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Research article

Improvement of parboiled brown rice properties using pre-germination process

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Abstract

Importance of the work: Germination and parboiling were employed to improve the parboiled pre-germinated brown rice production.
Objectives: To improve parboiled brown rice properties using a pre-germination process.
Materials & Methods: Pre-germinated brown rice (PGBR) samples were prepared from paddy of Thai rice cultivars: Chai Nat1 (CNT1), Riceberry (RB) and Sun-Pah-Twang1 (SPT1). All samples were soaked in water at 30 °C for 12 hr and then incubated at 30 °C for 32–38 hr. Subsequently, all PGBR samples were parboiled under mild (100 °C, 10 min, 0 bar) and severe conditions (120 °C, 10 min, 1.05 bar) for comparison, before being dried until the moisture content was less than 12%. Later, all samples were analyzed for their physical, chemical and physicochemical properties.
Results: Increased head rice yield and decreased yellowness were significantly affected by severe parboiling, while mild parboiling increased the redness of PPGBR from CNT1and SPT1. Both conditions of parboiling increased the crude protein (9.27–10.70%) and lipid (3.69–4.64%) contents but decreased the total starch content (80.78–81.98%). The alkali spreading score of CNT1 was 5 points (gelatinization temperature (GT) at 70–74 °C), while both RB and SPT1 had scores of 6 points (GT at 65–69 °C) under mild and severe parboiling, respectively. All three Thai rice cultivars showed a V-type X-ray diffraction pattern. Scanning electron micrographs confirmed gelatinization of the PPGBR for all three Thai rice cultivars with parboiling. Texture analysis revealed that cooked PPGBR had a lower hardness than cooked PBR for all three Thai rice cultivars.
Main finding: Combined severe parboiling with germination improved the PPGBR quality of all rice cultivars.

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Introduction

Modern-day consumers are increasingly attracted to pre-germinated brown rice (PGBR), which contains many bioactive compounds (Liu et al., 2020). Soaking and germination improve the texture of pre-germinated brown rice (PGBR), which also has high nutritional value, a soft texture after cooking and several other health benefits (Tian et al., 2004; Han et al., 2016). Parboiling is a hydrothermal process consisting of soaking, gelatinization and dehydration that changes the physicochemical, nutrition, cooking and organoleptic properties of the rice grain (Liu et al., 2020). It reduces rice stickiness, increases hardness and darkens the color (Lamberts et al., 2006; Tian et al., 2018; Liu et al., 2020). Thailand's export of parboiled rice was estimated at USD 475.59 million (Thai Customs, 2021). However, no parboiled rice is sold in Thailand because it is not popular among Thai consumers due to its hard crumbly texture and smell (Tansuchat et al., 2017). Three important changes in rice constituents occur during parboiling (Derycke et al., 2005). The first is starch gelatinization, which has an impact on the organoleptic properties of cooked parboiled rice. The second, the formation of crystalline amylose-lipid complexes during heating affects the firmer texture (Tian et al., 2018; Liu et al., 2020). The third change, the formation of disulfide bonds between components of the rice protein fraction, contributes to a harder and less sticky cooked rice texture (Han et al., 2016). Germination treatment has been used to improve the quality of parboiled brown rice. Soaking and germinating treatment of paddy is commonly used in parboiling, which is conducted under a restricted moisture content of more than 30% for 10–14 hr at 28–30 °C, with an incubating temperature of 28–35 °C for 16–24 hr (Panchan and Naivikul, 2009; Moongngarm and Saetung, 2010; Rattanadee and Naivikul, 2011). It is reported that germination of paddy increased the nutritional value and improves the cooking quality of parboiled brown rice (Han et al., 2016; Hu et al, 2019). On the other hand, in addition to parboiling conditions, the rice cultivar are also important for producing parboiled pre-germination. Han et al. (2016) found that the medium or long grains of rice can combine parboiling with germination to enhance the physicochemical properties of parboiled brown rice. However, the textural properties for both long and medium grains, which have different amylose content, are unaffected. Nevertheless, studies have been performed on correlating rice cultivars, germination and steaming to the quality of parboiled brown rice. In terms of final product quality, rice cultivars and steaming are efficient in achieving cooked quality (Han et al., 2016). However, very little work has been done on the comparative effect of rice cultivars, germination and steaming on the quality of parboiled pre-germinated brown rice (PPGBR). The goals of this study were to improve the properties of parboiled brown rice using the pre-germination process and to evaluate the properties of parboiled brown rice affected by three Thai rice cultivars and different parboiling methods, with potential applications on alternative raw materials to produce soft-textured parboiled rice.

