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Thermal optimization of parboiling conditions for modulating physical, milling and cooking quality attributes of rice (*Pusa Basmati-1*)

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ABSTRACT

The present investigation was conducted to study the effect of different soaking temperatures during parboiling on the physical, milling, colour and cooking characteristics of PB-1 rice. Raw paddy had a moisture content of $11.19 \pm 0.68\%$, bulk density of $465.3 \pm 29.0 \text{ kg/m}^3$, true density of $545.3 \pm 8.0 \text{ kg/m}^3$ and porosity of 14.67% . The colour values of raw paddy were 55.45, 6.43 and 27.46 for L^* , a^* and b^* , respectively. Paddy was soaked at 50, 60, 70 and 80 °C for 5 h, followed by steaming at 100 °C for 10 min and drying at 45 °C for 2 h. Moisture content after soaking increased from $47.94 \pm 0.49\%$ at 50 °C to $66.79 \pm 0.22\%$ at 80 °C. After steaming, moisture content ranged from 45.59 ± 1.21 to $74.41 \pm 0.84\%$, while after drying it ranged from 14.13 ± 0.22 to $19.01 \pm 0.59\%$. Milling rice yield was highest at 60 °C (78.99%), whereas head rice yield was highest at 50 °C (85.84%). Parboiling increased the L^* value of milled rice compared with raw paddy, while a^* values decreased with increasing soaking temperature. The highest water absorption and volume expansion were observed at 70 °C, with values of 324.0 and 343.75%, respectively. The results demonstrate that soaking temperature substantially influenced hydration, milling recovery, colour and cooking characteristics of PB-1 rice. The findings are consistent with earlier studies showing that soaking temperature and subsequent heat treatment influence water absorption, starch gelatinization, grain strength, milling yield and cooking quality.

Keywords: Paddy, Soaking temperature, Parboiling, Milling yield, Head rice yield, Broken rice yield

Introduction

Rice is one of the major cereal food crops and is consumed in different forms throughout the world. Paddy processing involves several operations, including cleaning, drying, parboiling, Dehusking, milling and polishing. Among these operations, parboiling is an important hydrothermal treatment used to improve the milling characteristics and functional quality of rice. Parboiling generally consists of three major operations: soaking, steaming and drying. During soaking, water penetrates into the rice kernel, increasing its moisture content. This is followed by steaming, during which starch gelatinization occurs. The parboiled grain is subsequently dried to a moisture content suitable for milling. These changes alter the physical structure of the endosperm and can improve grain strength and resistance to breakage during milling. The temperature of soaking is an important factor in determining the rate of water absorption. Bhattacharya *et al.* (1966) [1] reported that water absorption by paddy increases with increasing temperature and that appropriate hot-water soaking can improve milling quality. They also reported varietal differences in hydration and milling response. Parboiling can also influence rice colour. Increased severity of hydrothermal treatment may cause changes in reflectance characteristics and darker colour because of the movement of pigments and chemical reactions occurring during processing. Bhattacharya *et al.* (1966) [1] observed that soaking and steaming conditions affected the cooking quality and colour of parboiled rice. Previous research has demonstrated that soaking temperature significantly affects head rice yield, broken rice percentage, water uptake and other quality characteristics. In one study involving soaking temperatures from 40 to 80 °C, increasing soaking temperature and steaming duration affected head rice yield and cooking properties of rice. Therefore, the present study was undertaken to investigate the effect of soaking temperatures of 50, 60, 70 and 80 °C on the moisture absorption, milling yield, head rice yield, broken rice yield, colour characteristics and cooking properties of PB-1 rice. Milling characteristics of paddy were determined by using the procedure expressed by Alizadeh (2011) [2]. The head rice and broken rice were sorted directly by both outlets of sheller. Broken rice yield was very important milling characteristics for the determination of rice quality reported by Chavan *et al.*, (2016) [3].

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Materials and methods

Raw material

PB-1 paddy was selected and collected for the experiment from the Seed Processing Centre, SVPUAT Meerut. The raw paddy was cleaned to remove foreign matter and other extraneous materials before conducting the experimental treatments.

Determination of physical properties

The physical properties of raw paddy were determined in terms of moisture content, bulk density, true density and porosity, colour values etc.

