Influence of sodium chloride and vacuum impregnation on the quality and bioactive compounds of parboiled glutinous rice

Patiwit Loypimai¹ · Kulab Sittisuanjik¹ · Anuchita Moongngarm² · Wilawan Pimthong¹

Revised: 6 April 2017 / Accepted: 11 April 2017 / Published online: 24 April 2017
© Association of Food Scientists & Technologists (India) 2017

Abstract This study investigated the effect of NaCl (2 and 4% (w/v)) and vacuum impregnation (VI) (150, 200, 250, and 300 Pa) on the quality parameters (water uptake, elongation ratio, visual color, and texture), tocopherols, γ -oryzanol and phenolic compounds of parboiled rice. Parboiling with NaCl and VI resulted in increased lightness and higher concentrations of bioactive compounds than rice parboiled by the traditional method. The highest concentration of tocopherols, γ -oryzanol, and phenolic acids (syringic, and ferulic acids) were obtained from parboiled rice with NaCl concentration at 2% (w/v) and VI at 250 and 300 Pa. As the NaCl concentration and VI levels increased the hardness L^* , b^* and ΔE values also increased, but the a^* value and water uptake decreased. Results suggested that NaCl–VI soaking was observed to be an effective method for parboiling which promoted the visual color and enhanced the concentration of bioactive compounds in the parboiled rice.

Keywords Bioactive compound · Parboiled rice · NaCl · Vacuum impregnation

Introduction

Glutinous rice (*Oryza sativa* L.) is popular rice type in Thailand for both domestic consumption and export due to its superior qualities of fineness, aroma, taste and protein content. It also contains very high quantities of bioactive components such as tocopherols, tocotrienols, γ -oryzanol and phenolic compounds especially in the outer pericarp and aleurone layers covering the grains (Loypimai et al. 2009). A number of researchers have revealed that these compounds are beneficial for human health (Qureshi et al. 2000; Tiwari and Cummins 2009).

Parboiling is an alternative technique to preserve nutritional value and enhances the functional properties and organoleptic quality of rice (Sareepuang et al. 2008). Traditionally, the parboiling process consists of three main steps: soaking the rough rice in water until the kernels are saturated, gelatinization of the rice starch by steaming and finally dehydrating the gelatinized rice kernels to a moisture content suitable for milling or storage (Heinemann et al. 2005; Sareepuang et al. 2008; Ayamdoo et al. 2013). Among these processes, soaking is the most critical step because it takes a long time (~ 24 –48 h) to reach the appropriate moisture content of the grains (Thammapat et al. 2016). As a result of the soaking step, fermentation occurs with odor development, loss of soluble nutritional substances, microbial growth and discordance (Ali and Ojha 1976). Therefore, some additional treatments need to be added to prevent spoilage and protect bioactive compound loss during soaking. In this study, sodium chloride (NaCl) as common salt was chosen to add in the parboiling process of rice in order to prevent the growth of spoilage microorganism, food-borne pathogens, improve the taste and also used as a wetting agent. Moreover, the previous study by Thammapat et al. (2015), also found that adding sodium chloride to

✉ Patiwit Loypimai
patiwit.loypimai@gmail.com

¹ Division of Food Science and Technology, Faculty of Science and Technology, Bansomdejchaopraya Rajabhat University, Bangkok 10600, Thailand

² Department of Food Technology and Nutrition, Faculty of Technology, Maharakham University, Maharakham 44150, Thailand

prepare the parboiled rice could improve the nutritional value and quality of the cooked rice. However, this technique still has some disadvantages during rice soaking because it is time consuming which may result in microbial growth and enzymatic reactions as a result in losing of color, taste and smell of the parboiled rice.

Vacuum impregnation (VI) is an effective process by which air within the pores is expanded under reduced pressure and the oxygen is removed resulting in extended shelf life of the product (Fito 1994; Betoret et al. 2015). Successful applications for VI include preventing discoloration of fruit pieces from enzymatic and oxidative browning (Alzamora et al. 2000; Betoret et al. 2015), improving the salting process of cheese (González et al. 1999), and enhancing the concentration of ascorbic acid and iron in whole potato tubers (Hironaka et al. 2011; Erihemu et al. 2014). Previous studies (Bello et al. 2008; Tian et al. 2014) have shown that rice soaking under pressure or vacuum could help to increase the rate of water diffusion and consequently the soaking time decreased. The color, the texture, and the retrogradation properties of cooked normal rice and waxy rice were also improved by the vacuum soaking (Tian et al. 2014). Therefore, the development of an economic rice parboiling technique to reduce processing time, while offering high yields of both nutrients and bioactive phytochemicals requires further investigation.

This study, therefore, aimed to investigate the application of NaCl and VI techniques during the soaking step and evaluate the effects on the quality parameters (water uptake, elongation ratio, visual color, and texture), tocopherols, and phenolic compounds in parboiled rice.

