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Physicochemical properties of germinated dehulled rice flour and energy requirement in germination as affected by ultrasound treatment

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ABSTRACT

Limited data are published regarding changes in the physicochemical properties of rice flours from germinated de-hulled rice treated by ultrasound. This work was undertaken to evaluate the effect of ultrasound treatment (25 kHz, 16 W/L, 5 min) on starch hydrolysis and functional properties of rice flours produced from ultrasound-treated red rice and brown rice germinated for up to 36 h. Environmental Scanning Electron Microscopy (ESEM) microimages showed that the ultrasound treatment altered the surface microstructure of rice, which helped to improve moisture transfer during steam-cooking. The flours from sonicated germinated de-hulled rice exhibited significantly ($p < .05$) enhanced starch hydrolysis, increased the glucose content, and decreased falling number values and viscosities determined by a Rapid Visco Analyzer. The amylase activity of the germinating red rice and brown rice displayed different sensitivity to ultrasonic treatment. The ultrasonic pre-treatment resulted in a significant reduction in energy use during germination with a potential to further reduce energy use in germinated rice cooking process. The present study indicated that ultrasound could be a low-power consumption method to modify the rheological behavior of germinated rice flour, as well as an efficient approach to improve the texture, flavor, and nutrient properties of steam-cooked germinated rice.

1. Introduction

Rice is an important staple crop for over half of the world's population, providing 21% of global human per capita energy and 15% of per capita protein. Dehulled rice including brown rice, red rice, purple rice, and black rice, is classified as a whole grain [1]. Germination is a simple and economic method for grain quality improvement that has gained increasing interest due to the health benefits of germinated grains [2]. During rice germination, hydrolytic enzymes are activated, resulted in decomposition of food polymers into their molecular compounds, e.g. breaking down of amylose and amylopectin into maltose, dextrin, and glucose by endogenous amylases, along with proteins degradation into peptides and amino acids [3,4]. Germinated dehulled rice is reported to improve digestion and absorption, and enhance bioactive compounds such as γ-aminobutyric acid (GABA), γ-oryzanol, and vitamins [5].

A few studies have examined the use of germinated rice in end product formulations, such as in composite flour bread [6], fermented rice bread [7], and sugar-snap cookies [8]. Substituting wheat flour with 30% germinated rice flour in regular bread formulation did not negatively affect sensory acceptance [9], and the flour mix exhibited a lower peak viscosity than regular wheat flour [6]. Adding germinated rice flour in brown rice bread was reported to increase GABA and polyphenols, enhance antioxidant activity, and reduce phytic acid content [7]. Incorporation of germinated rice flour in cookies also enhanced the brown color of the finished product, due to Maillard reaction between reducing sugars and protein during the baking process [8].

Power ultrasound, also known as high-intensity ultrasound, operates at frequencies of between 20 and 100 kHz. As a non-thermal processing method, it has numbers of advantages such as high-efficiency, non-toxic, and environmentally friendly. In recent years, power ultrasound has been investigated for use in food processing and preservation applications [10–13]. It has been tested to assist such unit operations as homogenization, degassing, cutting, microbial and enzyme inactivation, extraction, and drying, among others [10,12]. Recently,

Abbreviations: GBR, Germinated Brown Rice; GRR, Germinated Red Rice; RVA, Rapid Visco Analyzer; FN, Falling Number; GABA, Gamma-Aminobutyric Acid; ESEM, Environmental Scanning Electron Microscopy; PV, peak viscosity; TV, through viscosity; FV, final viscosity

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ultrasound was used as a form of physical energy to stimulate seeds for increasing germination rate, sprouts growth, and health-promoting compounds [14]. Switchgrass seeds treated with ultrasound exhibited an increase in seedling growth [15]. Enhanced germination rate was observed in sonicated wheat seeds (45 kHz, 160 W, 10 min) after soaking for 3 h [16]. Ultrasound treatment for 5 and 30 min after soaking increased GABA content in 72 h-germinated soft white wheat by 10.26% and 30.69% [17]. In soybean seeds treated with an ultrasonic bath (300 W, 40 kHz, 0.35 W/cm^2) for 30 min during soaking in water at 25 °C, an increase in germination rate by 18.07%, sprout length by 24.42%, total essential amino acids by 18.28%, and GABA by 43.39% after 5 days of germination, compared to the untreated sample, was treated [18].

During germination, elevated enzyme activity promotes the hydrolysis of starch to sugar and results in a change in the pasting and nutritional properties of germinated rice flour [5,6]. Moderate ultrasonication was reported to increase enzymatic activity thus accelerate the germination of aged grass seeds of tall fescue and Russian wildrye [19]. Yu et al. (2014) reported that α-amylase activity was modified by power ultrasound, and attributed the changes to sonication-induced modification of secondary and tertiary structures [20]. They postulated that the structural modifications may have exposed more active sites to enzyme, thus increasing hydrolysis rate and bioactivity. Utilizing the known benefits of controlled germination and power ultrasonic treatment on quality improvement of germinated grains when applied separately, Ding et al. (2018) for the first time combined the two treatments in germinated red rice (*Oryza sativa* L.) and reported significant enhancement in such plant metabolites as GABA, O-phosphoethanolamine, and glucose-6-phosphate [21]. This work looked into other aspects of controlled germination and ultrasound treated rice, as outlined in the following four objectives: 1) to examine the effect of controlled germination and power ultrasound treatment on rice starch hydrolysis during germination, and determine the color and the viscosity properties of germinated rice flour; 2) to determine the effect of power ultrasound on the surface microstructure of de-hulled rice; 3) to compare the change in the texture characteristics of steam-cooked germinated rice.; and 4) to examine the energy consumption in germination process.

2. Materials and methods

2.1. Raw materials and preparation of germinated de-hulled rice flour

Two commercial varieties of long grain de-hulled rice (*Oryza sativa* L.) with high germination rate (> 98%), i.e. red rice and brown rice, were purchased from Whole Foods Market Inc. (Chicago, Illinois, USA). According to the method of Ding et al. (2016), the dehulled rice was soaked in 0.1% NaOCl solution for 10 min for surface sterilization, rinsed with sterile water, then soaked in water at 26 ± 2 °C for 12 h [4]. Treatment of grain samples by ultrasound was done following the method described in Section 2.2. The treated samples and control group (regular germination) were put on germination trays, which were placed in a controlled growth chamber (Z-3-1-H/AC, Cincinnati Sub-Zero, Cincinnati, OH, USA). The germination was performed at 28 ± 2 °C, with moisture (> 95%) supplied by an ultrasonic humidifier (mist maker) (1.7 MHz, SPT SU-2020, Sunpentown, City of Industry, CA, USA) [21]. The germinated rice was removed from the germination chamber at selected germinating times of 8, 24, and 36 h. Samples were dried at 80 °C for 2 h in a hot-air dryer (OHG 100, Gallenkamp, London, UK), ground by a Perten 3100 laboratory mill (Perten Instruments, Sweden) with a 0.8 mm metal mesh, and passed through a 0.6 mm screen.