Materials and Methods

Rice materials

Three Thai rice cultivars (*Oryza sativa* L.): Chai Nat1 (CNT1, high amylose, 30.78%); Riceberry (RB, low amylose, 15.55%); and San-Pah-Twang1 (SPT1, waxy, 1.75% amylose content). The Chai Nat1 paddy was purchased from the Pathum Thani Rice Research Center, Pathum Thani, Thailand. Riceberry paddy was kindly supplied by the Rice Gene Discovery and Rice Science Center, Kasetsart University, Kamphaeng Sean Campus, Nakhon Pathom, Thailand. San-Pah-Twang1 was purchased from the Chiang Mai Rice Research Center, Chiang Mai, Thailand. The paddy was cleaned and stored in plastic bags at -18 °C until use.

Preparation of pre-germinated brown rice and parboiled pre-germinated brown rice

PGBR samples were carried out as described in the previous study (Rattanadee and Naivikul, 2011; Yamirudeng and Naivikul, 2016) by soaking the rice paddy (250 g) in 30 °C water for 12 hr and changing the soaking water every 6 hr to avoid microbial growth. The soaked paddy samples were placed in 11.5 cm ×17 cm ×3.8 cm plastic boxes layered with wet cotton cloth and covered with lids. All samples were incubated at 30 °C and 85% relative humidity until reaching embryonic growth at 1–2 mm shoot length for 32 hr (CNT1), 34 hr (RB) and 38 hr (SPT1). The PPGBR samples were prepared following Rattanadee and Naivikul (2011) with some modifications. All samples were heated by steaming in a quick pressure cooker (FAGOR, Innova 6.1., Spain) at different temperatures and times (100 °C for 10 min at 0 bar for mild parboiling conditions and 120 °C for 10 min at 1.05 bar for severe parboiling conditions). The control sample of parboiled brown rice (PBR) was steamed at 121 °C for 8 min. All samples were dried using a tray dryer at 45 ± 10 °C until the moisture content was less than 12% and then dehulled using a dehuller (Thongthawee, Thailand). The flour from all samples was ground and passed through a 100-mesh sieve, packed in plastic bags and stored at -18 °C for further analysis.

Physical properties

Percentage of head rice yield

To determine the percentage of head rice yield (% HRY), the parboiled paddy rice samples were first shelled using a laboratory rice dehuller (Sinthavee Garage, Thailand). The resulting brown rice was separated into head rice and broken kernels on a shaker (Sinthavee Garage, Thailand). The percentage HRY was calculated using the weight of brown rice (Patindol et al., 2008).

Color measurements

The color of rice samples was increased tenfold by placing them in a clear Petri dish covered with a white plate. Color was measured as L*, a*, and b* color spaces: L* is a brightness measure ranging from black (0) to white (100); a* describes a red-green color, with positive a* values indicating redness and negative a* values indicating greenness; and b* describes a yellow-blue color, with positive b* values indicating yellowness and negative b* values indicating blueness.

Chemical properties

The crude protein content and crude lipid content of the rice samples were determined following the approved methods of Association of Official Analytical Chemists (2002). A factor of N × 5.95 was applied to convert nitrogen to crude protein content. The total starch content was determined following the approved methods of American Association of Cereal Chemists (2000) using the Megazyme Assay Kit (Megazyme Intl. Ireland Ltd., Ireland).

Physicochemical properties

Determination of alkali spreading scores

All alkali spreading scores of all samples were determined following the modified method of Juliano (1985) using duplicate samples of 10 grains soaked in 10 mL of 1.7% KOH at 30 °C for 23 hr. Then, the soaked rice grains were scored from 1 to 7; (1 = intact; 2 = grain slightly swollen; 3 = grain swollen, collar incomplete and narrow; 4 = grain swollen, collar complete and wide; 5 = grain split or segmented, collar complete and wide; 6 = grain dispersed, merging with collar; and 7 = greatly dispersed), corresponding to gelatinization temperatures of: 2–3 high (75–79 °C); 4–5, intermediate (70–74 °C); and 6–7, low (55–69 °C).

Scanning electron microscopy

The morphology of all rice samples was examined using a scanning electron microscopy (SEM; JSM 5600LV, JOEL, Japan) at a 20 kV accelerating voltage. Samples were mounted on an aluminum stub, sputter-coated with gold and investigated using SEM following the modified method of Poochinya et al. (2007).

