Effect of Parboiling on Milling, Physicochemical, and Textural Properties of Medium- and Long-Grain Germinated Brown Rice

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ABSTRACT

Germinated brown rice is considered a more nutritious and palatable cooked product than conventional brown rice. However, germination usually decreases rice milling yield and alters some physicochemical properties. Parboiling is commonly used to increase milling yield and retain nutrients, but it also changes rice color and texture. The objective of this study was to investigate the effect of parboiling on milling, physicochemical, and textural properties of a medium-grain and a long-grain rice after germination at varying durations. Germinated rice samples of three germination durations were prepared with one germination time before the optimum time at which 70% of rice revealed hull protrusion, the optimum time, and one time after. Germinated rice was then immediately parboiled at 120°C for 20 min and was then immediately dried. The milling, physicochemical, and textural properties of parboiled germinated rice from both cultivars were determined. Parboiling significantly decreased the percentage of brokens, whiteness, and the apparent amylose content and increased γ-aminobutyric acid content (GABA) in the nongerminated rice and rice at the first germination duration for both cultivars. Parboiling reduced pasting viscosities for both cultivars, but Jupiter still exhibited higher pasting viscosities than Wells. Cooked parboiled germinated rice was overall softer than nonparboiled rice because of kernel splitting, but Wells remained harder and less sticky than Jupiter. In conclusion, it is beneficial to combine parboiling with germination to enhance nutritional values and improve milling properties without affecting textural properties for both rice cultivars.

Germinated brown rice is a functional food popular in Asia for its high γ-aminobutyric acid (GABA) content. GABA is primarily an inhibitory neurotransmitter linked to numerous health benefits such as reducing blood pressure, improving sleeplessness, reducing cardiovascular diseases, and diabetes regulation, and it may also limit weight gain (Kayahara et al. 2001; Oh and Oh 2004; Roohinejad et al. 2009). Germination also activates enzymes such as α-amylase, protease, phytase, and lipase to result in softer and sweeter cooked brown rice (Jiamyangyuen and Ooraikul 2008). Because rice bran contributes to a hard, chewy texture usually not favored by some consumers, increasing softness is an important attribute in eating quality of cooked germinated brown rice (Roberts 1979; Matz 1991).

Parboiling is a hydrothermal treatment that involves soaking, heating, and drying of rough rice. This practice is commonly used to increase head rice yield and better retain nutrients such as water-soluble vitamins and minerals owing to steam pressure applied to the kernels (Choudhury 1991). Soaking is required to increase the moisture content of rough rice to around 30–35% for proper germination and effective parboiling (Bhattacharya 1985). When under heat and pressure, starch gelatinization and amylose-lipid complexation occur, followed by starch retrogradation upon cooling and drying of the rice kernels. The extents of starch retrogradation and complexation with lipids increase with parboiling severity, which consequently could increase cooked rice hardness (Derycke et al. 2005a; Lamberts et al. 2009). The formation and strengthening of protein barriers from disulfide cross-linking during parboiling may restrict water absorption of rice during cooking (Derycke et al. 2005b). The changes of starch, lipids, and proteins during parboiling contribute to harder and less sticky cooked rice texture (Kato et al. 1983).

Germinated brown rice became darker, more yellow, and had a higher reducing sugar content, a lower crude protein content, and a lower pasting profile after parboiling (Panchan and Naivikul 2009; Rattanadee and Naivikul 2011). Komatsuzaki et al. (2007) reported an increase in GABA content after germinated brown rice was steamed. Cheevitsopon and Noomhorm (2011) found an increase in overall cooked rice hardness when rice was steamed and then dried with a fluidized bed dryer at high temperatures (110–150°C), but recently Cheevitsopon and Noomhorm (2015) reported a reduction in GABA content but no change in cooked rice hardness when simultaneously parboiling and drying germinated brown rice using superheated steam with a fluidized bed dryer. Most of these studies used aromatic rice to study the effect of parboiling on germinated rice.

