raw and Parboiled PB1121 Paddy

Raw and parboiled paddy samples were dehusked prior to milling. Results (Table 1) indicated that dehusking of raw paddy took four passes to achieve desired level when only 3 - 4% of paddy remained un-husked, whereas, parboiled paddy took three passes to achieve the same level of dehusking. Thus, parboiling process made the dehusking of PB1121 paddy easier. It might be due to loosening and splitting of husk during parboiling. Brown rice, brokens, husk and un-husked paddy obtained from raw paddy were 57.18%, 14.52%, 24.62% and 3.43%, respectively; whereas that obtained from parboiled paddy was 62.59%, 7.08%, 25.17% and 4.25%, respectively. Thus, brown rice yield of parboiled paddy was higher (9.46%) than that of raw paddy, which clearly indicated the superiority of parboiled paddy in terms of brown rice yield over

Table 1. Different fractions of paddy obtained after dehusking

Sl. No.	Fraction	Raw paddy	Parboiled paddy
1.	Brown rice, %	57.18	62.59
2.	Brokens, %	14.52	7.08
3.	Husk, %	24.62	25.17
4.	Un-husked paddy, %	3.43	4.25

raw paddy. Buggenh out *et al*. (2013)had observed that cracks, chalkiness and incomplete filling of grain are completely healed and cemented during parboiling, which ultimately reduced the breakage during milling.

Effect of DOM on Milling Time and HRY

Milling time required to achieve desired DOM was lesser in raw rice than parboiled rice (Table 2). Due to increased hardness (from 11.16 N of raw rice to 17.92 N of parboiled rice) and tight adherence of bran with the endosperm, milling of parboiled rice was difficult, and that ultimately contributed to higher milling time requirement for parboiled rice as compared to raw rice. Results (Table 2) showed that the rate of bran removal from raw and parboiled grain (d_{DOM}/dt) was initially higher (3.37 and 2.31 DOM.min^{-1}, respectively), and it gradually decreased as the DOM increased from 5% to 10 per cent. At 10% DOM, this rate reduced to 1.86 DOM.min^{-1} and 1.53 DOM.min^{-1} for raw and parboiled rice, respectively. Initial higher rate of bran removal might be due to the fact that bran is softer than the endosperm. Visual observations indicated that after 7% DOM, milling started to remove the outer layers of endosperm (starchy white granules were observed in the bran) that were tightly held with the endosperm thus lowering the rate of bran removal. Also, removal of germ at initial stage of milling might have contributed to the higher initial rate of bran removal. Results also showed that rate of bran removal from raw rice were higher than that of parboiled rice. It might be due to the fact that bran and outer layers of endosperm of parboiled rice were tightly adhered to the endosperm as compared to raw rice, which led to reduced d_{DOM}/dt.

DOM as well as parboiling significantly (p=0.05) affected HRY (brown rice basis) of PB1121 rice (Table 3). HRY of parboiled rice at each corresponding DOM (as mentioned in Table 3) was higher by almost 10% than the HRY of raw rice, thereby underscoring the need of parboiling the PB1121 rice. Results (Table 3) also indicated that increase in DOM was linked to decrease in HRY of both raw and parboiled rice. In case of raw rice, HRY decreased by 9.70% when DOM increased from 5.05% to 10.29% (approximately 5%), whereas, this decrease was by 8.58% for parboiled rice. It might be influenced by the percentage of brokens, which was considerably higher in raw rice than parboiled rice at each corresponding DOM (Table 3). Higher level of DOM (10%) in raw rice led to heavy breakage (up to 17.80%), whereas maximum breakage was observed up to 8.09% in parboiled rice. Increased HRY due to parboiling has also been reported by Dutta and Mahanta (2012) and Buggenhout *et al*. (2013).

Table 2. Rate of bran removal from raw and parboiled (P) rice

Sl. No.	DOM, %	Rate, d_{DOM}/dt for raw rice	Rate, d_{DOM}/dt) for parboiled rice
1.	5	3.37	2.31
2.	6	2.18	1.84
3.	7	2.18	2.45
4.	8	2.18	1.38
5.	9	2.08	1.27
6.	10	1.86	1.53

Effect of DOM

Brokens obtained from dehusking and milling

Brokens obtained during dehusking as well as milling were collected and classified into three classes of(a) very fine (≤ 14 mesh size), (b) fine (>14 mesh, but < 1/4th of grain length), and (c) coarse (≥1/4th of grain length, but < 3/4th of grain length). Amounts of very fine, fine and coarse brokens obtained during dehusking of raw paddy were 19.42%, 30.44% and 49.66%, respectively; whereas that obtained during dehusking of parboiled paddy were 3.53%, 30.08% and 61.16% respectively (Table 4). Similarly, percentages of these