2.2. Power ultrasound treatment

The laboratory method of Yu et al. (2016) and Ding et al (2018) was used with slight modifications to treat red rice and brown rice samples [21,22]. The set-up consisted of an ultrasound generator (25 kHz) and a water tank (height (H) 500 mm × length (L) 460 mm × width (W) 660 mm). Two transducer boxes (1 kW each, H × L × W of 400 mm × 400 mm × 90 mm), each with 10 piezoelectric transducers, were installed face to face to the inner walls of the tank in an upright position, with a space of 480 mm between them. A specially-designed rice sample holder (H × L × W of 250 mm × 400 mm × 8 mm) was used to hold the rice samples (50 g), which was placed in the water tank parallel to the transducer boxes. The kernels of red rice and brown rice were sonicated for 5 min after soaking. This setup allowed a relatively uniform ultrasound field in the treatment tank, as shown in Fig. 1; the acoustic power density (APD) in the treatment tank was 16 W/L measured using rating power (2000 W) divided by the water volume (125 L). The treatments were performed at amplitude of 100% and room temperature (23–24 °C).

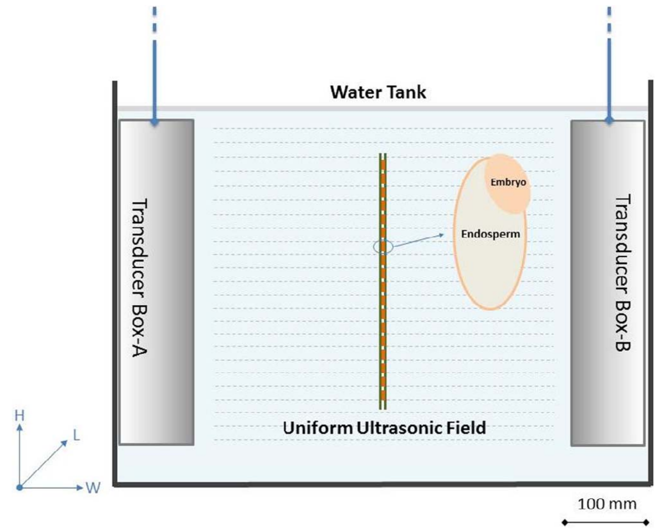

Fig. 1. A cross-sectional view of the lab-scale power ultrasound treatment tank.

2.3. Environmental Scanning Electron Microscopy (ESEM)

The surface microstructures of the germinated brown rice (GBR) and germinated red rice (GRR) grains before drying and milling were observed using ESEM following the method of Duta and Culetu (2015) [23]. The ESEM micrographs were obtained with a Quanta FEG 450 ESEM (FEI Company, Hillsboro, Oregon) at an accelerating potential of 30 kV. The samples were mounted on an aluminum stub using a tiny carbon adhesive tape. The beam working distance between the samples and the detector was 10 m. A 20 KV accelerating voltage was applied, and the vacuum was 1.0 Torr.

2.4. Determination of moisture, total starch, and glucose content

Moisture content was determined using the AACC International Method 44-15.02. The total starch content was determined using the enzyme hydrolysis method from Chinese Standard Method GB/T 5009.9-2008. The glucose content was measured using a Glucose (GO) Assay Kit (Product Code GAGO-20, Sigma-Aldrich, MO, USA), which contains a glucose oxidase/peroxidase reagent, an *O*-dianisidine reagent, and a glucose standard solution (1.0 mg/mL D-glucose in 0.1% benzoic acid). Briefly, 0.8 mL of the *O*-dianisidine reagent was added to an amber bottle containing 39.2 mL of glucose oxidase/peroxidase reagent. After vortexing and homogenization, the mixture was used as the assay reagent. The determination method-1 of Sigma Glucose (GO) assay kit technical bulletin was used to start the reaction by adding 2.0 mL of assay reagent to the first tube and mixing. Then the tubes were kept at 37 °C for 30 min, with the reaction monitored every 60 s. At each time interval, the reaction was stopped by adding 2.0 mL of 12 N H_2SO_4 into the tube. The absorbance of each tube was measured against the reagent blank at 540 nm.

2.5. Determination of Hagberg Falling Number (FN)

Hagberg Falling Number (FN) test is a viscometric assay that involves a rapid gelatinization of a grain flour suspension in a boiling water bath. The FN value was determined using the AACC International Method 56-81.03 with an FN 1500 System (Perten Instruments, Sweden) and a sample size of 7 g (14% moisture basis) in 25 mL of water. The FN value is defined as the total time in seconds required to stir (60 s) and allow a stirrer to fall a specified distance through the heated suspension.

2.6. Color measurement

The color of the GBR and GRR powders was measured with a Hunter Lab Color FlexEZ Spectrophotometer (Hunter Associates Laboratory, Inc., Reston, VA, USA) using the Hunter scale for L*, a*, and b*. The sample was placed in a transparent sample holder and 5 readings were taken at each of the five locations in the holder, i.e. center-up-down-right-left. The results were expressed as tristimulus values: L*, lightness (0 = black, 100 = white), a* (−a = greenness, +a = redness), and *b (−b = blueness, +b = yellowness). The total color difference was defined as ΔE [24,25]. The ΔE of GBR and GRR flours compared to raw dehulled rice flour was calculated with Eq. (1), in which L_0*, a_0*, and b_0* are the average values of the raw dehulled rice flour (Group "0H" in Table 1), whereas L*, a*, and b* are the average values of GBR and GRR after soaking, germinating, and drying (Group "8H, 8H US, 24H, 24H US, 36H, 36H US" in Table 1).

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (1)$$

2.7. Starch pasting properties

Starch pasting properties of the rice flour were measured with a Rapid Visco Analyzer (RVA-4 series, Newport Scientific, NSW, Australia) following the AACC International Method 76-21.01. Flour samples (3.5 g each, 14% moisture content, wet basis) and 25 mL water were mixed to form a slurry that was homogenized with a plastic paddle right before RVA test. The slurry in the analyzer was stirred at 960 rpm for 10 s and then at 160 rpm for the remainder of the test. The heating temperature was initially set at 50 °C, held for 1 min, and raised to 95 °C over 3.75 min. Then the slurry was held at 95 °C for 2.5 min, cooled to 50 °C over 3.75 min, and held at 50 °C for 2 min. The RVA results were expressed in cP. The RVA viscosity parameters include the highest viscosity of the paste after gelatinization (peak viscosity, PV), the shear-thinned viscosity of the paste (trough viscosity, TV), final viscosity (FV), breakdown (= PV-TV), and setback (= FV-PV) from the RVA profile of each test sample [26,27].

Table 1
Effects of germination time and ultrasound treatment on color of germinated rice flour.