X-ray diffraction patterns

PPGBR flour X-ray diffraction (XRD) patterns were determined using an X-ray diffractometer (Panalytical, X-Pert PRO, Japan) equipped with graphite crystal monochromatic Cu-K radiation of 1.542 A°, 30 kV, scanning, 2-theta 4–40°, step angle of 0.02°, count time of 0.5 s, divergence slit of 1°, receiving slit of 1/2° and scattering slit of 1/4°.

Textural properties

Cooked PPGBR samples were prepared using an automatic rice cooker (KSH-D06 SHARP, Japan). Water was added to each the PPGBR with a ratio of 1: 2.7 (CNT1), 2.4 (RB) and 2.3 (SPT1), respectively. The switch was turned off automatically after the rice had been cooked for 20 min. Samples of the cooked rice were held in the rice cooker for an additional 15 min. The cooked rice was removed from the rice cooker for texture analysis. A texture analyzer (TA-XT Plus, Stable Micro Systems, UK) was utilized to examine the textural properties of the cooked PPGBR according to Tian et al. (2004). Three cooked PPGBR grains were placed at the center of a 25 mm diameter cylinder aluminum probe at a pre-test speed of 1 mm/s, a test speed of 0.5 mm/s, a post-test speed of 1 mm/s and a trigger force of 10 g. The deformation level was 60% of the original sample height and the partly broken rice was compressed again. The parameters recorded from the test curves were hardness and cohesiveness. All texture analyses were replicated at least 10 times for each sample and the results were presented as mean values for statistical analysis.

Statistical analysis

The SPSS Version 11 software (SPSS, USA) was used to analyze the results. Analysis of variance was carried out and means were compared using Duncan's multiple range test whereby the tests were considered significant at $p < 0.05$.

Results and Discussion

Physical properties

Percentage of head rice yield

The percentage of HRY, indicating the quality of milled rice, is shown in Table 1. The HRY of all three Thai rice cultivars substantially decreased after pre-germination. Pinkaew et al. (2016) reported that increasing amylase activity during the germination process might cause weakness of the starch molecules, leading to easy breaking of the kernels during milling. On the contrary, parboiling increased the percentage HRY in all samples in the range 89.99–96.46%. Increasing the degree of parboiling from mild to severe conditions increased the percentage HRY in all rice varieties, indicating starch gelatinization during parboiling resulted in improved grain strength and resistance to breakage (Dooyum et al., 2016). Furthermore, according to Han et al. (2016) reported that parboiling is an effective way of reducing breakage after germination primarily attributed to starch gelatinization that seals fissures present naturally and resulting from soaking and germination.

Table 1 Effect of parboiling on head rice yield (percentage ± SD) from three Thai rice cultivars: brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), parboiled pre-germinated brown rice/mild parboiling (PPGBR/mild) and parboiled pre-germinated brown rice/severe parboiling (PPGBR/severe)

Treatment	Head rice yield (%)		
	CNT1	RB	SPT1
BR	80.92 ± 1.61^{cA}	78.43 ± 1.01^{cB}	74.30 ± 1.38^{cC}
PGBR	62.80 ± 1.43^{dB}	67.54 ± 1.52^{dA}	40.86 ± 0.60^{dC}
PBR	89.99 ± 0.93^{bB}	92.66 ± 0.55^{bA}	92.76 ± 0.99^{bA}
PPGBR/mild	90.30 ± 0.29^{bB}	94.09 ± 0.17^{bA}	94.66 ± 1.96^{bA}
PPGBR/severe	94.76 ± 0.99^{aB}	96.33 ± 0.29^{aA}	96.46 ± 0.83^{aA}

CNT1 = Chai Nat1; RB = Riceberry; SPT1 = San-Pah-Twang1
Different lowercase or uppercase superscripts indicate significant ($p < 0 .05$) differences among means in the same column or row, respectively.

Color measurement

From Table 2, the brightness of all three Thai rice cultivars increased noticeably after the pre-germination process, possibly due to bran pigments leaching into the water during the soaking process (Lamberts et al., 2006). The brightness of all three Thai rice cultivars decreased dramatically and became darker from mild to severe parboiling, while the redness and yellowness of CNT1 and SPT1 increased but, RB decreased significantly ($p < 0.05$). Similar to Martins et al. (2021), they found that changes in color of red paddy after parboiling have become less red and less yellow. The reason can be the different pigments of husk and bran from rice varieties (Martins et al., 2021), and during soaking paddy, the pigments could be leached, diffused from the bran layer into the endosperm, or degraded during the parboiling process (Oli et al., 2016). We found that severe parboiling conditions had a stronger effect on L* and a* than mild parboiling. This result concurred with that of Lamberts et al. (2006), who reported darkening and increased redness and yellowness of parboiled rice samples depending on the severity of the parboiling conditions. However, increased