Table 3. HRY (brown rice basis) of Raw and parboiled rice with different DOM

Sl. No.	DOM, %	HRY (brown rice basis), %	Brokens, (%)
		NPR	
1.	5.05	81.61^{f}	13.34^{g}
2.	6.14	79.00^{e}	14.86^{h}
3.	7.23	77.08^{d}	15.69^{i}
4.	8.32	75.11^{c}	16.57^{j}
5.	9.36	73.53^{b}	17.11^{k}
6.	10.29	71.91^{a}	17.80^{l}
		PR	
1.	5.20	90.22^{k}	4.58^{a}
2.	6.12	88.61^{j}	5.27^{b}
3.	7.14	87.05^{i}	5.81^{c}
4.	8.06	85.51^{h}	6.43^{d}
5.	9.12	83.67^{g}	7.21^{e}
6.	10.27	81.64^{f}	8.09^{f}

Note: Values followed by same superscript alphabet in a column do not differ significantly (α=0.05) classes were 24.92%, 42.91%, 30.96% and 9.64%, 50.08%, 37.64% during milling (about 8% DOM) of raw and parboiled rice, respectively. Results (Table 4) revealed that percentage of very fine brokens was higher in case of raw rice during both dehusking and milling as compared to parboiled rice. It might be due to the fact that raw rice endosperm had cracks and voids within the grain, and its endosperm was composed of distinct polyhedral starch granules contributing to the presence of very fine brokens. On the contrary, starch was a compact mass without distinct starch granules, and thus small amount of very fine brokens was observed in case of parboiled rice (Fofana *et al*., 2011).

The study revealed that along with HRY, parboiling increased the amount of fine brokens and coarse brokens as well. These two fractions can be considered as marketable rice as they do not contain brokens smaller than ¼ of the whole grain length (Araullo *et al*., 1976). Thus, parboiling of PB1121 rice was found to be beneficial not only in improving head rice yield, but also beneficial in producing higher amount of marketable rice. During milling operation, the yield of fine brokens and coarse brokens together from parboiled rice was higher by almost 13.85% than that from raw rice.

Cooking qualities

Cooking times of raw and parboiled brown rice were 22 min and 24 min, respectively (Table 5). Such difference in cooking time might be due to hardness of parboiled rice as compared to raw rice. Results (Table 5) show that at 5% and 6% DOM, cooking time of raw rice was higher than that of parboiled rice; but at 7%, 8% and 9% DOM, both rices took same time to cook. At 10% DOM, cooking time of parboiled rice was higher than that of raw rice. Bran layer provided the major obstruction to water absorption during cooking. At 5% and 6% DOM, some portion of the bran was still present on the raw grain that contributed to higher cooking time. But, at these levels of DOM, parboiled rice took lesser time (1 to 2 min) to cook. Cooking time was decided on the basis of disappearance of white cores within the grain, and as parboiled rice starch was previously gelatinized (during parboiling), it took lesser time to disappear white cores and thus required lesser cooking time.

Table 4. Classification of brokens obtained after dehusking and milling

Sl. No.	Brokens classification	Brokens obtained, %			
		Dehusking		Milling	
		Raw paddy	Parboiled paddy	Raw rice	Parboiled rice
1.	Very fine	19.42^a	3.53^a	24.92^a	9.64^a
2.	Fine	30.44^b	30.08^b	42.91^c	50.08^c
3.	Coarse	49.66^c	61.16^c	30.96^b	37.64^b

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

VER, LE, WUR and GSL

VER, LE and GSL of both raw and parboiled rice increased with DOM (Table 5). VER was almost same for raw and parboiled rice at each DOM. LER of raw rice was more (4 - 22.94%) than that of parboiled rice at each corresponding DOM. It might be due to the compact, amorphous nature of parboiled rice starch, which showed low tendency to swell. WUR of raw rice was higher (16.09 - 40.62%) than that of parboiled rice at each DOM. From the results, it could be inferred that although white cores in the parboiled rice disappeared in shorter cooking time, its cooking was not over and could be continued for more duration to bring the rice to similar hardness (9.52 - 14.73 N) as that of cooked raw rice (Fig.1). Table 5 shows that GSL of parboiled rice was comparatively lesser than that of raw rice at each DOM, and might be due to harder and compact grain attributed to gelatinization.

Thus, results revealed that although white cores within the parboiled rice grain disappeared within shorter cooking time, its cooking could be extended to achieve higher VER, LER and WUR without considerable increase in GSL. Rice with high VER, LER and WUR and lesser cooking time is considered to have better cooking qualities. Length expansion, volume expansion and water uptake ratio are economically desirable in the food service industry as they lead to fuller plate for the same amount of rice (Gujral and Vishal, 2003).