Bulk density was determined from the mass occupied by a known volume of paddy without intentional compaction. True density represents the mass per unit volume of the actual grain material, while porosity represents the percentage of void spaces in the bulk grain. Colour characteristics were measured using a colorimeter (Make: 3nh colorimeter) and expressed values in terms of L^* , a^* and b^* .

- L^* represents lightness, ranging from 0 (black) to 100 (white).
- a^* represents the red (+) to green (−) axis.
- b^* represents the yellow (+) to blue (−) axis.

The same colour system was used for evaluating the parboiled milled rice.

Parboiling treatment

Paddy was subjected to four soaking temperatures: 50 °C, 60 °C, 70 °C, 80 °C. The soaking duration was 5 h for each treatment. After soaking, the paddy was steamed at 100 °C for 10 min. The steamed paddy was subsequently dried at 45 °C for 2 h. This experimental procedure is consistent with the general principle of rice parboiling involving hydration, thermal treatment and drying.

Milling Quality of paddy

In the process of removing the husk from paddy, the dried paddy (size: 1000 g) was milled using a Rice Sheller (Make: Nyagah Mechanical Engineering Ltd.), to separate the kernels from the husk. For the determination of the broken rice yield (%) was taken from the outlet of sheller in triplicate. The grains which were smaller than $\frac{3}{4}$ of the grain length were considered as the broken grains. The milling yield (%), head rice yield (%) and broken rice yield (%) were calculated by below given equations respectively reported by Kumar *et al.*, (2025) [4]; Bhattacharya *et al.*, (1966) [1]; Ishfaq *et al.*, 2023; IRRI, (2026) [5, 6].

Milling yield

$$\text{Milling rice yield (\%)} = \frac{\text{Weight of milled rice}}{\text{Weight of paddy}} \times 100$$

Head rice yield

$$\text{Head rice yield (\%)} = \frac{\text{Weight of head rice}}{\text{Weight of paddy}} \times 100$$

Broken rice yield

$$\text{Broken rice yield (\%)} = \frac{\text{Weight of broken rice (g)}}{\text{Weight of milled rice (g)}} \times 100$$

This approach is consistent with the milling-quality methodology reported by Miah *et al.*, (2002) [7], in which head rice yield was expressed as the percentage of whole kernels relative to total milled rice and broken rice was calculated as the remainder.

Cooking quality

Water absorption

Water absorption of milled rice was determined after cooking and expressed as the percentage increase in weight due to water uptake. Water uptake is an important cooking-quality characteristic because processing and starch properties influence the ability of rice kernels to absorb water during cooking reported by Juliano, (1985) [8]; Sood *et al.*, (1982) [9].

$$\text{Water absorption (\%)} = \frac{\text{Weight of cooked rice} - \text{Weight of raw rice}}{\text{Weight of raw rice}} \times 100$$

Volume expansion

Volume expansion was determined by comparing the volume of cooked rice with its volume before cooking. It is an important cooking-quality parameter and is influenced by grain characteristics and

$$\text{Volume expansion (\%)} = \frac{\text{Volume after cooking} - \text{Volume before cooking}}{\text{Volume before cooking}} \times 100$$

Elongation ratio

The cooked samples used in the water absorption and volume expansion tests will be used to determine the grain elongation ratio of the rice samples. Fifteen grains will randomly select from each replicate. The

length of the cooked and un-cooked grains will be measured using a digital vernier calliper reported by Kumar *et al.*, (2025) [4]; Villota *et al.*, (2016) [10].

$$\text{Elongation ratio (\%)} = \frac{L_c - L_u}{L_u} \times 100$$

Where,

L_c - Length of cooked rice in mm.

L_u - Length of uncooked rice in mm.

Results and discussion

Physical and colour characteristics of raw PB-1 paddy

The physical and colour characteristics of raw PB-1 paddy are presented in Table 1.

Physical characteristics of raw paddy

The initial moisture content of raw PB-1 paddy was $11.19 \pm 0.68\%$, while bulk density, true density and porosity were $465.3 \pm 29.0 \text{ kg/m}^3$, $545.3 \pm 8.0 \text{ kg/m}^3$ and 14.67% , respectively. These

physical properties are important in parboiling because they influence the movement of water and heat through the grain during soaking, steaming and drying. Grain moisture content determines the initial hydration status, whereas density and porosity influence the available void spaces and pathways for moisture movement. During parboiling, water penetrates into the paddy kernel and redistributes within the grain, resulting in substantial changes in moisture content. The observed physical characteristics provide the initial condition of the paddy before hydrothermal treatment. Variation in grain structure and physical properties among rice varieties can influence hydration, heat transfer and subsequent milling behaviour. The effect of processing conditions on moisture movement and milling quality has been reported in earlier studies on parboiled rice reported by Bhattacharya *et al.*, (1966) [1]; Miah *et al.*, (2002) [7].