Table 2 Effect of parboiling on color values of three Thai rice cultivars: brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), parboiled pre-germinated brown rice/mild parboiling (PPGBR/mild) and parboiled pre-germinated brown rice/severe parboiling (PPGBR/severe)

Sample	Brightness (L)			Redness (a)			Yellowness (b)		
	CNT1	RB	SPT1	CNT1	RB	SPT1	CNT1	RB	SPT1
BR	66.46 ± 0.29^{bB}	22.46 ± 0.13^{bC}	$73.97 \pm 0.21b^{A}$	1.78 ± 0.07^{cB}	6.13 ± 0.11^{bA}	0.32 ± 0.10^{dC}	20.11 ± 0.08^{dA}	2.32 ± 0.22^{bB}	21.64 ± 0.29^{eA}
PGBR	69.36 ± 0.13^{aB}	24.37 ± 0.33^{aC}	$74.68 \pm 0.30a^{A}$	1.57 ± 0.05^{dB}	6.31 ± 0.11^{aA}	0.45 ± 0.08^{cC}	19.33 ± 0.15^{eB}	3.29 ± 0.14^{aC}	22.75 ± 0.15^{dA}
PBR	61.36 ± 0.30^{cA}	20.78 ± 0.13^{cB}	60.90 ± 0.08^{dA}	1.92 ± 0.02^{abB}	5.14 ± 0.02^{cA}	1.77 ± 0.06^{aB}	26.35 ± 0.11^{aA}	1.26 ± 0.10^{cdB}	27.61 ± 0.05^{bA}
PPGBR/mild	61.50 ± 0.21^{cA}	20.86 ± 0.13^{cB}	62.54 ± 0.34^{cA}	1.84 ± 0.02^{cB}	5.20 ± 0.05^{cA}	1.56 ± 0.08^{bC}	25.39 ± 0.32^{bB}	1.45 ± 0.12^{cC}	29.33 ± 0.26^{aA}
PPGBR/severe	59.41 ± 0.50^{dA}	20.68 ± 0.12^{cB}	59.76 ± 0.15^{eA}	2.21 ± 0.05^{aB}	4.74 ± 0.09^{dA}	1.84 ± 0.09^{aC}	23.48 ± 0.15^{B}	1.21 ± 0.09^{C}	26.85 ± 0.09^{A}

CNT1 = Chai Nat1; RB = Riceberry; SPT1 = San-Pah-Twang1
Mean±SD in the same column superscripted with different lowercase letters indicate significant ($p < 0 .05$) differences; Different uppercase superscripts in the same row indicate significant ($p < 0.05$) differences of each trait among rice cultivars.

b* values of PPGBR were more pronounced under mild parboiled conditions. The changes in color of PBR and PPGBR were caused by the pigment of bran migrating and diffusing into the endosperm during soaking (Lamberts et al., 2006), while Maillard reaction, caramelization reaction and other reactions were occurred during steaming (Hu et al., 2019; Liu et al., 2020). These involved carbonyl groups of reducing sugars and the free amino groups of amino acids, peptides and proteins (Lamberts et al., 2008).

Chemical properties

The crude protein, crude lipid and total starch contents of BR, PGBR, PBR and PPGBR from three Thai rice cultivars were significantly different ($p < 0.05$) as presented in Table 3. The results demonstrated that PPGBR using both types of parboiling from three Thai rice cultivars had higher crude protein (9.27–10.70%) than BR (7.46–9.55%), PBR (8.34–9.76%) and PGBR (8.35–10.32%). The reason can be attributed to the germination, during which their proteins have been hydrolyzed by a protease enzyme. This process results in an increase in peptides and the amino acids of germinated rice grain (Moongngarm and Saetung, 2010). Additionally, the crude protein of PPGBR increased significantly ($p < 0.05$). This finding agrees with Rattanadee and Naivikul (2011), but some studies reported no change in their crude protein content during parboiling (Oli et al., 2016) because the steaming had not changed total protein and amino acid content, although the protein bodies in the kernel were ruptured (Bhattacharya, 2011). The highest level of crude lipid content was found in PPGBR (3.69–4.64%) and there was no significant difference ($p > 0.05$) from PGBR (3.64–4.21%). The increase in crude lipid content as a result of parboiling is due to the lipid bodies of the non-starch lipids being broken and fat being released from the surface of the kernel (Oli et al., 2016). The total starch content of BR and of all three Thai rice cultivars was significantly higher than total PGBR (Table 3). The total starch content of PGBR was decreased because an alpha-amylase hydrolyzed starch into oligosaccharide during the germination process (Mohan et al., 2010). When parboiling of PGBR using mild conditions, the total starch content found that PPGBR (80.78–81.98%) was not significantly different ($p > 0.05$) from PGBR (81.50–81.98%). However, the severe condition of parboiling showed somewhat lower total starch content than the mild condition for all three Thai rice cultivars.