It is evident from Table 5 that cooking index (CI) increased with DOM in both raw and parboiled rice, which further indicated that removal of bran layer allowed grain to absorb more water, increase in length and volume, and to reduce cooking time (Mohapatra and Bal, 2006). Table 5 also shows that parboiled rice had lower values of CI than the raw rice at each corresponding DOM, indicating the superiority of raw rice in terms of cooking qualities. But, cooking qualities of parboiled rice could be improved by extending the cooking time, which in turn would increase VER, LER and WUR. Parboiled rice starch has better ability to

Table 5. Effect of DOM on cooking qualities of raw and parboiled rice

Sl. No.	DOM, %	Cooking time, min	VER	LER	WUR	GSL, %	CI
				Raw rice			
1.	0	22 ± 2^{d}	1.66 ± 0.21^{a}	1.30 ± 0.33^{b}	1.01 ± 0.22^{b}	0.49 ± 0.21^{b}	0.10
2.	5	17 ± 2^{c}	1.77 ± 0.11^{b}	1.76 ± 0.21^{f}	1.57 ± 0.25^{i}	2.38 ± 0.22^{c}	0.29
3.	6	16 ± 3^{bc}	1.80 ± 0.32^{b}	1.79 ± 0.58^{f}	1.69 ± 0.66^{j}	5.62 ± 0.33^{j}	0.34
4.	7	15 ± 1^{abc}	1.95 ± 0.25^{d}	1.91 ± 0.56^{g}	1.80 ± 0.45^{k}	5.14 ± 0.48^{i}	0.45
5.	8	14 ± 2^{b}	1.96 ± 0.95^{d}	1.97 ± 0.45^{h}	1.51 ± 0.48^{h}	5.92 ± 0.24^{k}	0.42
6.	9	14 ± 2^{ab}	2.07 ± 0.06^{e}	2.05 ± 0.47^{i}	1.42 ± 0.45^{g}	6.41±0.84l	0.43
7.	10	13 ± 1^{ab}	2.09 ± 0.14^{e}	2.09 ± 0.46^{i}	1.37 ± 0.89^{fg}	7.99 ± 0.41^{m}	0.46
				Parboiled rice			
1.	0	24 ± 2^{e}	1.63 ± 0.11^{a}	1.25 ± 0.2^{a}	0.87 ± 0.21^{a}	0.40 ± 0.55^{a}	0.07
2.	5	15 ± 2^{abc}	1.75 ± 0.22^{b}	1.50 ± 0.36^{c}	1.13 ± 0.35^{c}	2.74 ± 0.48^{d}	0.20
3.	6	15 ± 3^{abc}	1.78 ± 0.64^{b}	1.59 ± 0.24^{d}	1.35 ± 0.44^{ef}	3.40 ± 0.65^{e}	0.25
4.	7	15 ± 1^{abc}	1.88 ± 0.32^{c}	1.61 ± 0.22^{d}	1.38 ± 0.91^{fg}	3.82 ± 0.45^{f}	0.28
5.	8	14 ± 1^{ab}	1.91 ± 0.15^{cd}	1.70 ± 0.87^{e}	1.31 ± 0.11^{de}	4.10 ± 0.45^{g}	0.30
6.	9	14 ± 2^{ab}	1.96 ± 0.24^{d}	1.71 ± 0.54^{e}	1.29 ± 0.08^{d}	4.10 ± 0.68^{g}	0.31
7.	10	14 ± 1^{ab}	2.06 ± 0.22^{e}	1.70 ± 0.22^{e}	1.28 ± 0.25^{d}	4.74 ± 0.84^{g}	0.32

[Mean ± SD; Values followed by same alphabet in a column do not differ significantly (α=0.05)]

swell and absorb more water than the raw rice starch, and it gives non-sticky cooked rice but requires considerably higher cooking time (Sareepuang *et al.*, 2008).

Textural Properties of Cooked Rice

Textural properties of rice are the indicators of its cooking qualities. It is evident from Fig.1 and Table 6 that fracturability (Fig.1a), hardness (Fig.1b), gumminess (Fig.1e), springiness (Fig.1f) and chewiness (Fig.1g) of cooked parboiled rice were higher than that of cooked raw rice at same DOM; whereas cohesiveness (Fig.1c) and adhesiveness (Fig.1d) of raw rice were higher than that of parboiled rice. Negative values of adhesiveness in Table 6 are due to negative force area of the first bite in test curves.

Hardness

Hardness of raw and parboiled rice decreased with DOM (Table 6 and Fig.1b). Its values for cooked raw and parboiled rice varied from 15.41 - 55.91 N and 16.83 - 83.00 N, respectively. Presence of bran layer might have added hardness to the cooked brown grain. Parboiled grains were more compact and firmer, which might have attributed extra hardness to the cooked grain.