Materials and methods

Chemicals and reagents

Standard ($\pm$)- α -tocopherol, (+)- δ -tocopherol, (+)- γ -tocopherol, (+)- γ -tocotrienol, *p*-coumaric acid and syringic acid (Sigma-Aldrich Chemical Co., St. Louis, Mo, USA) were used as references along with HPLC grades of methanol, *n*-butanol and ethanol (BDH, Poole, UK). γ -Oryzanol standard was purchased from Tsuno Food Industrial Co., Ltd. (Wakayama, Japan). Standards of gallic, caffeic, and ferulic acids were obtained from Fluka Chemie GmbH (Buchs, Switzerland). All other chemicals and reagents used were analytical grade.

Rice material

Glutinous rice (*Oryza sativa* L. CV. RD6) from the December 2014 harvest was purchased from a rice milling

factory in Surin Province, Thailand. The paddy rice was cleaned, placed in a chamber and stored at room temperature for 6 months prior to the experiment. The initial moisture content of the sample was determined using the AOAC method (AOAC 2000).

Parboiling process of the rough rice

NaCl as a wetting agent and VI were applied for the parboiling of the rough rice. Briefly, 400 g samples of paddy rice were separated from foreign materials and placed into 2 L beakers containing NaCl solution at concentrations of 2 and 4% (w/v) which were then placed into a 30 L vacuum chamber (PolyLab®, Thailand) equipped with a vacuum pump (Gast-model DOA-P504-BN-Labmodel, Germany). Four different levels of vacuum pressure (100, 150, 200, and 250 Pa) were applied to accelerate the moisture absorption of the grains to $30 \pm 2\%$ (wet basis) (the optimal soaking time obtained from our preliminary study) for 3–4 h depending on the level of vacuum treatment and NaCl concentration (Fig. 1). Atmospheric pressure was then restored and the samples were kept in solution for 30 min. A vacuum meter placed between the vacuum pump and vacuum chamber was used to measure and control the pressure. The grains were then drained through cheesecloth and the samples covering the cheesecloth were immediately steamed for 15 min at 120 °C using an autoclave (HVE-50, Hirayama, Japan) fitted with a pressure gauge (Thammapat et al. 2015). Before complete gelatinization, the grains were removed from the chamber and dried in a hot air tray dryer (OLM-500, Memmert, Germany) with 70% relative humidity (RH) at

Fig. 1 Soaking times of each condition to obtain suitable moisture content of rice grains [$30 \pm 2\%$ (wet basis)] during soaking step in different concentrations of NaCl solution and different levels of vacuum impregnation (VI)

50 °C for 12–14 h until the final moisture content of $12 \pm 2\%$ (wet basis) was achieved. Following drying, all samples were milled using a rice milling machine (DSA-30A, Au-Sintawee, Thailand) set at $8 \pm 1.0\%$ degree of milling. The milled parboiled rice samples were then packed in polyethylene bags and stored in the dark at 4 °C until required for analysis. All experiments were performed in triplicates ($n = 3$) for each treatment.

The traditional method was carried out adhering to the procedure previously described by Saif et al. (2004) with some modifications. In short, after cleaning, 400 g of paddy rice was placed in a chamber and soaked in tap water at room temperature (~ 25 °C) overnight (24 h) to increase moisture absorption (approximately ~ 25 – 30% wet basis of final moisture content). The grains were then drained by hand and steamed in an autoclave (HVE-50, Hirayama, Japan) at 120 °C for 15 min. The steamed samples were dried, stored and milled using the same conditions followed for the parboiling method.

Cooking properties

Water uptake

Two grams of rice was cooked with 20 mL water in a 100 mL beaker placed on an electric heater following the procedure described by Sareepuang et al. (2008). Samples were removed during the cooking time for weighing and water uptake was calculated using the equation.

$$\text{Water uptake}(\%) = \frac{\text{Weight of cooked rice}}{\text{Weight of raw rice}}$$

Elongation ratio

The elongation ratio was determined according to the method of Sareepuang et al. (2008). Briefly, two grams of rice were cooked with 20 mL water in a 100 mL beaker placed on an electric heater. Samples were removed during the cooking process to measure the length and width. The elongation ratio was calculated using the equation:

$$\text{Elongation ratio} = \frac{\text{Length of cooked rice}}{\text{Length of raw rice}}$$

Color measurement

After milling, the visual color of the samples was measured using a Minolta Chroma Meter CR-300 (Konica Minolta, Japan). The results were represented as L^* for lightness, a^* for redness or greenness and b^* for yellowness or blueness. Total color difference (ΔE) was calculated.

Texture analysis

Texture profile analysis (TPA) was performed using a texture analyzer (TA-XT2i plus Stable Micro System Ltd., Godalming, UK) following the method reported by Ahmad et al. (2017) with some modifications. After cooking and cooling to approximately 30 °C, thirteen grams of each sample were molded into a block using a cylindrical container (50 mm inside diameter and 100 mm height) and then compressed to 50% strain over a fixed distance with a 6-mm diameter cylindrical stainless steel probe. The program was set to move the probe at 1.0 mm/s during the pre-test, at 5.0 mm/s during the post-test phases and at 2.0 mm/s during the test phase. Parameters derived from the two-cycle curves of the TPA test were hardness and stickiness.