Germination time and US treatment		L*	a*	b*	ΔE
Red rice	0H	67.25 ± 0.07^e	7.77 ± 0.03^a	10.86 ± 0.03^a	–
	8H	68.35 ± 0.06^b	7.24 ± 0.04^b	10.44 ± 0.04^b	1.29
	8H US	68.13 ± 0.08^c	7.21 ± 0.02^b	10.34 ± 0.02^c	1.16
	24H	68.54 ± 0.07^a	6.83 ± 0.03^d	9.98 ± 0.01^e	1.82
	24H US	67.92 ± 0.05^d	7.00 ± 0.01^c	10.16 ± 0.01^d	1.24
	36H	68.49 ± 0.12^a	6.76 ± 0.01^e	9.97 ± 0.01^e	1.83
	36H US	68.21 ± 0.06^c	6.74 ± 0.04^e	9.84 ± 0.05^f	1.74
Brown rice	0H	84.64 ± 0.05^a	1.31 ± 0.04^d	12.94 ± 0.04^f	–
	8H	83.53 ± 0.02^b	1.56 ± 0.03^b	13.86 ± 0.03^d	1.46
	8H US	83.30 ± 0.05^c	1.57 ± 0.03^b	14.14 ± 0.03^b	1.82
	24H	82.34 ± 0.04^e	1.47 ± 0.05^c	13.74 ± 0.07^e	2.45
	24H US	82.37 ± 0.05^{de}	1.66 ± 0.04^a	14.28 ± 0.04^a	2.66
	36H	82.48 ± 0.05^d	1.65 ± 0.04^a	14.27 ± 0.07^a	2.57
	36H US	81.74 ± 0.08^f	1.58 ± 0.04^b	13.99 ± 0.07^c	3.10

*ΔE means average color difference, US means the samples with ultrasound treatment (25 kHz, 16 W/L, 5 min) after soaking. Differences in each column are highlighted by different letters a–d or a–d at $p < .05$ (n = 5).

2.8. Texture characteristics of steamed-cooked germinated rice

According to the traditional rice steam-cooking method in Asia, whole-grain 36-h GBR and GRR samples before drying were cooked for 40 min by steaming. The firmness of the cooked GBR and GRR was measured using a TA-XT Plus Texture Analyzer (Texture Technologies Co., New York, USA). For each measurement, 10 g of steamed rice was filled in a transparent glass cup (round-bottom, 46 mm diameter) on the base, one cycle system with 70% compression ratio was used with the force-versus-time program [28]. The plunger was a flat type (20 mm diameter) made of aluminum. The plunger speed was 1.0 mm/s.

2.9. Energy consumption measurement

Energy consumption of the ultrasonic humidifier (two phase) over a 36 h-germination period was measured using a P4460 Kill-A-Watt EZ Electricity Usage Monitor (P3 International Corporation, New York, NY, USA). The average electric power of the germination chamber (three phase) was measured with a Fluke 1735 Three-Phase Power Quality Logger (Fluke Corporation, Everett, WA, USA). The average hourly energy consumption of germination process was calculated and reported.

2.10. Statistical analysis

Color and texture measurements were conducted 5 times with all other analyses conducted in triplicate, and the results were reported as mean ± standard deviation. The significance of differences among treatment means was determined using the one-way analysis of variance (ANOVA) calculated by SPSS version 22 (SPSS Institute, Chicago, IL, USA) at a 5% level of significance.

3. Results and discussion

3.1. Effect of ultrasound on grain surface microstructure

ESEM was used to study the effect of ultrasound treatment on the surface microstructure of the GBR and GRR kernels. In Fig. 2b and d, holes and cracks can be observed on the surfaces of the GBR-US and GRR-US that were sonicated for 5 min after soaking, especially along the cell wall of adjacent cells, while the surfaces of rice samples without ultrasound treatment were absent of these blemishes (Fig. 2a and c). The formation of these cracks and holes at micro-scale (μm scale) is attributed to acoustic cavitation and resulting the micro-scale physical activities, such as shock wave, water impinging jets at solid-liquid interfaces with speed of up to 200 m/s, and high stress rate caused by high heating/cooling rate [12]. It was reported that collapsing cavitation bubble occurring at or in close vicinity to the surface of the plant membranes produced microfractures on soybean flakes [29] and punched holes on the cell wall of *E. coli* K12 as [30].

The changes in surface structure would also lead to enhanced mass transfer. For instance, the ultrasound was shown to reduce the hydration time of mung beans by 25% [31] and corn kernels by 35% [32]. In this study, these micro-openings on the surface of rice kernels introduced new pathways for water to enter the rice grains, thus an ultrasound pre-treatment of dehulled rice is expected to enhance hydration process and shorten processing or cooking time.

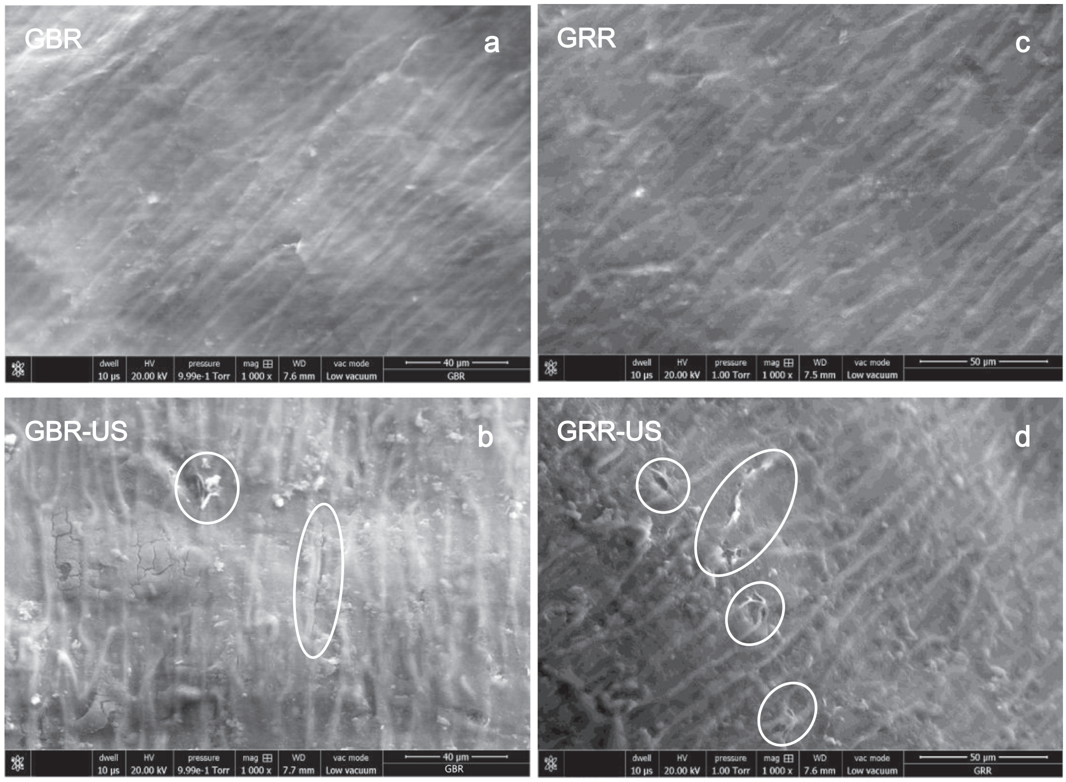

Fig. 2. Effect of ultrasound treatment on the microstructure of the rice surface. * a and c are non-treated samples, b and d are ultrasound (25 kHz, 16 W/L, 5 min) treated samples. GBR means germinated brown rice, GRR means germinated red rice. Environmental Scanning Electron Microscopy (ESEM) micrographs were carried out with a Quanta FEG 450 ESEM (FEI Company, Hillsboro, Oregon) at an accelerating potential of 30 kV. The holds and cracks were pointed out by white cycles.