Cohesiveness

Cohesiveness (degree to which the rice deforms rather breaks on compression) increased with DOM up to 6%, and subsequently decreased (Table 6 and Fig.1c). At lower DOM, bran tightly held the cooked endosperm, but after its removal starchy cooked endosperm crumbled. Results (Fig.1c) also showed that cooked raw rice had higher cohesiveness than the cooked parboiled rice. Adhesiveness (force required to lift the plunger from the food material after compression) increased with DOM in case of cooked raw rice (Table 6 and Fig.1d). But it was zero at all levels of DOM for cooked parboiled rice. With increasing DOM, proteins, fats, minerals and ash were removed from the grain and starchy endosperm were exposed as aleurone layer, pericarp and seed coat were removed during milling, thus increasing the adhesiveness of cooked rice (Park *et al.*, 2001). Parboiled cooked grains were non-sticky and more intact; and hence did not show any adhesiveness.

Springiness

Springiness is the rate at which a deformed material goes back to its original state after the deforming force is removed. Fig.1(f) and Table 6 shows that springiness of both raw and parboiled rice increased with DOM.

Table 6. Effect of DOM on textural properties of rice

Sl. No.	DOM, %	Fracturability, N	Hardness, N	Cohesiveness	Adhesiveness	Gumminess	Springiness	Chewiness
Raw rice								
1.	0	28.43^{h}	55.91^{l}	0.10^{b}	$(-)1.21^{a}$	5.61^{g}	0.66^{b}	3.68^{h}
2.	5	14.73^{d}	22.91^{j}	0.14^{d}	0.00	3.12^{f}	0.57^{a}	1.87^{f}
3.	6	9.52^{a}	12.19^{a}	0.10^{b}	$(-)0.16^{b}$	1.26^{a}	0.96^{ef}	1.22^{a}
4.	7	10.29^{b}	14.05^{d}	0.11^{c}	0.00	1.54^{b}	0.92^{e}	1.39^{c}
5.	8	10.19^{b}	13.59^{c}	0.11^{c}	0.00	1.55^{b}	1.01^{f}	1.59^{d}
6.	9	10.02^{b}	13.10^{b}	0.11^{c}	0.00	1.40^{ab}	0.92^{e}	1.29^{b}
7.	10	13.40^{c}	15.41^{e}	0.12^{d}	0.00	1.88^{c}	0.72^{c}	1.35^{c}
Parboiled rice								
1.	0	30.11^{i}	83.00^{m}	0.09^{a}	0.00	7.26^{h}	0.59^{a}	4.33^{i}
2.	5	17.32^{f}	26.44^{k}	0.11^{c}	0.00	2.81^{e}	0.85^{d}	2.40^{g}
3.	6	17.98^{g}	21.84^{i}	0.11c	0.00	2.39^{d}	0.95^{e}	2.26^{g}
4.	7	14.82^{d}	19.12^{h}	0.11^{c}	0.00	2.15^{cd}	0.82^{d}	1.74^{e}
5.	8	14.75^{d}	18.59^{g}	0.11^{c}	0.00	1.98^{c}	0.92^{e}	1.82^{f}
6.	9	14.06^{cd}	17.32^{f}	0.11^{c}	0.00	1.86^{c}	0.92^{e}	1.71^{e}
7.	10	15.28^{e}	16.83^{ef}	0.09^{a}	0.00	1.57^{b}	0.86^{d}	1.36^{c}

[Values followed by same superscript alphabet in a column do not differ significantly (α=0.05)]

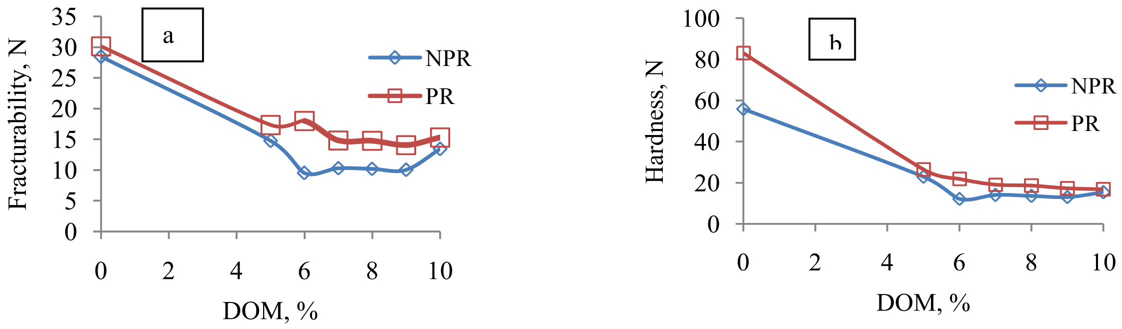
Chewiness is the product of hardness, cohesiveness and springiness. Hence, it represented the combined effect of these three properties. Fig.1(g) and Table 6 shows that chewiness decreased with DOM. Initial higher chewiness at lower DOM was due to high values of hardness. Parboiled rice exhibited more chewiness than raw rice, which was due to the firmness of cooked parboiled grains.