Table 1. Physical and Colour properties of raw PB-1 paddy

Physical properties				Colour properties		
Moisture (%)	Bulk density (kg/m ³)	True density (kg/m ³)	Porosity (%)	L*	a*	b*
11.19 ± 0.68	465.3 ± 29.0	545.3 ± 8.0	14.67	55.45	6.43	27.46

Colour characteristics of raw PB-1 paddy

The raw PB-1 paddy showed an L^* value of 55.45, an a^* value of 6.43 and a b^* value of 27.46 given in the Table. 1. The positive a^* value indicated a tendency towards the red direction, while the positive b^* value indicated a yellow component. Colour is an important quality attribute of rice because hydrothermal treatment can modify the optical characteristics of the grain. During parboiling, soaking and steam-

ing may promote the movement of water-soluble pigments and other compounds from the outer layers towards the endosperm. The intensity of these changes depends on the severity of soaking and steaming conditions. Thus, colour characteristics can be used to assess changes occurring in rice during hydrothermal processing, similar trends were followed by Bhattacharya *et al.*, (1966) [1]; Yadav *et al.*, (2008) [11].

Changes in moisture content during parboiling

Table 2. Changes in moisture content during parboiling at different soaking temperatures

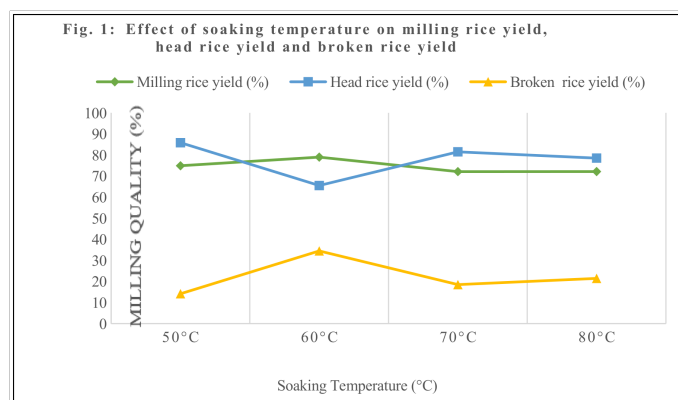
Soaking temperature	Raw paddy (%)	Soaking, 5 h (%)	Steaming, 100 °C, 10 min (%)	Drying, 45 °C, 2 h (%)
50 °C	11.19 ± 0.68	47.94 ± 0.49	45.59 ± 1.21	19.01 ± 0.59
60 °C	11.19 ± 0.68	45.10 ± 0.22	46.43 ± 0.12	18.82 ± 1.65
70 °C	11.19 ± 0.68	49.23 ± 0.28	55.23 ± 0.17	14.13 ± 0.22
80 °C	11.19 ± 0.68	66.79 ± 0.22	74.41 ± 0.84	16.85 ± 0.20

A considerable increase in moisture content was observed after soaking at all temperatures. The moisture content increased from 11.19% in raw paddy to 47.94, 45.10, 49.23 and 66.79% after soaking at 50, 60, 70 and 80 °C, respectively. The highest moisture content was obtained at 80 °C ($66.79 \pm 0.22\%$), indicating greater water uptake at the higher soaking temperature. The increase in moisture content with increasing soaking temperature can be attributed to the enhanced rate of water diffusion into the grain at higher temperatures. Temperature increases the rate of moisture transfer and reduces the time required for hydration. However, the present results also show that the response was not perfectly linear because the moisture content at 60 °C was slightly lower than that at 50 °C. Such variation may be associated with differences in grain structure, moisture distribution and experimental behaviour during soaking. After steaming at 100 °C for 10 min, moisture contents were 45.59, 46.43, 55.23 and 74.41% at 50, 60, 70 and 80 °C, respectively. The highest moisture content after steaming was again recorded at 80 °C. Steaming provides additional heat and moisture and promotes hydrothermal changes within the grain. Following drying at 45 °C for 2 h, moisture content decreased to 19.01, 18.82, 14.13 and 16.85%, respectively given in the Table 2. The reduction was associated with moisture removal during drying. The greater water uptake at higher soaking temperatures is in agree-

ment with the established effect of temperature on paddy hydration during parboiling reported by Bhattacharya *et al.*, (1966) [1]. Similar effects of hot soaking on moisture absorption and subsequent rice quality have also been reported by Miah *et al.* (2002) [7].