Physicochemical properties

Alkali spreading score

The alkaline spreading scores of all three Thai rice cultivars were different, as shown in Fig. 1 and Table 4. The BR was somewhat swollen (score 2). After germination, the PGBR was shown to have grain swollen but the collar was incomplete and narrow (score 3), which is classified as a high gelatinization temperature, and which can be cooked at 75–79 °C. The alkali spread score of germinated rice parboiled was similar to that of rice parboiled but increased with severe parboiling. PPGBR was separated from CNT1.The collar shape has been completed and is widely open (Fig. 1). Its alkaline spreading score was 5, indicating that it can be cooked at temperatures ranging from 70–74 °C. On the other hand, PPGBR from RB and SPT1 (score at 6) were cooked at a low gelatinization temperature of 65–69 °C. The degree of gelatinization temperature is related to the overall rice cooking behavior (Mariotti et al., 2010) and the texture of the cooked rice (Panchan and Naivikul, 2009).

Table 3 Chemical properties of three Thai rice cultivars: brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), parboiled pre-germinated brown rice/mild parboiling (PPGBR/mild) and parboiled pre-germinated brown rice/severe parboiling (PPGBR/severe)

Sample	Crude protein (% dry basis)			Crude lipid (% dry basis)			Total starch (% dry basis)		
	CNT1	RB	SPT1	CNT1	RB	SPT1	CNT1	RB	SPT1
BR	8.85±0.02^{cB}	9.55±0.01^{dA}	7.46±0.06^{cC}	3.20±0.05^{cC}	3.78±0.03^{bA}	3.28±0.04^{dB}	84.16±0.20^{aA}	83.96±0.03^{aA}	83.04±0.27^{bB}
PGBR	9.41±0.01^{bB}	10.32±0.08^{bA}	8.35±0.07^{bC}	3.90±0.08^{aB}	4.21±0.11^{aA}	3.64±0.03^{aC}	81.79±0.14^{cA}	81.49±0.08^{cB}	81.69±0.07^{cdA}
PBR	8.94±0.05^{cB}	9.76±0.07^{cA}	8.38±0.04^{bC}	3.52±0.14^{bA}	3.80±0.23^{cA}	3.50±0.04^{cA}	83.29±0.05^{bA}	83.19±0.43^{bA}	83.55±0.47^{aA}
PPGBR/mild	9.82±0.09^{aB}	10.63±0.04^{aA}	9.27±0.04^{aC}	3.91±0.05^{aB}	4.64±0.23^{aA}	3.71±0.13^{aB}	81.82±0.09^{cB}	81.50±0.06^{cC}	81.98±0.08^{cA}
PPGBR/severe	9.89±0.07^{aB}	10.70±0.06^{aA}	9.29±0.06^{aC}	3.69±0.14^{bC}	4.63±0.04^{aA}	3.91±0.06^{aB}	80.78±0.59^{dA}	81.07±0.18^{dA}	81.37±0.07^{dA}

CNT1 = Chai Nat1; RB = Riceberry; SPT1 = San-Pah-Twang1

Mean±SD in the same column superscripted with different lowercase letters indicate significant ($p < 0 .05$) differences; Different uppercase superscripts in the same row indicate significant ($p < 0.05$) differences of each trait among rice cultivars.