Therefore, it could be inferred that cooked parboiled rice was non-sticky (no adhesiveness) and firmer (higher chewiness) compared to cooked raw rice.This is a desirable effect for consumers who prefer such rice over sticky and soft rice.

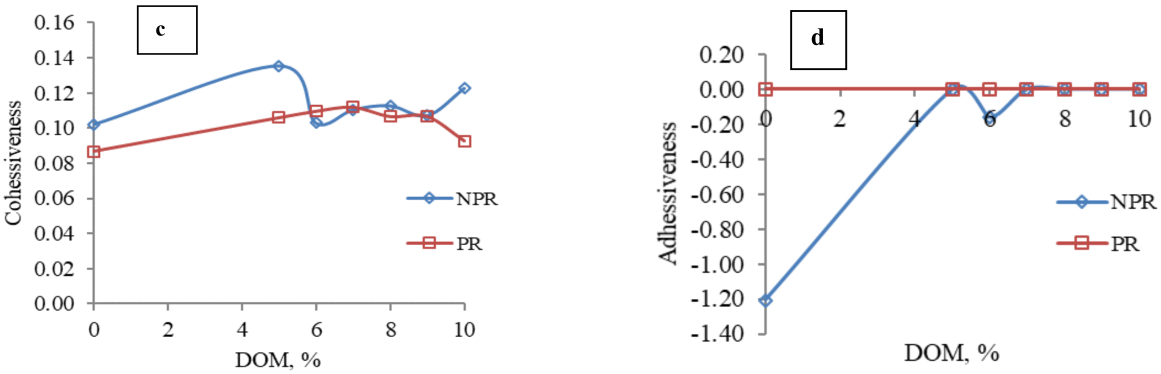
Mineral composition

Rice bran is a rich source of minerals. The bran is removed during milling, and hence the minerals as well. Table 7 presents the variations in mineral composition of raw and parboiled rice at different DOM values. It shows that brown rice in both cases had higher mineral composition than the polished rice at all DOM. P, K, Mg, Zn and S constituted the major portion (about 97%) of mineral composition in PB1121 rice. It is evident from Table 7 that P, Mg and Fe decreased with DOM in both raw and parboiled rice, depicting that these minerals were mainly concentrated in the bran and outer layers of rice grain. On the contrary, Mn, Zn, Cu and S were found to be almost constant with increasing DOM, indicating that these minerals were distributed evenly along the radius of the grain. Similar results were reported by Hansen *et al.* (2012) on Zn content of raw rice. K content of parboiled rice was found to be more than that of raw rice at each DOM, indicating diffusion of K from the husk and outer layers into the lower layers of the grain. P and Fe content of parboiled rice was more than the raw rice at each DOM. However, Ca was only found in the brown rice, and it was absent in polished raw and parboiled rice at any DOM.

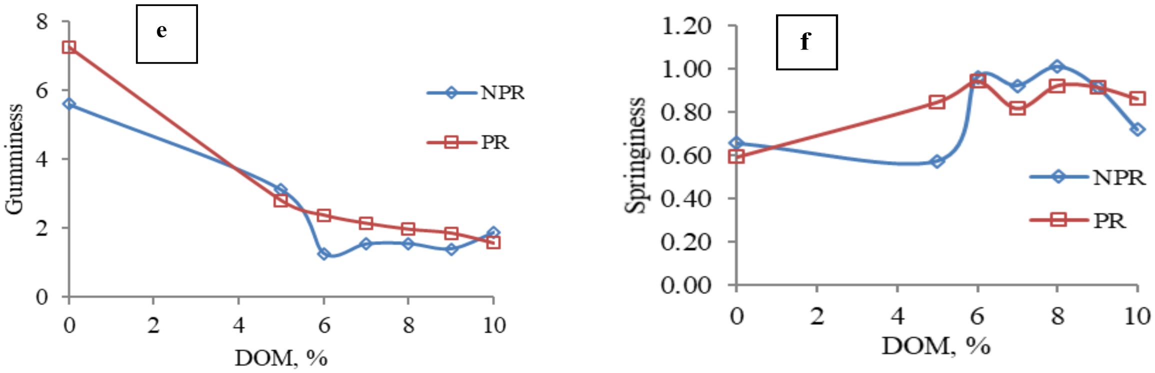
Total mineral content (last column of Table 7) in rice shows that mineral content of raw rice at 0% and 5% DOM was higher than that of parboiled rice at corresponding DOM. Parboiled rice had higher mineral content at DOM ≥6% as compared to raw rice. It might be due to the diffusion of minerals into the endosperm during parboiling (Kale *et al.*, 2015). Thus, results clearly show that though milling reduced the mineral composition of rice with increasing DOM, parboiling could retain higher amount of minerals thereby underscoring the nutritive value of parboiled polished rice.