Because of limited information and contradictory results, there is a need for further understanding the effects of parboiling on germinated brown rice with relation to grain type and germination duration. Different grain types may differ in germination properties and subsequently parboiling properties because of their different physical characteristics and compositions. Miyoshi and Sato (1997) reported different responses to germination stimulant treatments between japonica and indica rice cultivars. Therefore, the objective of this study was to compare the effects of parboiling on the milling, physicochemical, and textural properties of germinated long-grain and medium-grain rice at varying germination durations compared with their respective germinated brown rice counterparts.

MATERIALS AND METHODS

Materials. Rough rice of two cultivars, Wells (long grain) and Jupiter (medium grain), from the 2012 crop were provided by the University of Arkansas Rice Research and Extension Center in Stuttgart, Arkansas. The dimensions (length, width, and thickness) of 100 kernels of rough and brown rice were measured with a Satake rice image analyzer equipped with a NaiS image checker 30R (Satake, Hiroshima, Japan).

Germination Process. Rough rice (400 g) of each cultivar was soaked in 1.25% NaClO at 25°C for 30 min for disinfecting (Yang et al. 2001). The sample was rinsed three times under tap water prior to a final rinse with deionized water and was then soaked in excess water in a 9 × 13 × 2 in. stainless steel pan at 25°C in a water bath (OLS200, Grant Instruments, Cambridge, U.K.). The minimum soaking time to reach equilibrium moisture content was determined by establishing the water absorption curve for each cultivar. Rice samples were removed every 10 min for the first hour and then every hour up to 24 h, pat dried, and weighed. The moisture content of soaked rice was calculated based on the initial moisture content by using the following equation:

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$$MC(\%) = 100 \times [(FWW\text{-}IDW)/IDW] \quad (1)$$

where MC is moisture content, FWW is final wet weight, and IDW is initial dry weight. All treated rice samples were soaked until the time when moisture content approached equilibrium.

After the soaking, the rice sample was rinsed again with deionized water prior to the germination procedure. For germination, approximately 240 g of each soaked rice was placed on top of two damp cheese cloths on metal racks, which were situated in two 9 × 13 × 2 in. stainless steel pans with deionized water filled up to 1 in. height of the pan. Aluminum foil and masking tape were used to insulate and seal the pan and rice before placing it in an incubator (APT.line BF, Binder, Tuttlingen, Germany) at 30–34°C. Twenty random whole kernels were removed from the cheese cloths regularly to determine the germination degree by counting the number of kernels showing protrusion through the hull and the embryonic growth length (cm). The optimum germination time was determined when 70% of the rice population displayed hull protrusion (duration 2) as either S1 or S2 stages (Counce et al. 2000). Two additional germination times were selected: one prior to and one following the optimum time (duration 1 and duration 3, respectively). The germination durations were 10, 26 (optimum), and 34 h for Wells and 24, 40 (optimum), and 48 h for Jupiter. One control soaked for 12 h without incubation (0 h) was used for each cultivar. The control and germinated samples were replicated twice.

Parboiling. After soaking and germination, rough rice was transferred and evenly spread onto a perforated rack placed into an autoclave (2340E, Tuttnauer Brinkmann, Westbury, NY, U.S.A.). Soaked or germinated rice samples were immediately parboiled under steaming pressure (18 psi) and temperature (120°C) for 20 min. After autoclaving, rough rice was dried to 12 ± 0.5% moisture content in an equilibrium moisture content chamber (dry bulb 26°C, wet bulb 13.5°C) and stored at 4°C.

Milling Properties. Parboiled and dried germinated rough rice of 150 g was dehulled by passing through a Satake dehusker (THU-35, Satake, Hiroshima, Japan) twice, because one dehulling pass was inadequate to remove most hulls. Dehulled rice weight was recorded, and head brown rice was separated from broken kernels by using a double-tray sizing machine (GrainMan Machinery, Miami, FL, U.S.A.). Premature, chalky, or defective rice was removed from whole kernels. The percentage of brokens (%) was calculated by the weight of rice fragments less than three quarters of a whole kernel divided by the original 150 g of rough rice. For physicochemical analyses, whole rice kernels were ground into flour with a UDY cyclone sample mill (UDY, Fort Collins, CO, U.S.A.) fitted with a 0.50 mm sieve.