3.2. Effects of germination time and ultrasound treatment on the starch hydrolysis

3.2.1. Changes of total starch content

The total starch content of the sonicated brown rice and red rice after controlled germination for 8/24/36 h was shown in Fig. 3a. It can be seen that, the starch content in the GRR and GBR slightly decreased during germination for up to 36 h, i.e. by 7.95% from 66.31 mg/100 g (raw red rice) to 61.04 mg/100 g (36-h GRR), and by 10.88% from 68.49 mg/100 g (raw brown rice) to 61.04 mg/100 g (36-h GBR). The 5-min ultrasound treatment after soaking accelerated the starch hydrolysis during germination, with a significant difference seen on the red rice germinated for 36 h ($p < .05$). The total starch content of the 36-h GRR-US flour was 4.01 mg/100 g less than the untreated group 36-h GRR ($p < .05$), while no significant difference was found between the treated and untreated GBR samples. The different response on starch hydrolysis between GBR and GRR may be caused by the different sensitivity of rice cultivars to ultrasound treatment and their different starch profiles before germination. The enhanced hydrolysis in ultrasound treated samples can be attributed to two factors. First, the surface holes and cracks shown in Fig. 2 and the enhanced cell membrane permeability of sonicated seed coat [18] can accelerate water intake during germination thus providing more abundant substrate for enzymatic hydrolysis. Second, the ultrasound-induced changes in cellular structures and endogenous enzyme activity may improve the release of enzymes through the cell wall thus improving the hydrolysis efficiency of amylase [16].

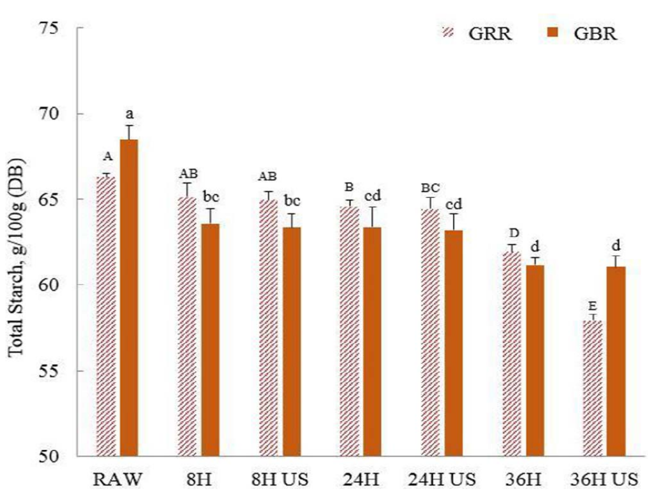

Fig. 3a. Effects of germination time and ultrasound treatment on the total starch content. *RAW means de-hulled rice before germination; US means the samples with ultrasound treatment for 5 min after soaking; Differences in concentrations are highlighted by different letters A–D or a–d at $p < .05$.

3.2.2. Changes in glucose content

The glucose content of the sonicated brown rice and red rice was shown in Fig. 3b. A significant increase in glucose content with the germination time can be observed. Further, the difference in glucose content between the treated sample and the control was more pronounced at later germination stages. The GRR and GBR showed a significant difference in glucose content after germinating for 36 h versus the raw rice, thus the glucose content could be used as an indicator of the degree of germination. There is a further jump in glucose content after ultrasound treatment (Fig. 3b). The glucose content of ultrasound treated 36-h GRR and 36-h GBR was 246.08 mg/100 g and 481.25 mg/100 g, which was 30.06 mg/100 g and 98.34 mg/100 g higher than control, 209.72 mg/100 g and 430.25 mg/100 g higher than the raw dehulled rice, respectively (Fig. 3b).

The increase of glucose content after ultrasound treatment can be

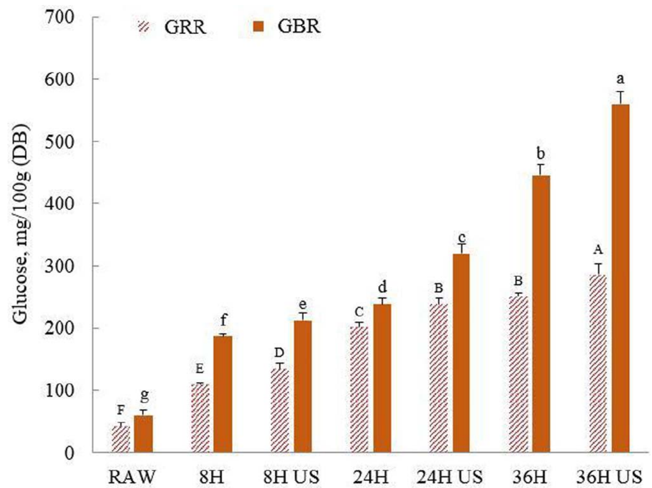

Fig. 3b. Effects of germination time and ultrasound treatment on the glucose content. *RAW means de-hulled rice before germination; US means the samples with ultrasound treatment for 5 min after soaking; Differences in concentrations are highlighted by different letters A–D or a–d at $p < .05$.

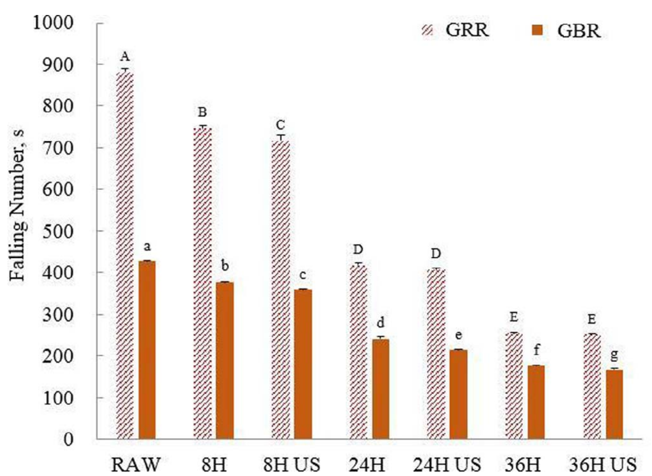

Fig. 3c. Effects of germination time and ultrasound treatment on the Falling Number (FN). *RAW means de-hulled rice before germination; US means the samples with ultrasound treatment for 5 min after soaking; Differences in FN (14% moisture basis) values are highlighted by different letters A–D or a–d at $p < .05$.

linked to enhanced activity of starch hydrolytic enzymes [18], which accelerated hydrolysis of starch and resulted in an improved accumulation of glucose during germination. The α-amylase breaks down starch into glucose or dextrin; further hydrolysis of dextrin produces glucose during germination [33]. The amylase hydrolysis of rice starch during the germination can improve the overall digestion and absorption of rice products, and increased reducing sugar content can improve the taste of cooked dehulled rice. In this work, the accelerated accumulation of glucose and decreased FN values (Fig. 3c) during the germination indicated that the amylase hydrolysis activity was significantly promoted during the soaking and sprouting process, in agreement with the work of Mares and Mrva (2008).

3.2.3. Changes of Falling Number values

As shown in Fig. 3c, the FN values of all the rice flours decreased with the germination time. In addition, the FN values of the GBR and GRR were significantly different. The FN of the 8-h, 24-h, 36-h GRR was 747 s, 419 s, 256 s, respectively, which was 134 s (15.21%), 462 s (52.44%), and 625 s (70.94%) less than the raw red rice. The FN of the 8-h, 24-h, 36-h GBR was 377 s, 240 s, 176 s, respectively, which was 50 s (11.71%), 187 s (43.79%), and 251 s (58.78%) less than the raw brown rice. The ultrasound-treated samples exhibited a faster-reducing trend of FN value for both rice flours after 8 h, 24 h, 36 h of germination (Fig. 3c).