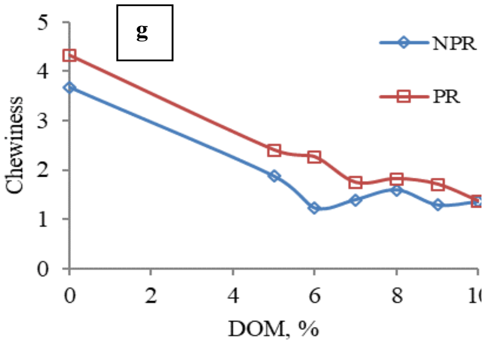
Fracturability **Hardness**



Cohesiveness **Adhesiveness**



Gumminess **Springiness**



Chewiness

Fig. 1: Effect of DOM on textural profile of cooked raw (NPR) and parboiled (PR) rice

Table 7. Mineral composition (mineral mg.100 g^{-1} rice) in raw and parboiled rice at different DOM

Sl. No.	DOM, %	P	K	Ca	Mg	Mn	Fe	Zn	Cu	S	Σ
Raw rice											
1.	0	172.90±11.32n	186.22±12.61	2.79±0.61	53.85±6.21k	0.35±0.06b	9.14±2.11i	43.18±6.36c	1.51±0.6i	34.59±6.39h	504.53±36.13m
2.	5	94.70±5.63h	204.84±14.17c	0.70±0.11	45.25±5.32i	0.48±0.05e	3.67±1.10e	38.64±6.55b	1.08±0.5d	35.54±4.36i	424.91±51.21j
3.	6	84.11±6.31e	186.22±12.61b	0.00±0.0	46.27±3.25i	0.62±0.11g	2.46±0.98b	37.13±4.32a	1.08±0.9d	48.87±7.21l	406.76±45.39f
4.	7	81.81±9.11d	186.22±12.61b	0.00±0.0	40.92±5.12g	0.55±0.02f	2.15±0.36a	40.15±4.25c	0.94±0.3b	39.35±3.21k	392.08±16.17e
5.	8	69.75±10.12c	167.60±16.55a	0.00±0.0	37.35±3.65f	0.62±0.06g	2.00±0.25a	46.21±2.15f	0.94±0.2b	32.09±4.51e	356.55±22.34c
6.	9	60.73±7.56b	167.60±16.55a	0.00±0.0	31.90±8.32d	0.48±0.09e	2.76±0.45c	37.13±6.36a	0.86±0.5a	31.42±6.25d	333.11±25.16a
7.	10	58.81±8.21a	167.60±16.55a	0.00±0.0	29.35±2.36c	0.62±0.06g	2.46±0.56b	49.24±8.22g	1.01±0.4c	31.55±1.25d	340.63±36.91b
Parboiled rice											
1.	0	163.87±14.21m	186.22±12.61b	2.09±0.61	51.93±83.21j	0.36±0.02c	9.14±1.25i	43.18±5.33c	1.15±0.5e	39.77±4.39k	497.72±25.14l
2.	5	98.37±12.21l	204.84±14.17c	0.00±0.0	41.61±2.32h	0.48±0.05e	5.85±1.16h	44.69±3.36e	1.44±0.6h	28.90±3.29b	422.18±41.29i
3.	6	96.76±4.32j	204.84±14.17c	0.00±0.0	34.43±4.21e	0.41±0.04d	5.65±0.95g	46.21±4.25f	1.29±0.8g	30.55±4.36c	420.15±17.91h
4.	7	95.07±6.21hi	204.84±14.17c	0.00±0.0	37.23±2.51f	0.34±0.06b	3.37±0.36d	40.15±4.22c	1.22±0.5f	38.38±4.25j	429.60±45.25k
5.	8	97.03±3.21jk	204.84±14.17c	0.00±0.0	29.08±6.21c	0.41±0.05d	3.37±1.14d	44.69±3.61e	3.02±1.6k	32.76±6.21f	415.21±49.31g
6.	9	87.40±9.54g	204.84±14.17c	0.00±0.0	23.08±3.91b	0.21±0.12a	4.43±1.31f	43.18±5.21d	3.53±1.4l	28.05±2.25a	394.71±31.14e
7.	10	85.76±5.21ef	186.22±12.61b	0.00±0.0	20.11±6.21a	0.34±0.09b	3.31±1.25d	44.69±6.18e	2.88±0.7j	33.84±6.21g	376.15±37.68d

[Mean ± SD; Values followed by same alphabet in a column do not differ significantly (α=0.05)]

PCA of Cooking Qualities and Textural Properties of Cooked Raw and Parboiled Rice

PCA was applied to cooking qualities and textural properties of raw and parboiled rice and summarized in Fig.2 (a, b). The highest explained variance (PC1) for raw rice was associated with adhesiveness, VER, LER, WUR and GSL in one direction; while fracturability, hardness, gumminess, chewiness and cooking time on opposite direction. It explained 74.59% variance, whereas second factor (PC2) explained about 14.30% variance. PC2 was found to be associated with cohesiveness and springiness.