Milling quality

Milling rice yield of parboiled rice: The milling rice yield of Pusa Basmati-1 rice varied with soaking temperature, ranging from 72.12 to 78.99%. The highest milling rice yield (78.99%) was recorded at 60 °C, followed by 74.89% at 50 °C, whereas the lowest milling rice yield was observed at 70 °C (72.12%), followed by 80 °C (72.14%) given in the Fig. 1. The increase in milling yield from 50 to 60 °C may be attributed to improved moisture absorption and more uniform hydration of the grain, which can strengthen the kernel structure and reduce losses during milling. However, the reduction in milling yield at 70 and 80 °C may be associated with excessive hydrothermal treatment and changes in kernel structure that can increase milling losses. Bhattacharya *et al.* (1966) [1] reported that soaking and hydrothermal processing conditions considerably influence the milling recovery of rice, while Miah *et al.*, (2002) [7] observed that appropriate hot-soaking conditions improve the physical integrity of rice kernels and consequently affect milling quality. Thus, under the present experimental conditions, 60 °C resulted in the highest milling rice yield (78.99%).



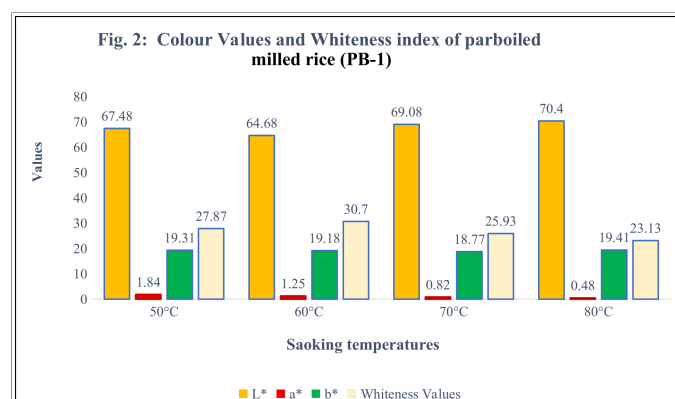
Head rice yield of parboiled rice: Head rice yield ranged from 65.53 to 85.84%. The maximum head rice yield was obtained at 50 °C (85.84%), whereas the minimum was observed at 60 °C (65.53%) given in the Fig. 1. The results indicate that head rice recovery did not follow a linear relationship with soaking temperature. Head rice yield is influenced by grain strength, internal fissures, moisture distribution and the severity of hydrothermal treatment. Parboiling can improve kernel strength through starch gelatinization and structural modification of the endosperm, thereby reducing breakage during milling. However, the effectiveness of treatment depends on the combination of soaking, steaming and drying conditions. The high head rice yield obtained at 50 °C may indicate that the treatment provided adequate hydration and thermal modification without causing excessive structural changes. In contrast, the considerably lower value at 60 °C suggests that the response of PB-1 was influenced by treatment-specific moisture distribution or drying behaviour. Similar effects of hot soaking and parboiling conditions on milling and head rice yield have been reported previously by Miah *et al.*, (2002) [7]; Meresa *et al.*, (2020) [12].

Broken rice yield of parboiled rice: The broken rice yield of Pusa Basmati-1 rice varied considerably with soaking temperature, ranging from 14.16 to 34.47%. The lowest broken rice yield (14.16%) was observed at 50 °C, whereas the highest (34.47%) was recorded at 60 °C. Thereafter, broken rice yield decreased to 18.49% at 70 °C and increased slightly to 21.47% at 80 °C. The higher broken rice yield at 60 °C indicates greater kernel breakage during milling given in the Fig. 1, which may be associated with differences in moisture absorption and distribution within the grain during soaking. In contrast, the lower broken rice yield at 50 and 70 °C suggests better kernel integrity and greater resistance to milling stress. Miah *et al.*, (2002) [7] reported that suitable soaking and parboiling conditions can reduce internal fissuring of rice kernels, thereby reduce breakage and increase head rice yield. Similarly, Bhattacharya *et al.* (1966) [1] reported that soaking conditions influence the milling behaviour of rice and that insufficient or inappropriate processing may increase kernel breakage. Thus, under the present experimental conditions, 50 °C resulted in the lowest broken rice yield, while 60 °C produced the highest broken rice yield