Previous studies reported that sprouting decreased FN value of wheat grains due to an increased α-amylase activity [35]. Mares and Mrva (2008) reported that since the activity of endogenous α-amylase increased during germination, the rapid reduction in starch paste viscosity was a result of an enhanced hydrolysis of starch macromolecules, which followed an inverse curvilinear relationship between the enzymatic activity and the FN value [34]. Similarly, in this study, the decrease in FN values may also be caused by an increase in α-amylase activity of the germinated rice. Therefore, the FN value can be used as an indicator of the viscosity of whole-grain rice flour as a function of germination time.

3.3. Effects of germination time and ultrasound treatment on the color and viscosity properties of germinated de-hulled rice flour

3.3.1. Changes of color

The color parameters L^*, a^*, b^*, and ΔE value of all the samples were list in Table 1. As shown in Table 1, the L^* value of the GBR decreased significantly with germination time. The ultrasound pre-treatment further lowered the L^* value, probably due to the non-enzymatic browning (Maillard) reaction during drying between (increased) sugar content and free amino acids [7]. The L^* value of GRR did not show a noticeable change with increasing germination time, which might be caused by the interference from pigments in pericarp [36]. The ΔE of both GBR and GRR showed an increased trend with germination time (Table 1). The ultrasound pre-treatment improved the ΔE increasing of GBR flour, while slowed down this increased trend of GRR.

The color is an important performance characteristic of rice flour affecting the appearance of finished products since rice flour generally serves as the foundational ingredient for the rice-based products. As can be seen in Table 1, the un-treated GBR flour (0H) was whiter (higher L^* value) and less yellow (smaller yellowness, $+b^*$) than the germinated and sonicated brown rice flour, showing that controlled germination and sonication made the brown rice look browner. However, for red rice, the controlled germination and sonication made the red rice less red (smaller redness $+a^*$) than the un-treated GRR flour (0H). Thus, two rice cultivars responded differently to germination and ultrasound treatment.

3.3.2. Changes of viscosity

The effects of germination time and ultrasound treatment on RVA viscosities of rice flours are shown in Table 2. A decrease in the peak viscosity, trough viscosity, breakdown, final viscosity, setback and the pasting temperature can be observed in all the flour samples after germination for up to 36 h (Table 2). Similar changes in pasting profile by germination were reported by Wichamanee and Teerarat (2012), which showed that the germinated rice flour had a lower peak viscosity, breakdown viscosity, final viscosity and set back than the control [37]. The peak viscosity, trough viscosity, and final viscosity of the red rice were higher than the brown rice (Table 2). The gelatinization viscosity is one of the main physicochemical properties of starch or grain flours, which is affected by the starch source, the proportion of amylose and amylopectin, and the degree of starch hydrolysis. The reduction in pasting viscosity of germinated dehulled rice flour could be caused by the activated endogenous enzymes in whole grain rice, including α-amylase, β-amylase, limit dextrinase, and α-glucosinase, which convert starch into smaller molecules.

The ultrasound treatment resulted in a further reduction of the peak viscosity, trough viscosity, and final viscosity of the GBR flour, with the changes for the GRR flour less pronounced. The different response of GRR and GBR might be caused by the difference in the sensitivity of amylase activity in the rice to power ultrasound. The ultrasound-treated GRR and GBR flour showed lower setback values in the 8 h- and 24 h-

Table 2
Effects of germination time and ultrasound treatment on RVA pasting properties of germinated rice flour.

Germination time and US treatment		PV, cP	TV, cP	Breakdown, cP	FV, cP	Setback, cP
Red rice	0H	2103 ± 80[c]	1488 ± 65[b]	615 ± 15[d]	3296 ± 33[a]	1194 ± 47[a]
	8H	2364 ± 92[b]	1570 ± 36[a]	794 ± 56[bc]	3326 ± 52[a]	962 ± 41[b]
	8H US	2555 ± 60a	1609 ± 31[a]	946 ± 29[a]	3388 ± 42[a]	833 ± 18[c]
	24H	1838 ± 35[d]	1124 ± 8[d]	714 ± 27[c]	2597 ± 46[b]	760 ± 12[d]
	24H US	2031 ± 6[c]	1225 ± 14[c]	806 ± 19[b]	2691 ± 12[b]	660 ± 17[e]
	36H	1059 ± 10[f]	562 ± 2[f]	498 ± 12[f]	1467 ± 16[d]	408 ± 26 [g]
	36H US	1128 ± 52[e]	634 ± 14[e]	525 ± 7[e]	1628 ± 19[c]	459 ± 5[f]
Brown rice	0H	1679 ± 56[a]	942 ± 25[a]	738 ± 32[a]	2623 ± 47[a]	944 ± 9[a]
	8H	1558 ± 38[b]	882 ± 19[b]	676 ± 19[b]	2121 ± 28[b]	564 ± 10[b]
	8H US	1493 ± 29[c]	822 ± 23[c]	671 ± 6[b]	2015 ± 31[c]	523 ± 3[c]
	24H	1060 ± 6[d]	513 ± 3[d]	547 ± 3[c]	1458 ± 18[d]	398 ± 12[d]
	24H US	988 ± 14[e]	455 ± 5[e]	533 ± 12[c]	1359 ± 8[e]	372 ± 6[e]
	36H	343 ± 2[f]	26 ± 1[f]	318 ± 6[d]	218 ± 3[f]	-125 ± 1 [g]
	36H US	315 ± 13[f]	15 ± 1[f]	291 ± 1[d]	220 ± 8[f]	-95 ± 5[f]

[*]US means the samples with ultrasound treatment (25 kHz, 16 W/L, 5 min) after soaking. PV, peak viscosity; TV, trough viscosity; FV, final viscosity. Differences in each column are highlighted by different letters a–d or a–d at $p < .05$.

germinated samples than the control (Table 2). The significantly changes in the RVA viscosities of GBR flours by ultrasonication may provide an advantage for end-product production. The RVA pasting properties, including the setback value, were reported to be useful in predicting the degree of stickiness of cooked rice [38]. Thus, the changes in the rheology properties of rice flours produced from germinated and sonicated rice kernels may provide a useful method to improve the eating quality of cooked de-hulled rice. For traditional rice consumers, a more sticky rice is preferable, especially for whole grain rice.

3.4. Effects of ultrasound on the sprouts growth and texture of steam-cooked germinated de-hulled rice

3.4.1. Effect on the sprouting speed

As shown in Table 3, the growth speed of rice sprout was improved by 22.3% (GRR) and 26.9% (GBR) in ultrasound treated samples. This result in agreement with Yang et al. (2015) who observed an increase in the length of soybean sprout by 24.4% with ultrasound treatment [18]. Chen et al. (2012) reported that an ultrasound treatment (25 min, 38 °C, and 300 W output power) increased the uptake of water of switchgrass seeds during the early imbibition period, resulting in accelerated germination [39]. The ultrasonic treatment was also shown to improve seedling growth of tall fescue and Russian wild rye by Liu et al. (2016). They postulated that the acoustic cavitation produced by power ultrasound might have increased the porosity inside of the seeds thus improving oxygen availability and water absorption during the first stage of their germination test [19]. It is known that physiological signals, such as sugars and phytohormones, are associated with phenotypic changes when plants perceive environmental stresses, which are also associated with sprouts growth and seedling development [40]. Similarly, in this study, the endogenous phytohormone level of treated plant tissue might have be enhanced by the ultrasonic treatment, resulting in enhanced sprouting. This is because phytohormones, such as jasmonic acid (JA), abscisic acid (ABA), salicylic acid (SA), and ethylene (ET) are major players in a signaling network responses to both biotic and abiotic stresses [41]. The response of phytohormones to ultrasonic stress is a new area where further research is needed.