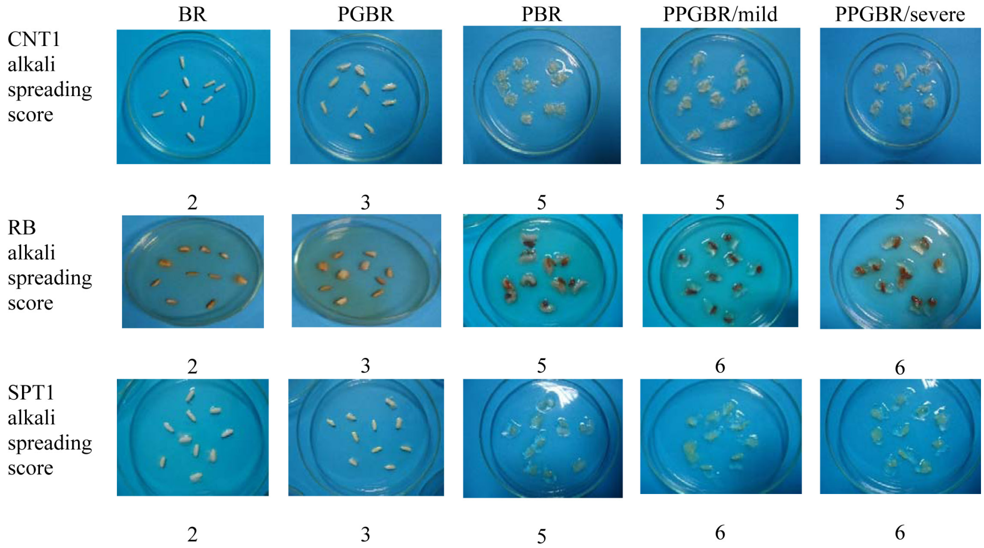

Fig. 1 Alkali spreading scores (below image) of brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), parboiled pre-germinated brown rice/mild parboiling (PPGBR/mild) and parboiled pre-germinated brown rice/severe parboiling (PPGBR/severe) of three Thai rice cultivars, where CNT1 = Chai Nat1, RB = Riceberry and SPT1 = San-Pah-Twang1

Table 4 Alkali spreading value of brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), parboiled pre-germinated brown rice/mild parboiling (PPGBR/mild) and parboiled pre-germinated brown rice/severe parboiling (PPGBR/severe) of three Thai rice cultivars

Sample	Alkali spreading value			Category and gelatinization temperature (°C)		
	CNT1	RB	SPT1	CNT1	RB	SPT1
BR	2	2	2	High (74.5–79)	High (74.5–79)	High (74.5–79)
PGBR	3	3	3	High (74.5–79)	High (74.5–79)	High (74.5–79)
PBR	5	5	5	Intermediate (70–74)	Intermediate (70–74)	Intermediate (70–74)
PPGBR/mild	5	6	6	Intermediate (70–74)	Low (65–69)	Low (65–69)
PPGBR/severe	5	6	6	Intermediate (70–74)	Low (65–69)	Low (65–69)

CNT1 = Chai Nat1; RB= Riceberry; SPT1 = San-Pah-Twang1

Scanning electron microscopy

SEM was used to visualize the microstructure of individual rice kernel samples from all three Thai rice cultivars and examine the impact of parboiling conditions on the rice grain microstructure. In Fig. 2, BR starch granules are characterized by their surface embedded in a continuous matrix. After germination, the starch granules were slightly modified and appeared within the granules. Under SEM, the BR and PGBR starch granules were easy to distinguish; their sharp edges could clearly be seen. On the other hand, the PBR and PPGBR samples of all three Thai rice cultivars had smooth, glassy, flat and fused surfaces of gelatinized starch granules, indicating that protein and starch had been destroyed and reconstructed during the parboiling process, resulting in a change to the internal structure of the rice (Liu et al., 2020).

X-ray diffraction patterns

The similar XRD patterns of the BR and PGBR samples from all three Thai rice cultivars had a sharper peak at diffraction angles (2θ°) of 15°, 17°, 18° and 23° (Fig. 3), which is typical of the A-type crystalline structure of native starch (Sittipod and Shi, 2016). After the parboiling process, the PPGBR samples of all three Thai rice cultivars using mild conditions had a decreased peak diffraction angle but also a new peak diffraction angle at 20°. Furthermore, the PBR and PPGBR samples under severe conditions had sharper peak diffraction angles at 20°, indicating an increased V-type crystalline structure and a greater proportion of amylose-lipid complexes due to migration of lipids from the bran to the endosperm and interaction with starch (Liu et al., 2020). The XRD pattern of CNT1 was different from RB and SPT1 because of the amylose content, which can greatly influence the extent of crystallite formation during parboiling (Lamberts et al., 2009).