The color of dehulled brown rice kernels was measured with a Minolta colorimeter (CR 400, Minolta, Osaka, Japan), and whiteness (*L*) and yellowness (*b*) values were recorded. The colorimetric meter was calibrated with the reference white plates provided, and two readings were taken for each replicate sample.

Physicochemical Properties. The apparent amylose content of the rice flour was determined by the colorimetric method of Juliano et al. (1981).

Free GABA was prepared according to the method of Cohen and Michaud (1993) with modifications. Ungerminated or germinated brown rice flour (200 mg) was weighed into a plastic tube, and 1.8 mL of deionized water was added. The mixture was centrifuged (microcentrifuge 5415D, Eppendorf, Hauppauge, NY, U.S.A.) at 2,300 × *g* for 10 min. Supernatant (1 mL) was pipetted and mixed with 200 µL of 0.4M $NaHCO_3$ and 400 µL of 6mM Dabsyl-Cl acetonitrile solution. The reaction was performed at 55°C for 1 h. After derivation, the sample was filtered into a vial and injected into a System Gold HPLC (Beckman-Coulter, Fullerton, CA, U.S.A.) with an autosampler (model 508), dual pump (model 126), and photodiode array detector (model 168) with Beckman-Coulter System 32 Karat software (version 8, 2006) to analyze samples. Analysis was performed with a modified method of Liu et al. (2015) using a Kinetex C18 column (100 mm × 4.6 mm i.d., 2.6 µm; Phenomenex, Torrance, CA, U.S.A.) and a binary gradient of deionized water (pH 9.0) for mobile phase A in water and methanol (pH 9.0) for phase B at a flow rate of 1.0 mL/min. The gradient began at 20% B and increased linearly to 100% B over 20 min; it was then held isocratically at 100% B for 10 min before returning to 20% B. The derivatized γ-butyric acid samples were identified and quantified by comparing retention time and slope to a derivatized commercial GABA standard (A5835, Sigma-Aldrich, Saint Louis, MO, U.S.A.).

Thermal properties were measured with a differential scanning calorimeter (DSC) (Diamond, Perkin-Elmer, Norwalk, CT, U.S.A.). Approximately 8 mg of ground parboiled rice flour was weighed into a stainless steel pan with 16 µL of deionized water added via a microsyringe. The pan was sealed and equilibrated at room temperature for 24 h prior to heating from 25 to 150°C at 10°C/min. An empty pan was used as a reference. Onset, peak, and conclusion temperatures (°C) and enthalpy (J/g) were calculated.

Pasting properties were determined with a Rapid Visco Analyzer (RVA) (Newport Scientific, Warriewood, NSW, Australia) according to AACC International Approved Method 61-02.01. Rice slurry was prepared by mixing 3.0 g of rice flour (12% moisture basis) with 25.0 mL of deionized water in an RVA canister. The slurry was rapidly heated to 50°C, heated from 50 to 95°C at 5°C/min, held at 95°C for 5 min, cooled from 95 to 50°C at 5°C/min, and then held at 50°C for 5 min. Peak, breakdown, setback, and final viscosities (cP) were recorded.

Texture Analysis. Parboiled germinated brown rice and parboiled soaked brown rice were cooked according to the method of Perez and Juliano (1979) with a consumer rice cooker (ARC-914B, Aroma Housewares, San Diego, CA, U.S.A.). Whole kernels (5 g) were soaked in deionized water in a 100 mL beaker for 30 min with a fixed water-to-rice ratio of 2.1:1 for Wells and 1.9:1 for Jupiter. Six beakers containing the soaked rice were placed on a metal rack placed within the cooking bowl holding 250 g of deionized water. Cooking duration was determined by removing 10 kernels every 5 min after cooking for 30 min until a minimum of nine kernels showed no starchy cores when compressed between two glass plates, indicating cooking completion (Ranghino 1966). Cooked rice was gently mixed, transferred to an airtight plastic zipper bag, placed in a thermoinsulator, and used within 30 min for texture analysis.