In this study, the effect of temperature change during a 5-min ultrasound treatment on the germination was ignored. The goal of this study was a develop a low acoustic power density (APD) treatment to stimulate the plant making them “happy” to produce more compounds with health benefit. Therefore, we used very low APD of 16 W/L compared to many traditional power ultrasound applications. The change in temperature for a 5-min treatment can be estimated as following: specific heat capacity of water = 4.2 kJ/kg, the rated total ultrasound output energy = 600 kJ (2000 W∗300 s); for a water mass of 125 kg, the temperature change $\Delta T = 1.14$ °C, without considering the heat transfer to the metal tank and to the environment. We therefore did not take into consideration changes in temperature.

Table 3
Effects of ultrasound treatment on the sprouts growth speed and texture of steam-cooked 36 h-germinated rice.

	Sample	Sprouts growth speed, mm/day	Moisture content before steaming, %	Hardness of steam-cooked rice, N
Red rice	36H	2.78 ± 0.20[d]	45.28 ± 0.96[a]	60.32 ± 0.42[a]
	36H US	3.40 ± 0.33[c]	44.84 ± 1.50[a]	34.10 ± 0.82[c]
Brown rice	36H	4.20 ± 0.47[b]	42.26 ± 0.79[a]	39.81 ± 0.90[b]
	36H US	5.33 ± 0.52[a]	43.12 ± 2.96[a]	24.18 ± 0.60[d]

[*]US means the samples with ultrasound treatment (25 kHz, 16 W/L, 5 min) after soaking. Differences in each column are highlighted by different letters a–d or a–d at $p < .05$.

3.4.2. Effect on the efficiency of steam-cooking process

Steaming is a traditional cooking method widely used in the production of rice- and rice flour-based products in Asian countries, such as Chinese Nuo Mi Ci, Mi Gao, Fa Gao, Zong Zi, and He Fen, Japanese Sushi and Mochi, and Korean rice cakes (known as *Seolgitteok*) [42]. It is also a key step in parboiling process of hulled (husked) rice [43], dehulled (dehusked) rice [44], and germinated brown rice and red rice [25,45]. A few studies with chickpeas showed that the moisture absorption rate of chickpeas was increased by power ultrasound (25 kHz) treatment, and the time used to cook the chickpeas was reduced [46,47]. Thus, ultrasound treatment could also be used to reduce the soaking times of rough rice and enhance the rice parboiling process.

In this study, the effect of ultrasound pre-treatment on cooking time was examined using the hardness of the steamed germinated dehulled rice as a criterion. The hardness of the sonicated steam-cooked 36-h-germinated rice was significantly lower than the germinated rice without sonication. For the red rice, the hardness of the 36-h germinated rice was 60.32 N while that treated with ultrasound was 34.10 N, 43.4% lower than the no ultrasound treated. Similarly, for the brown rice, ultrasound treated samples were softer with a hardness 39.2% lower than the rice without ultrasound treatment (Table 3). As a result, the ultrasound pre-treated germinated rice should have a shorten steam-cooking time to reach the edible status., because the hardness of cooked rice is an important indication of the degree of cooking.

3.5. Energy consumption

During the 36 h-germination, the average electric power of the germination chamber was 60 W, and hourly energy consumption of the ultrasonic humidifier was 16 Wh, respectively. From Table 3, since the ultrasound treated sample had a faster growth speed, and thus less time will be used to reach the same sprout length as the sample without ultrasound treatment. The germination time of the ultrasound-treated sample to reach the same sprout length is estimated to be is 29.4 h (36 h∗2.78/3.4) for the red rice and 28.4 h (36 h∗4.2/5.33) for the brown rice, using the growth rate in Table 3. Consequently, the energy consumption reduction of ultrasound treated sample due to reduced germination time is (36–29.4)∗60 Wh + [(36–29.4)/29.4] ∗16 Wh = 399.6 Wh for the red rice and (36–28.4) ∗60 Wh + [(36–28.4)/28.4]∗16 Wh = 460.3 Wh, a 18.3% and 21.1% reduction on energy consumption compared to the germination process without ultrasound treatment, respectively.

On the other hand, the improved hardens in the ultrasound-treated rice and thus reduced cooking time enables another energy saving. The energy requirement during parboiling rice process generally depends on the steaming temperature and time [48]. A higher steaming temperature could shorten the parboiling time [25,49]. To reach the same degree of cooking, due to a faster reduction in hardness of rice in ultrasound-treated rice, a reduction in steaming time without increasing the temperature can be achieved, which can be translated to a reduction in energy use. Moreover, a shortened steaming time will reduce loss of bound phenolics in germinated rice [45], thus the application of ultrasound pre-treatment in parboiling has the potential to reduce the losses of phytochemical content.

4. Conclusion

Power ultrasound treatment (25 kHz, 16 W/L, 5 min) of soaked brown rice and red rice kernels significantly enhanced the biophysical, physiological and biochemical processes during germination, as shown by improvements in the amylase hydrolysis, moisture transfer through the waxy layer, sprout growing speed (by 22.3–26.9%), and the cooking efficiency of steamed GBR and GRR. The energy consumption during germination stage was significantly reduced by the ultrasound pre-treatment. It is highlighted that the results obtained are highly relevant from both the scientific and industrial point of views. Power ultrasound could be used as a useful tool for the germinated grain ingredient producers, breeding researchers, and grain seedling propagators to shorten the seedling growth cycle, enhance sprouting efficiency, and reduce production cost; it may also provide a novel approach to improve the sensory characteristics of cooked de-hulled rice and shorten the rice steaming time.