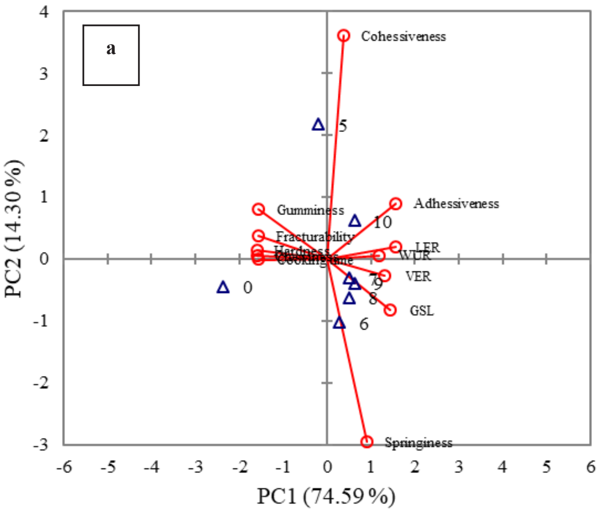


Fig.2a: **Plots of first two principal components obtained for cooking and textural properties of raw rice**

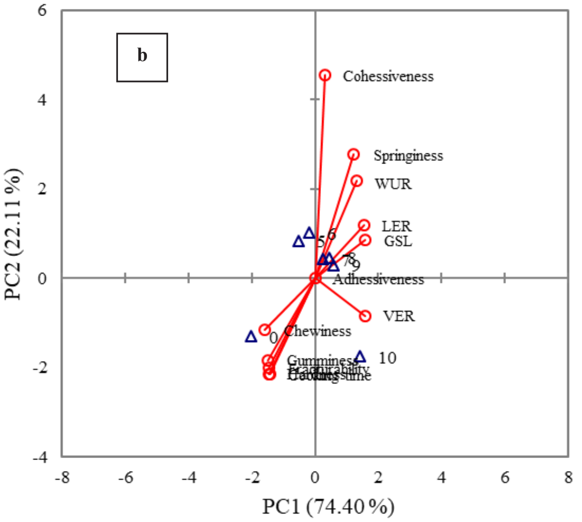


Fig.2b: **Plots of first two principal components obtained for cooking and textural properties of parboiled rice**

PC1 of parboiled rice explained 74.40% variance, and was found to be associated with springiness, VER, LER, WUR and GSL in one direction; whereas fracturability, hardness, gumminess, chewiness and cooking time in opposite direction. PC2, with explained variance equal to 22.11%, was found to be associated with cohesiveness only. PC1 and PC2 jointly could account for 88.89% and 96.51% of the total variance explained for cooking and textural properties of raw and parboiled rice, respectively.

It is evident fromFig.2 (a, b) that un-milled rice (0% DOM) in both raw and parboiled cases was associated with cooking time, hardness, fracturability and gumminess. But higher values of these attributes are related with poor cooking qualities. Thus, both raw and parboiled un-milled rice were found with poor cooking qualities. From Fig.1(a), it is clear that 6%, 7%, 8% and 9% DOM were loaded on the right side of PC1, and closely associated with VER, LER, WUR and adhesiveness which are desirable attributes. However, Fig. 2(b)suggest that 7%, 8%, 9% and 10% DOM were loaded on the right side of the PC1, and associated with desirable cooking quality attributes.

Thus,from PCA, it could be stated that raw rice milled with 6-9% DOM possessed better cooking qualities; whereas parboiled rice milled up to 7-10% DOM had better cooking qualities.

PCA of mineral composition for optimisation of DOM

PCA performed for mineral composition of raw and parboiled rice was carried out during the study. Results Fig.3 (a, b) revealed that in case of raw rice, factor PC1 was associated with P, Ca, Mg, Mn, Fe, Cu and Σ (total mineral composition); whereas factor PC2 was found to be associated with K, Zn and S only. PC1 explained 62.18% variance, whereas 24.08% variance was explained by PC2.

In case of parboiled rice, PC1 was found to be associated with P, K. Ca, Mg, Fe, Cu, S and Σ with 56.18% variance explained. Factor PC2 explained 18.69% variance, and was associated with Mn and Zn only.