Texture analysis was performed with a 50 kg load cell and an aluminum plate 10 cm in diameter and 0.6 cm in thickness with a TA. XT Plus texture analyzer (Texture Technologies, Hamilton, MA, U.S.A.). A compression test mode was performed with 10 whole rice kernels at a speed of 5 mm/s; kernels were compressed to 0.3 mm, held for 5.0 s, and returned at 0.5 mm/s. The maximum compression force (peak force, N) and adhesiveness (area of negative force, N·s) were recorded as cooked rice hardness and stickiness, respectively (Saleh and Meullenet 2007). Measurements were conducted six times for each replicate sample.

Statistical Analysis. Four replications of the experimental treatment conditions were performed for each property. The treatment structure was a 2 × 2 × 4 factorial arrangement with two cultivars (Wells and Jupiter), two processing treatments (non-parboiled and parboiled), and three germination durations (with the 0 h control along with the three additional durations). The experimental design was a completely randomized design with 16 treatment combinations and four replications that were assigned independently to the experimental units. The analysis model for the design was fitted in the Fit Model platform of JMP PRO version 11.2.1 (SAS Institute, Cary, NC, U.S.A.) with the main effects and interaction. Tukey's honestly significant difference multiple comparisons test ($\alpha = 0.05$) was used to identify significant differences of the dozen treatment least squares means, including the control.

RESULTS AND DISCUSSION

Milling Properties. Jupiter and Wells had different kernel dimensions (Table I), and both were within the length-to-width ratio

limitations for rough and brown rice for medium-grain and long-grain rice cultivars, respectively, according to the Federal Grain Inspection Service of the U.S. Department of Agriculture (USDA 2014). Parboiling significantly decreased the percentage of brokens in germinated brown rice for both Jupiter and Wells cultivars ($P < 0.0001$) (Table II), which was also reported by Cheevitsopon and Noomhorm (2011). This reduction in brokens was primarily attributed to starch gelatinization that sealed fissures present naturally and resulting from soaking and germination (Bhattacharya 2004). The brokens were decreased by 12–17% in Wells, with the largest decrease for the longest germination time, and were decreased approximately 4% in Jupiter. Therefore, parboiling is an effective way of reducing brokens after germination.

There were no differences in whiteness (L value) among nonparboiled germinated rice for the same cultivar, with approximately 52 for Jupiter and 61 for Wells. Upon parboiling the whiteness significantly decreased for both cultivars ($P < 0.001$), but their difference still remained, with Wells having higher whiteness values than Jupiter (Table II). This finding agrees with Bhattacharya (1996), who reported decreasing whiteness with increasing parboiling time and pressure. The lower whiteness values in Jupiter samples were correlated with their higher soluble sugar contents (Han et al. 2016). Parboiled rice becomes discolored as a result of the Maillard reaction and the diffusion of hull and bran pigments into the endosperm during soaking (Houston et al. 1956; Bhattacharya 2004; Rordprapat et al. 2005; Lamberts et al. 2006; Parnsahkorn and Langkapin 2013). The results suggest that the Maillard reaction was the main contributor to the discoloring of parboiled rice, and germination duration had little impact on the whiteness of the resultant parboiled rice. Wells was more yellow than Jupiter ($P < 0.0001$), and parboiling overall increased yellowness of germinated Wells samples but not that of germinated Jupiter samples when compared with their respective nonparboiled counterparts. Cheevitsopon and Noomhorm (2011, 2015) attributed increased yellowness from parboiling of germinated jasmine brown rice to the Maillard reaction. However, the present results suggest that the Maillard reaction has a strong negative effect on the whiteness of parboiled germinated rice, but its impact on yellowness was not significant.