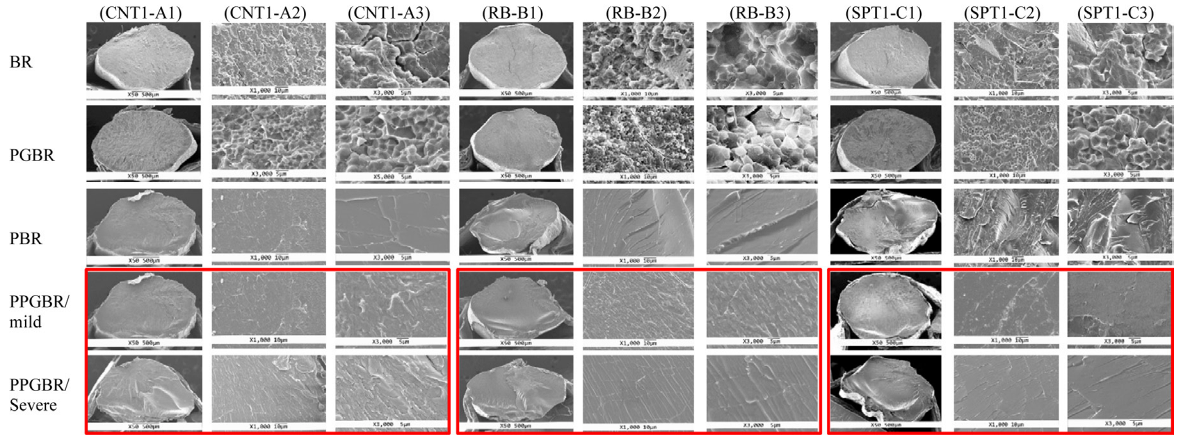

Fig. 2 Cross sections at different magnifications of brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), pre-germinated brown rice/mild parboiling (PPGBR/mild; red outline boxes) and parboiled brown rice/severe parboiling (PPGBR/severe; red outline boxes) of three Thai rice cultivars (CNT1-A1 = Chat Nat1 at 50×; CNT1-A2 = Chat Nat1 at 1,000×; CNT1-A3 = Chat Nat1 at 3,000×; RB-B1= Riceberry at 50×; RB-B2 = Riceberry at 1,000×; RB-B3 = Riceberry at 3,000×; SPT1-C1 = San-Pah-Twang1 at 50×; SPT1-C2 = San-Pah-Twang1 at 1,000×; SPT1-C3 = San-Pah-Twang1 at 3,000×)

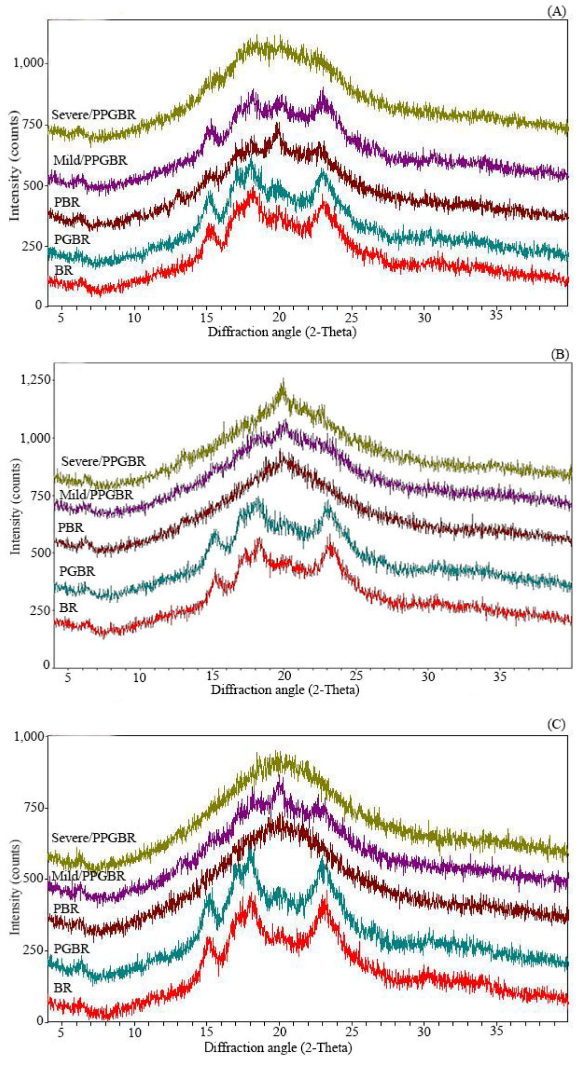

Fig. 3 X-ray diffraction patterns of brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), parboiled pre-germinated brown rice/mild parboiling (PPGBR/mild) and parboiled pre-germinated brown rice/severe parboiling (PPGBR/severe) from three Thai rice cultivars: (A) Chai Nat1; (B) Riceberry; (C) Sun-Pah-Twang1