Fig.3(a, b) obtained after varimax rotation indicate the location of DOM in the plot as well as its association with individual mineral. Fig.3(a) shows that observations for 0% DOM (un-milled) and 5% DOM

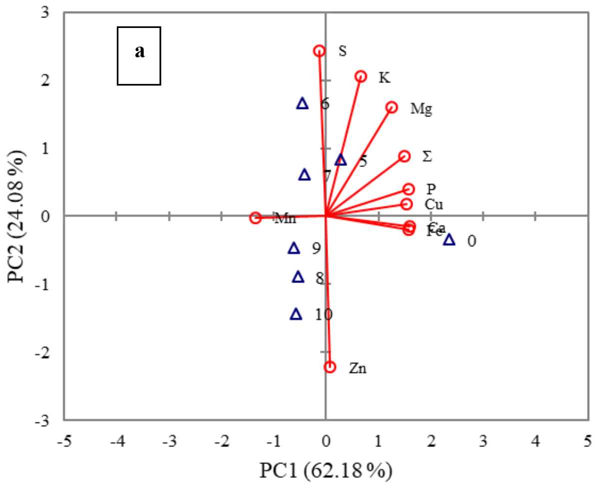


Fig. 3(a):Plots of first two principal components obtained for mineral composition of raw rice

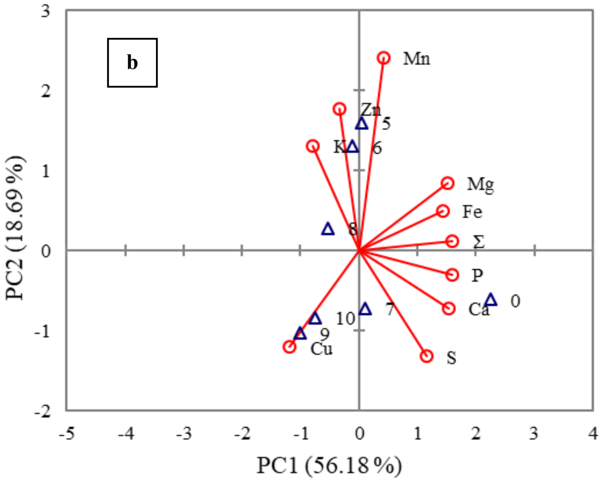


Fig. 3(b): Plots of first two principal components obtained for mineral composition of parboiled rice

were located on the right side of the PC1, and closely associated with almost all minerals.This indicated higher amount of minerals in these rice samples. It can also be observed that observations for 5%, 6% and 7% DOM were located on the upper half of the PC2, thereby indicating the presence of some of the minerals (S, K, Mg, P, Cu).Observations for 8%, 9% and 10% DOM did not show any close association with minerals, except Mn. Hence, on the basis of mineral composition, it can be commented that raw rice can be milled up to 7% DOM. In case of parboiled rice, Fig.3(b) shows that most of the minerals (Mn, Mg, Fe, P, Ca, S) were loaded on the right side of the PC1 and associated with observations for 0%, 5% and 7% DOM. DOM of 6% and 8% were loaded on the upper half of the PC2, and found to be associated with some portion of the mineral composition (Mn, Mg, Fe, Zn, K). However, observations for 9% and 10% DOM were found to be associated with only Cu. Thus, based on mineral composition, optimum DOM for parboiled rice was found to be 8 per cent.

Thus, on the basis of mineral composition, optimum DOM for PB1121 raw rice was found to be 7% and that for PB1121 parboiled rice was found to be 8 per cent. It can also be inferred that in case of raw rice, minerals were located in the bran layers and in the outer layers of endosperm. Milling of raw rice at ≥7% DOM removes maximum portion of the minerals from the grain. But parboiling diffused the minerals into the endosperm layers, and thus allowed additional milling (1% DOM) without affecting the mineral composition of parboiled rice as compared to raw rice.

Therefore, based on the results of PCA performed for cooking qualities, textural properties and mineral composition of raw and parboiled rice, it was concluded that raw PB1121 rice may be milled at ≤7% DOM, whereas parboiled rice may be milled at ≤8% DOM to produce rice with better cooking qualities and minimum reduction in its mineral composition.

CONCLUSIONS

Parboiled rice had lower values of cooking index than raw rice of PB1121 variety at each corresponding DOM, showing its inferiority to raw rice. However, fracturability, hardness, springiness, gumminess and chewiness of cooked parboiled rice were higher than that of raw rice at the same DOM; whereas cohesiveness and adhesiveness of rawrice were higher than that of parboiled rice. Cooked parboiled rice was thus non-sticky and firmer, compared to cooked raw rice. Mineral composition of brown rice was higher than that of milled rice. Mn, Zn, Cu and S were almost constant with increasing DOM. P, K and Fe content of parboiled rice was more than that ofraw rice at each DOM. Calcium was found in brown rice only. DOM adversely affected mineral composition of rice, but this effect was less severe in parboiled rice as parboiling diffused the minerals into the endosperm. PCA results revealed that raw and parboiled PB1121 rice should be milled up to 7% and 8% DOM, respectively, to obtain rice with better cooking qualities and minimum reduction in mineral content.

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