Colour properties of parboiled milled rice

The L^* values of parboiled milled PB-1 rice ranged from 64.68 to 70.40. The highest L^* value was recorded at 80 °C (70.40), while the lowest was observed at 60 °C (64.68). The a^* value decreased progressively from 1.84 at 50 °C to 0.48 at 80 °C, indicating a reduction in the red component. The b^* values varied relatively little, from 18.77 to 19.41. The increase in L^* compared with the raw paddy indicates a change in the optical properties of the milled grain after parboiling and milling Fig. 2. Removal of the outer layers during milling can substantially modify the measured colour. Changes in a^* and b^* values may also be associated with the migration and redistribution of coloured compounds during soaking and steaming. The reduction in a^* value with increasing soaking temperature indicates that soaking temperature influenced the red-green component of the grain colour. Hydrothermal treatment can alter the colour of rice through the mi-

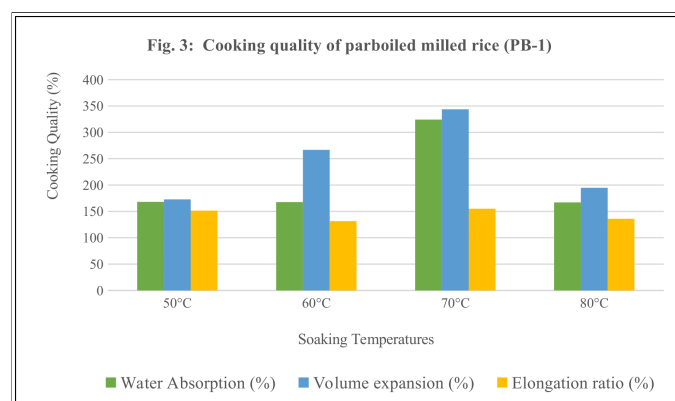
gration of compounds from the bran and outer layers and through chemical changes occurring during heating similar trends were followed by Bhattacharya *et al.*, (1966) [1]. Therefore, the colour changes observed in the present study demonstrate that soaking temperature affected the visual quality of parboiled PB-1 rice.



Whiteness index

The whiteness index of parboiled milled PB-1 rice ranged from 23.13 to 30.70 $\pm$ 0.43. The highest whiteness index was observed at 60 °C (30.70 $\pm$ 0.43), whereas the lowest value was obtained at 80 °C (23.13 $\pm$ 0.29) given in the Fig. 2. The lower whiteness index at the higher soaking temperature may be associated with greater hydrothermal treatment and the migration of compounds from the outer layers into the endosperm. More severe parboiling conditions can modify the optical properties of rice and reduce the perceived whiteness of the grain. The present observation is therefore consistent with the general influence of parboiling severity on rice colour and whiteness similar trends were followed by Bhattacharya *et al.*, (1966) [1]; Yadav *et al.*, (2008) [11].

Cooking quality



Water absorption: Water absorption showed considerable variation among the treatments. The values were 168.0, 167.6, 324.0 and 167.0% at 50, 60, 70 and 80 °C, respectively. The maximum water absorption was recorded at 70 °C (324.0%). Water absorption is an important cooking-quality characteristic because parboiling modifies the structural and physicochemical properties of rice starch. During hydrothermal treatment, starch undergoes gelatinization and structural rearrangement. These changes can influence the subsequent ability of the milled rice to absorb water during cooking. The substantially higher water absorption at 70 °C was accompanied by higher volume expansion and elongation ratio at the same temperature. This indicates that the treatment at 70 °C produced a distinct cooking response in PB-1 rice Fig. 3. However, the lower values at 50, 60 and 80 °C indicate that water absorption did not simply increase with soaking temperature. The result suggests that the relationship between soaking temperature and cooking quality depends on the extent of hydration

and the structural changes produced during parboiling. The effect of hot soaking on water absorption and cooking behaviour of rice has also been reported by Miah *et al.*, (2002) [7], while differences in hydrothermal treatment have been shown to influence starch-related cooking properties (Patindol *et al.*, 2015) [13].