Apparent Amylose Content. Overall, parboiling significantly decreased the apparent amylose content for nongerminated rice and all germinated rice samples for both cultivars ($P = 0.00267$). Nevertheless, there was no difference among samples from different germination durations for both cultivars. The decrease in apparent amylose content was attributed to strong interactions between starch and protein, which reduced interaction between amylose and iodine.

GABA Content. After parboiling, the GABA content significantly increased for both Jupiter and Wells for the nongerminated ones and the first germination duration, but it remained unchanged between the second and last germination durations (Table II). Inconsistent results in terms of parboiling effects on GABA content of germinated rice have been reported. Chungcharoen et al. (2014), Komatsuzaki et al. (2007), and Srisang et al. (2010, 2011) reported that germinated rice had unchanged or significantly increased GABA content after steaming and drying; however, Cheevitsopon and Noomhorm (2011, 2015) reported up to 50% reduction in GABA after parboiling with drying.

Thermal Properties. There were two endothermic transitions in parboiled germinated rice for both cultivars (Table III): retrograded amylopectin melting at a lower temperature and amylose-lipid complex melting at a higher temperature. Both cultivars had similar melting temperatures and enthalpies for both transitions, except that Wells had significantly higher retrogradation end temperatures and enthalpies, which were ascribed to a greater proportion of amylose and amylopectin long branch chains in long-grain Wells cultivar than in medium-grain Jupiter cultivar (Lu et al. 1997; Fan and Marks 1998; Jane et al. 1999; Inouchi et al. 2000; Patindol and Wang 2003; Patindol et al. 2005). The greater proportion of amylopectin long branch chains in Wells not only contributed to its higher gelatinization temperatures but also was responsible for its increased retrogradation extent. The lack of significant changes between germination durations for amylopectin

TABLE I
Means of Individual Rough and Brown Rice Grain Dimensions for Jupiter and Wells

	Jupiter		Wells	
Property	**Rough**	**Brown**	**Rough**	**Brown**
Length (mm)	7.95	5.77	9.46	7.34
Width (mm)	3.09	2.71	2.31	2.05
Thickness (mm)	2.12	1.89	1.94	1.80
Length/width ratio	2.58	2.13	4.10	3.58

TABLE II
Percentage of Brokens, Color, and γ-Aminobutyric Acid (GABA) Content of Nonparboiled or Parboiled Germinated Brown Rice at Varying Germination Durations (GD) for Jupiter and Wells[a]

Cultivar	Treatment	GD (h)	Brokens (%)	*L* Value	*b* Value	Apparent Amylose (%)	Free GABA (mg/100 g)
Jupiter	Nonparboiled	0[b]	5.56	52.93	16.74	12.5	69.1
		24	6.23	52.28	15.43	16.6	41.8
		40	6.63	52.49	15.60	15.0	57.9
		48	7.06	52.71	15.24	16.2	69.1
	Parboiled	0[c]	5.11	40.97	15.73	11.8	88.3
		24	2.53	41.04	15.74	13.0	99.7
		40	2.36	40.92	15.36	13.4	62.7
		48	2.42	42.71	15.44	11.6	56.6
Wells	Nonparboiled	0[b]	16.55	61.45	16.78	20.5	32.2
		10	15.71	60.16	16.23	20.5	30.2
		26	20.81	60.95	16.96	21.7	82.7
		34	19.60	60.72	15.68	19.7	96.4
	Parboiled	0[c]	4.46	45.59	16.85	18.7	47.5
		10	3.19	45.53	17.16	18.2	51.1
		26	3.23	43.29	16.85	18.3	76.7
		34	2.43	46.64	17.50	19.2	88.8
HSD value			0.33	0.0007	0.18	0.025	14.3

[a] Mean values are reported in the original scale, but some Tukey's honestly significant difference (HSD) test values ($\alpha = 0.05$) are reported in the scale of transformation required to meet the ANOVA requirement. HSD values are for the log of broken kernels (%), reciprocal of L (whiteness) values, square root of b (yellowness) values, and reciprocal of apparent amylose (%).
[b] Soaked brown rice.
[c] Parboiled soaked brown rice.

retrogradation properties in both cultivars support the previous study (Han et al. 2016) that germination did not significantly change amylopectin structure to result in different amounts and structures of retrograded crystallites.