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References

[1] M.H. Chen, A.M. McClung, C.J. Bergman, Concentrations of oligomers and polymers of proanthocyanidins in red and purple rice bran and their relationships to total phenolics, flavonoids, antioxidant capacity and whole grain color, Food Chem. 208 (2016) 279–287, http://dx.doi.org/10.1016/j.foodchem.2016.04.004.
[2] A. Moongngarm, N. Saetung, Comparison of chemical compositions and bioactive compounds of germinated rough rice and brown rice, Food Chem. 122 (2010) 782–788, http://dx.doi.org/10.1016/j.foodchem.2010.03.053.
[3] A.k. Singh, J. Rehal, A. Kaur, G. Jyot, Enhancement of attributes of cereals by germination and fermentation: A review, Crit. Rev. Food Sci. Nutr. 55 (2015) 1575–1589, http://dx.doi.org/10.1080/10408398.2012.706661.
[4] J. Ding, T. Yang, H. Feng, M. Dong, M. Slavin, S. Xiong, S. Zhao, Enhancing contents of γ-aminobutyric acid (GABA) and other micronutrients in dehulled rice during germination under normoxic and hypoxic conditions, J. Agric. Food Chem. 64 (2016) 1094–1102, http://dx.doi.org/10.1021/acs.jafc.5b04859.
[5] S.B. Patil, M.K. Khan, Germinated brown rice as a value added rice product: a review, J. Food Sci. Technol. 48 (2011) 661–667, http://dx.doi.org/10.1007/s13197-011-0232-4.
[6] P. Charoenthaikij, K. Jangchud, A. Jangchud, W. Prinyawiwatkul, H.K. No, Composite wheat-germinated brown rice flours: Selected physicochemical properties and bread application, Int. J. Food Sci. Technol. 47 (2012) 75–82, http://dx.doi.org/10.1111/j.1365-2621.2011.02809.x.
[7] F. Cornejo, P.J. Caceres, C. Martinez-Villaluenga, C.M. Rosell, J. Frias, Effects of germination on the nutritive value and bioactive compounds of brown rice breads, Food Chem. 173 (2015) 298–304, http://dx.doi.org/10.1016/j.foodchem.2014.10.037.
[8] H.J. Chung, A. Cho, S.T. Lim, Utilization of germinated and heat-moisture treated brown rices in sugar-snap cookies, LWT – Food Sci. Technol. 57 (2014) 260–266, http://dx.doi.org/10.1016/j.lwt.2014.01.018.
[9] P. Charoenthaikij, K. Jangchud, A. Jangchud, W. Prinyawiwatkul, P. Tungtrakul, Germination conditions affect selected quality of composite wheat-germinated brown rice flour and bread formulations, J. Food Sci. 75 (2010) 312–319, http://dx.doi.org/10.1111/j.1750-3841.2010.01712.x.
[10] M. Ashokkumar, Applications of ultrasound in food and bioprocessing, Ultrason. Sonochem. 25 (2015) 17–23, http://dx.doi.org/10.1016/j.ultsonch.2014.08.012.
[11] F. Chemat, N. Rombaut, A.G. Sicaire, A. Meullemiestre, A.S. Fabiano-Tixier, M. Abert-Vian, Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review, Ultrason. Sonochem. 34 (2017) 540–560, http://dx.doi.org/10.1016/j.ultsonch.2016.06.035.
[12] S. Kentish, H. Feng, Applications of power ultrasound in food processing, Annu. Rev. Food Sci. Technol. 5 (2014) 263–284, http://dx.doi.org/10.1146/annurev-food-030212-182537.
[13] K.S. Ojha, T.J. Mason, C.P. O'Donnell, J.P. Kerry, B.K. Tiwari, Ultrasound technology for food fermentation applications, Ultrason. Sonochem. 34 (2017) 410–417, http://dx.doi.org/10.1016/j.ultsonch.2016.06.001.
[14] J.A. Teixeira da Silva, J. Dobranszki, Sonication and ultrasound: Impact on plant growth and development, Plant Cell Tissue Organ Cult. 117 (2014) 131–143, http://dx.doi.org/10.1007/s11240-014-0429-0.
[15] Q. Wang, G. Chen, H. Yersaiyiti, Y. Liu, J. Cui, C. Wu, Y. Zhang, X. He, Modeling analysis on germination and seedling growth using ultrasound seed pretreatment in switchgrass, PLoS One 7 (2012) e47204, http://dx.doi.org/10.1371/journal.pone.0047204.
[16] Y.P. Chen, Q. Liu, X.Z. Yue, Z.W. Meng, J. Liang, Ultrasonic vibration seeds showed improved resistance to cadmium and lead in wheat seedling, Environ. Sci. Pollut. Res. 20 (2013) 4807–4816, http://dx.doi.org/10.1007/s11356-012-1411-1.
[17] J. Ding, G.G. Hou, B.V. Nemzer, S. Xiong, A. Dubat, H. Feng, Effects of controlled germination on selected physicochemical and functional properties of whole-wheat flour and enhanced γ-aminobutyric acid accumulation by ultrasonication, Food Chem. 243 (2018) 214–221, http://dx.doi.org/10.1016/j.foodchem.2017.09.128.
[18] H. Yang, J. Gao, A. Yang, H. Chen, The ultrasound-treated soybean seeds improve edibility and nutritional quality of soybean sprouts, Food Res. Int. 77 (2015) 704–710, http://dx.doi.org/10.1016/j.foodres.2015.01.011.
[19] J. Liu, Q. Wang, Đ. Karagić, X. Liu, J. Cui, J. Gui, M. Gu, W. Gao, Effects of ultrasonication on increased germination and improved seedling growth of aged grass seeds of tall fescue and Russian wildrye, Sci. Rep. 6 (2016) 22403, http://dx.doi.org/10.1038/srep22403.
[20] Z.L. Yu, W.C. Zeng, W.H. Zhang, X.P. Liao, B. Shi, Effect of ultrasound on the activity and conformation of α-amylase, papain and pepsin, Ultrason. Sonochem. 21 (2014) 930–936, http://dx.doi.org/10.1016/j.ultsonch.2013.11.002.
[21] J. Ding, A.V. Ulanov, M. Dong, T. Yang, B.V. Nemzer, S. Xiong, S. Zhao, H. Feng, Enhancement of gama-aminobutyric acid (GABA) and other health-related metabolites in germinated red rice (*Oryza sativa* L.) by ultrasonication, Ultrason. Sonochem. 40 (2018) 791–797, http://dx.doi.org/10.1016/j.ultsonch.2017.08.029.
[22] J. Yu, N.J. Engeseth, H. Feng, High intensity ultrasound as an abiotic elicitor——effects on antioxidant capacity and overall quality of romaine lettuce, Food Bioprocess Technol. 9 (2016) 262–273, http://dx.doi.org/10.1007/s11947-015-1616-7.
[23] D.E. Duta, A. Culetu, Evaluation of rheological, physicochemical, thermal, mechanical and sensory properties of oat-based gluten free cookies, J. Food Eng. 162 (2015) 1–8, http://dx.doi.org/10.1016/j.jfoodeng.2015.04.002.
[24] Y. Lu, L. Thomas, S. Schmidt, Differences in the thermal behavior of beet and cane sucrose sources, J. Food Eng. 201 (2017) 57–70, http://dx.doi.org/10.1016/j.

jfoodeng.2017.01.005.

[25] E. Cheevitsopon, A. Noomhorm, Effects of superheated steam fluidized bed drying on the quality of parboiled germinated brown rice, J. Food Process. Preserv. 39 (2015) 349–356, http://dx.doi.org/10.1111/jfpp.12239.

[26] Z. Zhang, Y. Niu, S.R. Eckhoff, H. Feng, Sonication enhanced cornstarch separation, Starch/Staerke 57 (2005) 240–245, http://dx.doi.org/10.1002/star.200400285.

[27] V. Ziegler, C.D. Ferreira, J.T.S. Goebel, S.L.M. El Halal, G.S. Santetti, L.C. Gutkoski, E.da R. Zavareze, M.C. Elias, Changes in properties of starch isolated from whole rice grains with brown, black, and red pericarp after storage at different temperatures, Food Chem. 216 (2017) 194–200, http://dx.doi.org/10.1016/j.foodchem.2016.08.045.