Volume expansion: Volume expansion ranged from 172.73 to 343.75%, with the highest value recorded at 70 °C (343.75%), followed by 60 °C (266.67%), 80 °C (194.74%) and 50 °C (172.73%). The high-volume expansion at 70 °C corresponds with the maximum water absorption observed at the same temperature. During cooking, absorbed water causes hydration and swelling of the starch matrix, resulting in an increase in the volume of the rice grain. The extent of expansion is affected by the starch characteristics and structural changes produced during hydrothermal processing. The results indicate that the 70 °C treatment promoted greater cooking expansion than the other treatments Fig. 3. The relationship between water absorption and volume expansion observed in the present study is consistent with the role of starch hydration and structural modification in determining rice cooking quality were found by Miah *et al.*, (2002) [7]; Patindol *et al.*, (2015) [13].

Elongation ratio: The elongation ratio ranged from 131.51 to 155.03%. The maximum elongation ratio was recorded at 70 °C (155.03%), followed by 50 °C (151.36%), 80 °C (135.91%) and 60 °C (131.51%). The comparatively higher elongation at 70 °C corresponded with the maximum water absorption and volume expansion observed at the same temperature Fig. 3. This indicates that the hydrothermal history of the grain influenced its cooking behaviour. During cooking, water penetration and starch swelling contribute to expansion of the rice kernel. However, the extent of elongation depends not only on water absorption but also on kernel structure and starch characteristics. Hydrothermal treatment can modify starch structure and consequently influence water uptake, swelling and grain expansion during cooking were followed by Patindol *et al.*, (2015) [13]. Similar effects of parboiling conditions on cooking properties have been reported in studies evaluating different soaking and steaming conditions similar trends were followed by Meresa *et al.*, (2020) [12].

Overall discussion

Overall, the results demonstrate that soaking temperature substantially influenced the physicochemical, milling and cooking characteristics of PB-1 rice. Increasing soaking temperature generally promoted moisture uptake, with the highest soaking moisture content recorded at 80 °C (66.79%). However, milling and cooking characteristics did not show a simple linear response. The highest milling rice yield was obtained at 60 °C (78.99%), whereas the highest head rice yield and lowest broken rice yield were obtained at 50 °C (85.84 and 14.16%, respectively). In contrast, the maximum water absorption (324.0%), volume expansion (343.75%) and elongation ratio (155.03%) were observed at 70 °C. These findings indicate that the soaking temperature producing maximum milling recovery was different from the temperature producing maximum cooking expansion. The differences among treatments can be attributed to variations in hydration, moisture redistribution, starch transformation and drying behaviour during parboiling. Parboiling involves a sequence of soaking, steaming and drying operations, and each stage contributes to the final structural and functional properties of rice followed by Bhattacharya *et al.*, (1966) [1]; Miah *et al.*, (2002) [7]. Therefore, evaluation of parboiling conditions should consider several quality attributes rather than relying on a single parameter. The present findings are also consistent with previous studies showing that hydrothermal processing can influence head rice yield, water uptake, milling quality and cooking characteristics similar trends were followed by Meresa *et al.*, (2020) [12]; Mohanty *et al.*, (2002) [14]. Thus, the observed differences among soaking temperatures appear to reflect the combined effects of hydration and thermal treatment on PB-1 grain structure.

Conclusion

The study demonstrated that parboiling temperature had a considerable influence on the moisture content, milling yield, head rice yield, colour, whiteness index, water absorption, volume expansion and elongation ratio of PB-1 rice. Moisture absorption increased considerably during hot-water soaking, with the highest moisture content after soaking observed at 80 °C. Milling rice yield was highest at 60 °C, whereas head rice yield was highest at 50 °C, the lowest broken rice yield was obtained at 50 °C. The highest water absorption, volume expansion and elongation ratio were observed at 70 °C. Colour characteristics also varied with soaking temperature, particularly L^* and a^* values. Thus, the results indicate that soaking temperature is an important processing variable in the parboiling of PB-1 rice. Therefore, optimization of parboiling conditions should consider milling recovery together with head rice yield, broken rice yield, colour and cooking characteristics rather than relying on a single quality attribute.

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Conflicts of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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