The amylose-lipid complexes were not present in nonparboiled germinated samples (Han et al. 2016), because they were formed during the heating process of parboiling (Priestley 1976). Kato et al. (1983) reported an increase in lipids bound to starch and protein after parboiling. After gelatinization, amylose and lipids may form an inclusion complex, and type II amylose-lipid complex is more thermodynamically favored and the preferred form at high crystallization temperatures, with peak melting temperatures of 110–120°C (Biliaderis and Galloway 1989; Biliaderis et al. 1993) when processed under high temperatures, as observed in this study. The specific temperatures to form amylose-lipid complexes are dependent on lipid characteristics (Tufvesson et al. 2003). The enthalpy values of amylose-lipid complex were similar to those reported by Newton et al. (2011). The lack of significant differences in amylose-lipid complex melting between germination durations for both cultivars agrees with the previous study (Han et al. 2016) and suggests that germination did not sufficiently alter amylose molecular size to change its interaction with lipids.

Pasting Properties. Jupiter had an overall higher pasting profile than Wells (Fig. 1) because of its higher amylopectin content (Chung et al. 2008). The pasting viscosities were significantly decreased after parboiling when compared with their germinated counterparts (Han et al. 2016) owing to reduced starch water-binding capacity after gelatinization, retrogradation, and interaction with protein and lipids, thereby decreasing swelling ability (Rao and Juliano 1970; Ali and Bhattacharya 1980; Soponronnarit et al. 2006; Patindol et al. 2008). Within each cultivar, there was little difference in pasting profiles between germination durations after parboiling. These results support the previous study, in which a similar pasting profile was found in germinated rice from the same cultivar at different germination durations when conducted in silver nitrate (Han et al. 2016).

Texture Analysis. Before parboiling, germinated brown rice samples from Wells were generally higher in hardness and lower in stickiness than those from Jupiter when cooked (Han et al. 2016). Parboiling resulted in a decrease in hardness for both cultivars but had different influences on stickiness. All parboiled germinated rice samples split after cooking; therefore, the decreased hardness for both cultivars was presumably because of kernel splitting. Similar to germinated rice, parboiled germinated Wells had significantly higher hardness and lower stickiness values than Jupiter ($P < 0.0001$) (Table IV). Parboiling resulted in a greater difference in hardness and stickiness between Wells and Jupiter, which was attributed to their different amylose contents and consequently different amounts of amylose-lipid complex after parboiling. Amylose content, amylose-lipid complexes, and long amylopectin chains have been found to be associated with cooked rice hardness (Biliaderis et al. 1993; Radhika Reddy et al. 1993; Ong and Blanshard 1995; Ramesh et al. 1999). As shown previously, amylose-lipid complex was formed during parboiling. It is possible that these newly formed complexes may be more concentrated on the endosperm–bran interface, where lipids and proteins are more abundant and contribute to kernel splitting by constricting swelling on the kernel surface as the endosperm swelled during cooking. Despite both cultivars splitting after cooking, the differences in decreased hardness between the two cultivars after parboiling were still present, in which germination had an overall effect of decreasing cooked rice hardness ($P = 0.001$) for both cultivars, more so than their nonparboiled germinated counterparts (Han et al. 2016). Therefore, parboiling did change the hardness of cooked germinated brown rice; however, the inherent difference in germinated rice still remained after parboiling.