Texture of cooked rice

The hardness values of the cooked BR samples from all three Thai rice cultivars were significantly higher than for the cooked PGBR samples (Table 5). The hardness of the PGBR samples decreased due to the conditions during germination that included partial hydrolyzation of starch granules by amylases in the endosperm and cell wall, resulting in a loss of rigidity and softening of the rice texture (Mohan et al., 2010). In addition, the parboiling condition for PPGBR affected the texture. All three Thai rice cultivars hardened slower than the equivalent PGBR samples under both mild and severe conditions. In contrast, when compared to PBR, PPGBR had a lower hardness. The PPGBR had notably decreased hardness, demonstrating starch hydrolysis during germination and during parboiling, with the starch gelatinization resulting in a homogenous compact mass that had a harder texture (Cheevitsopon and Noomhorm, 2011). These results concurred with Lamberts et al. (2009), Tian et al. (2018) and Liu et al. (2020), who reported that the parboiling process increased the hardness of rice. Furthermore, the PPGBR samples from the SPT1 cultivars had a lower hardness (5.98–6.05 N) than for the PPGBR samples (49.49–63.55 N) from CNT1 and RB. This may have been due to the amylose content in some of the rice cultivars. The cohesiveness of BR, PGBR, PBR, and PPGBR from all three Thai rice cultivars was associated with the hardness by decreasing the cohesiveness after the germination and parboiling processes due to amylose and amylopectin leaching out from the inside of the rice grains and a coated film of the cooking liquid may form three-dimensional networks on the surface of rice grains (Leelayuthsoontorn and Thipayarat, 2006).

Conclusions

Germination and parboiling were investigated to improve parboiled pre-germinated brown rice production. All PPGBR samples from the three Thai rice cultivars had better head rice yield, protein content, lipid content and texture properties after severe parboiling compared to mild parboiling. Parboiling significantly decreased the brightness and increased the yellowness and redness due to the type of rice cultivars. From the physicochemical properties, the surface of the PPGBR samples was smooth, glassy, flat and fused, indicating complete starch gelatinization after the parboiling. The V-type crystalline structure indicated that amylose-lipid complexes had aggregated during steaming. In addition, the type of rice cultivars changed the parboiled brown rice properties after germination and parboiling the rice, depending on the characteristics and chemical composition of rice. However, the cultivar type affected the transformations of protein, lipid and starch after germination and parboiling, resulting in softening of the rice. Thus, it would be suitable to combine germination and severe parboiling to improve the quality of PPGBR production from the three Thai rice cultivars. The waxy rice could be an alternative raw material for Thai consumers to produce soft-textured parboiled rice.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Table 5 Hardness and cohesiveness of cooked brown rice (BR), pre-germinated brown rice (PGBR), parboiled brown rice (PBR), parboiled pre-germinated brown rice/mild parboiling (PPGBR/mild) and parboiled pre-germinated brown rice/severe parboiling (PPGBR/severe) of three Thai rice cultivars

Treatment	Hardness (N)			Cohesiveness		
	CNT1	RB	SPT1	CNT1	RB	SPT1
BR	$57.08±5.90^{cA}$	$38.90±4.99^{cB}$	$3.79±0.60^{bC}$	$0.52±0.06^{aB}$	$0.39±0.03^{aB}$	$0.57±0.06^{aA}$
PGBR	$44.76±6.40^{dA}$	$29.42±3.20^{dB}$	$3.43±0.71^{bC}$	$0.51±0.03^{aB}$	$0.38±0.04^{aC}$	$0.49±0.05^{bB}$
PBR	$79.26±5.29^{aA}$	$52.94±1.52^{aB}$	$6.13±0.57^{aC}$	$0.38±0.02^{cA}$	$0.33±0.02^{dB}$	$0.33±0.02^{dB}$
PPGBR/mild	$63.55±3.30^{bB}$	$51.76±1.70^{cB}$	$6.05±0.48^{aC}$	$0.45±0.02^{bB}$	$0.36±0.01^{bB}$	$0.37±0.02^{cB}$
PPGBR/severe	$61.74±4.18^{bB}$	$49.49±2.95^{bB}$	$5.98±0.50^{aC}$	$0.47±0.04^{bA}$	$0.34±0.02^{cB}$	$0.36±0.03^{cB}$

CNT1 = Chai Nat1; RB = Riceberry; SPT1 = San-Pah-Twang1

Mean±SD in the same column superscripted with different lowercase letters indicate significant ($p < 0 .05$) differences; Different uppercase superscripts in the same row indicate significant ($p < 0.05$) differences of each trait among rice cultivars.

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