[28] H.S. Kwak, M. Kim, Y. Jeong, Physicochemical properties and determination of key instrumental quality measurement parameters of frozen-cooked rice by correlating consumer acceptance, J. Food Qual. 38 (2015) 192–200, http://dx.doi.org/10.1111/jfq.12138.

[29] H. Li, L. Pordesimo, J. Weiss, High intensity ultrasound-assisted extraction of oil from soybeans, Food Res. Int. 37 (2004) 731–738, http://dx.doi.org/10.1016/j.foodres.2004.02.016.

[30] E. Ugarte-Romero, H. Feng, S.E. Martin, K.R. Cadwallader, S.J. Robinson, Inactivation of Escherichia coli with power ultrasound in apple cider, J. Food Sci. 71 (2006) E102–E108, http://dx.doi.org/10.1111/j.1365-2621.2006.tb08890.x.

[31] A.C. Miano, J.da C. Pereira, N. Castanha, M.D.da M. Júnior, P.E.D. Augusto, Enhancing mung bean hydration using the ultrasound technology: description of mechanisms and impact on its germination and main components, Sci. Rep. 6 (2016) 38996, http://dx.doi.org/10.1038/srep38996.

[32] A.C. Miano, A. Ibarz, P.E.D. Augusto, Ultrasound technology enhances the hydration of corn kernels without affecting their starch properties, J. Food Eng. 197 (2017) 34–43, http://dx.doi.org/10.1016/j.jfoodeng.2016.10.024.

[33] S.S. Shaik, M. Carciofi, H.J. Martens, K.H. Hebelstrup, A. Blennow, Starch bioengineering affects cereal grain germination and seedling establishment, J. Exp. Bot. 65 (2014) 2257–2270, http://dx.doi.org/10.1093/jxb/eru107.

[34] D. Mares, K. Mrva, Late-maturity α-amylase: low falling number in wheat in the absence of preharvest sprouting, J. Cereal Sci. 47 (2008) 6–17, http://dx.doi.org/10.1016/j.jcs.2007.01.005.

[35] H. Olaerts, C. Roye, L.J. Derde, G. Sinnaeve, W.R. Meza, B. Bodson, C.M. Courtin, Evolution and distribution of hydrolytic enzyme activities during preharvest sprouting of wheat (*Triticum aestivum*) in the field, J. Agric. Food Chem. 64 (2016) 5644–5652, http://dx.doi.org/10.1021/acs.jafc.6b01711.

[36] Y. Shen, L. Jin, P. Xiao, Y. Lu, J. Bao, Total phenolics, flavonoids, antioxidant capacity in rice grain and their relations to grain color, size and weight, J. Cereal Sci. 49 (2009) 106–111, http://dx.doi.org/10.1016/j.jcs.2008.07.010.

[37] Y. Wichamanee, I. Teerarat, Production of germinated red jasmine brown rice and its physicochemical properties, Int. Food Res. J. 19 (2012) 1649–1654.

[38] P. Limpisut, V.K. Jindal, Comparison of rice flour pasting properties using Brabender Viscoamylograph and rapid visco analyser for evaluating cooked rice texture, Starch/Staerke 54 (2002) 350–357, http://dx.doi.org/10.1002/1521-379X(200208)54:8<350::AID-STAR350>3.0.CO;2-R.

[39] G. Chen, Q. Wang, Y. Liu, Y. Li, J. Cui, Y. Liu, H. Liu, Y. Zhang, Modelling analysis for enhancing seed vigour of switchgrass (*Panicum virgatum* L.) using an ultrasonic technique, Biomass Bioenergy 47 (2012) 426–435, http://dx.doi.org/10.1016/j.biombioe.2012.09.015.

[40] W.S. Chao, M. Doğramaci, D.P. Horvath, J.V. Anderson, M.E. Foley, Phytohormone balance and stress-related cellular responses are involved in the transition from bud to shoot growth in leafy spurge, BMC Plant Biol. 16 (2016) 47, http://dx.doi.org/10.1186/s12870-016-0735-2.

[41] M.P.M. Thoen, N.H. Davila Olivas, K.J. Kloth, S. Coolen, P.P. Huang, M.G.M. Aarts, J.A. Bac-Molenaar, J. Bakker, H.J. Bouwmeester, C. Broekgaarden, J. Bucher, J. Busscher-Lange, X. Cheng, E.F. Fradin, M.A. Jongsma, M.M. Julkowska, J.J.B. Keurentjes, W. Ligterink, C.M.J. Pieterse, C. Ruyter-Spira, G. Smant, C. Testerink, B. Usadel, J.J.A. van Loon, J.A. van Pelt, C.C. van Schaik, S.C.M. van Wees, R.G.F. Visser, R. Voorrips, B. Vosman, D. Vreugdenhil, S. Warmerdam, G.L. Wiegers, J. van Heerwaarden, W. Kruijer, F.A. van Eeuwijk, M. Dicke, Genetic architecture of plant stress resistance: Multi-trait genome-wide association mapping, New Phytol. (2016) 1346–1362, http://dx.doi.org/10.1111/nph.14220.

[42] Y.A. Kim, S.J. In, J. Rho, Effect of germinated grain flours on physicochemical characteristics of rice cakes, Seolgitteok, Food Sci. Biotechnol. 26 (2017) 21–28, http://dx.doi.org/10.1007/s10068-017-0003-8.

[43] T.B. Adhikaritanayake, A. Noomhorm, Effect of continuous steaming on parboiled rice quality, J. Food Eng. 36 (1998) 135–143, http://dx.doi.org/10.1016/S0260-8774(97)00086-1.

[44] N. Kar, R.K. Jain, P.P. Srivastav, Parboiling of dehusked rice, J. Food Eng. 39 (1999) 17–22, http://dx.doi.org/10.1016/S0260-8774(98)00138-1.

[45] Z. Hu, X. Tang, J. Liu, Z. Zhu, Y. Shao, Effect of parboiling on phytochemical content, antioxidant activity and physicochemical properties of germinated red rice, Food Chem. 214 (2017) 285–292, http://dx.doi.org/10.1016/j.foodchem.2016.07.097.

[46] A. Yildirim, M.D. Öner, M. Bayram, Effect of soaking and ultrasound treatments on texture of chickpea, J. Food Sci. Technol. 50 (2013) 455–465, http://dx.doi.org/10.1007/s13197-011-0362-8.

[47] A. Yildirim, M.D. Öner, Electrical conductivity, water absorption, leaching, and color change of chickpea (*Cicer arietinum* L.) during soaking with ultrasound treatment, Int. J. Food Prop. 18 (2015) 1359–1372, http://dx.doi.org/10.1080/10942912.2014.917660.

[48] M.R. Islam, N. Shimizu, T. Kimura, Energy requirement in parboiling and its relationship to some important quality indicators, J. Food Eng. 63 (2004) 433–439, http://dx.doi.org/10.1016/j.jfoodeng.2003.09.002.

[49] P. Thammapat, N. Meeso, S. Siriamornpun, Effects of the traditional method and an alternative parboiling process on the fatty acids, vitamin E, γ-oryzanol and phenolic acids of glutinous rice, Food Chem. 194 (2016) 230–236, http://dx.doi.org/10.1016/j.foodchem.2015.08.014.