The differences in stickiness between cultivars were greater after parboiling, with parboiled germinated Wells being significantly less sticky than its nonparboiled cooked rice (Han et al. 2016) (Table IV). Parboiled germinated Jupiter showed a significant decrease in stickiness once germinated but overall had similar stickiness as nonparboiled germinated rice (Han et al. 2016). The lack of overall differences between parboiled and nonparboiled Jupiter samples implies that splitting of the cooked kernels did not influence stickiness, because nonparboiled Jupiter did not split. Cooked rice hardness usually increased, whereas cooked rice stickiness decreased as a result of parboiling (Kato et al. 1983; Islam et al. 2001; Patindol et al. 2008). This may be a result of increased protein-starch complexes formed from parboiling, which were found to be negatively correlated with cooked rice stickiness (Kato et al. 1983; Hamaker et al. 1991). For Jupiter, more amylopectin might be

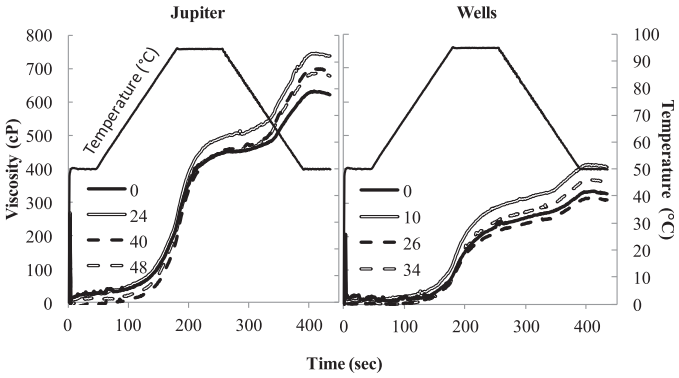

Fig. 1. Pasting profiles of parboiled brown rice and germinated brown rice at varying germination durations for Jupiter and Wells, as measured by a Rapid Visco Analyzer in water.

TABLE III
Thermal Properties of Parboiled Germinated Brown Rice at Varying Germination Durations (GD) for Jupiter and Wells[a]

Cultivar	GD (h)	Retrograded Amylopectin				Amylose-Lipid Complex			
		Onset Temp. (°C)	Peak Temp. (°C)	End Temp. (°C)	ΔH (J/g)	Onset Temp. (°C)	Peak Temp. (°C)	End Temp. (°C)	ΔH (J/g)
Jupiter	0	52.1	61.7	67.1	1.1	107.1	115.3	122.8	0.9
	24	51.6	61.1	66.8	1.0	106.2	114.4	122.4	1.0
	40	51.8	61.1	66.1	1.0	106.4	113.8	121.8	1.0
	48	50.6	61.0	67.1	1.2	105.8	113.5	123.7	0.9
Wells	0	50.8	60.8	68.7	2.9	107.3	114.8	122.5	1.2
	10	51.4	61.1	69.3	3.2	107.1	114.7	121.9	0.9
	26	52.7	61.2	69.8	3.4	107.0	115.0	122.6	1.1
	34	52.4	61.1	69.9	3.7	107.3	114.9	121.8	1.1
HSD value		0.05	0.02	0.02	0.26	2.33	1.19	2.00	0.26

[a] Mean values and Tukey's honestly significant difference (HSD) test values ($\alpha = 0.05$) are reported in the original scale. Germination duration of 0 indicates parboiled soaked brown rice. Temp. = temperature, and ΔH = enthalpy.

hydrolyzed with increasing germination (Han et al. 2016), thereby resulting in decreased protein-starch complex formation upon parboiling. However, for parboiled Wells the similar stickiness values across germination durations and its overall decreased stickiness compared with its nonparboiled germinated rice (Han et al. 2016) suggest that amylose content may play a more important role in affecting cooked rice stickiness than protein complexes, as suggested by Hamaker et al. (1991) and Kumar et al. (1976).

A significant three-way interaction was observed between rice cultivars, germination durations, and parboiling treatment for brokens, whiteness, and GABA content (P = 0.0291, 0.0131, and 0.0002, respectively) (Fig. 2). This observation implies that these three properties were impacted not only by parboiling treatment but also through a combined effect of the type of germinating rice at certain germination times. Compared with the parboiled nongerminated counterparts, the parboiled germinated Wells had significantly less brokens at the last germination duration, whereas parboiling significantly decreased brokens for Jupiter at the first germination duration. The whiteness value for parboiled germinated Wells significantly decreased at the second germination duration, whereas parboiled germinated Jupiter significantly increased at the last germination duration. Parboiling significantly increased the GABA content for nongerminated rice and rice at the first germination duration for both cultivars, but it did not change the GABA content for germinated rice between the second and last germination durations.

TABLE IV
Hardness and Stickiness of Cooked Parboiled Germinated Brown Rice at Varying Germination Durations (GD) for Jupiter and Wells[a]

Cultivar	GD (h)	Hardness (Peak Force, N)	Stickiness (Negative Force Area, N·s)[b]
Jupiter	0	41.3	2.26
	24	39.8	1.62
	40	38.1	2.09
	48	34.2	1.86
Wells	0	56.9	0.07
	10	58.3	0.13
	26	51.3	0.18
	34	52.1	0.14
HSD value		5.3	0.28

[a] Mean values and Tukey's honestly significant difference (HSD) test values (α = 0.05) are reported in the original scale. Germination duration of 0 indicates parboiled soaked brown rice.
[b] Negative values expressed as absolute value.

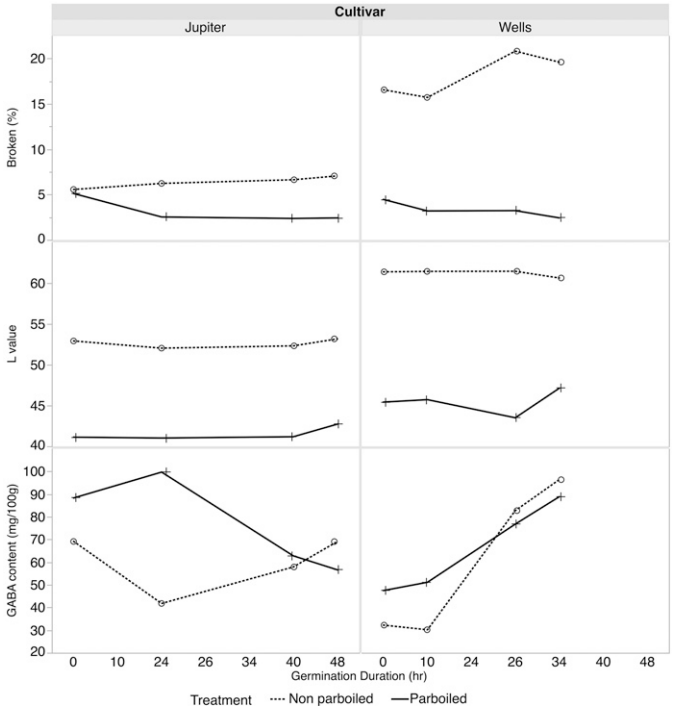

Fig. 2. Statistical three-way interactions for brokens, L value (whiteness), and γ-aminobutyric acid (GABA) content based on least squares means of parboiled germinated brown rice at varying germination durations for Jupiter and Wells.

CONCLUSIONS

Parboiling significantly changed the milling, physicochemical, and textural properties of germinated medium-grain Jupiter and long-grain Wells rice. Parboiling significantly decreased the percentage of brokens, whiteness, and the apparent amylose content for both cultivars but only increased yellowness in Wells. Parboiling significantly increased the GABA content for nongerminated rice and rice at the first germination duration for both cultivars. After parboiling, germinated rice from both cultivars had significantly lower pasting viscosities, although Jupiter remained overall higher in pasting viscosity than Wells. Both cooked germinated rice cultivars became softer after parboiling because of cooked kernel splitting and continued to soften with progressed germination time. The results demonstrate that some desired characteristics of germinated rice such as GABA content and cooked rice softness can be enhanced after parboiling compared with nongerminated parboiled rice for both rice types. However, parboiled germinated medium- and long-grain rice still exhibited inherently different color, pasting, and textural properties after parboiling.

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