Extraction and analysis of tocols and γ -oryzanol

The extraction of tocopherols and γ -oryzanol from each parboiled rice sample was performed according to our previous method (Loypimai et al. 2009). In short, each parboiled sample (3.0 g) was mixed with methanol at a ratio of 1: 10 (%w/v). The mixture was extracted with a sonicator (50% amplitude, 130 W, 20 kHz Vibra cell) for 5 min before centrifuging at $6000 \times g$ for 10 min. The supernatant was then collected and filtered through a 0.45 μm Whatman nylon syringe filter (GE Healthcare, USA) prior to high performance liquid chromatography (HPLC) analysis.

The extracts of tocopherols (α -tocopherol, δ -tocopherol, γ -tocopherol, γ -tocotrienol) and γ -oryzanol were analyzed by HPLC using a Shimadzu CL-10 HPLC system (Shimadzu, Japan) equipped with a photodiode array (PDA) detector, autosampler and a 150×4.6 mm i.d., 4 μm Phenomenex-C₁₈ HPLC column (Phenomenex Inc., CA, USA; Gimeno et al. 2001). The gradient elution was applied. The mobile phase solvent used was methanol: water: 1-butanol (92: 4: 4 (%v/v)) at a flow rate of 1.0 mL/min for 12 min. After that, the mobile phase was changed to methanol: water: 1-butanol (92: 3: 5, (%v/v)) with a flow rate of 1.5 mL/min within 25 min. The total gradient run time was 25 min before starting the next injection. Other chromatographic conditions used were: an injection volume of 20 μL , column temperature of 45 °C, and detection wavelength of 292 nm for ($\pm$)- α -tocopherol, (+)- δ -tocopherol, (+)- γ -tocopherol and (+)- γ -tocotrienol and 325 nm for γ -oryzanol. Individual compounds were identified based on the retention time and chromatography of the analytical standards.

Extraction and analysis of phenolic acids

Briefly, 0.5 g of each parboiled sample was added to 10 mL of methanol/HCl (100:1, v/v) containing 2.0% butylated hydroxyanisole (BHA) following the method of

Uzelac et al. (2005) and Loypimai et al. (2016) with slight modifications. The mixture was extracted by incubating in a shaking water bath at 35 °C for 12 h. After centrifuging at 6000×*g* for 5 min, the supernatant was passed through a 0.45 µm Whatman nylon syringe filter (GE Healthcare, USA) to obtain the extract sample, prior to injection into the HPLC system.

The HPLC system consisted of a Shimadzu LC-20AC pump, an autosampler, and a diode array detector (DAD). Twenty microliters of the extract were injected through an Inertsil® ODS-3 guard column (ø 4.0 × 10 mm, 5 µm, GL Science Inc., Tokyo, Japan) and separated by Apollo™ C18 analytical column (ø 4.6 × 250 mm, 5 µm, Alltech® Associates, Deerfield, IL, USA) at 40 °C. The mobile system used was a gradient of solvent A containing acetonitrile/deionized water (2/97.8, v/v) with 0.2% phosphoric acid, and solvent B which was a mixture of acetonitrile/deionized water (97.8/2, v/v) containing 0.2% phosphoric acid, with a flow rate of 0.6 mL/min. The linear gradient started with 20% solvent B, 50% solvent B for 30 min, 60% solvent B for 35 min, and 20% solvent B for 40 min at isocratic elution until 55 min. The results were expressed in µg phenolic acids/g of the parboiled rice sample using the calibration curve of the external standards.

Statistical analysis

Data obtained in all experiments were based on three replications for each treatment and reported as mean values and standard deviations. The statistics (SPSS trial version) employed for data analyses were F-test (one-way ANOVA). Duncan's Multiple Range Test was performed to determine the significant differences between treatments. Statistical significance was declared at $P < 0.05$.

Results and discussion

NaCl solution (2 and 4%) as a wetting agent and VI (150, 200, 250, and 300 Pa) were applied to reduce parboiling process time, improve the quality and increase the concentration of phytochemicals in the parboiled rice. Data were based on our preliminary investigation. The soaking times to obtain suitable moisture content of rice grains in NaCl solution and VI were ~3–4 h (Fig. 1). The optimal time for each condition was used. The effects of NaCl and VI on the quality parameters (water uptake, elongation ratio, visual color and texture), tocals, γ-oryzanol and phenolic compounds of parboiled rice were investigated and results were compared with parboiled rice obtained using the traditional method.

Effect of NaCl and VI on water uptake and elongation

Elongation ratios and water uptake of parboiled rice using the traditional method and parboiled rice samples from rough rice soaked with different concentrations of NaCl solution and different levels of VI are displayed in Fig. 2a, b. The concentration of NaCl and level of VI had a significant effect on both water uptake and elongation ratios ($P < 0.05$). The highest values of water uptake were observed in the parboiled rice soaked in NaCl at 2%, and VI at 250 and 300 Pa. The elongation ratio increased as NaCl concentration and the level of VI increased. However, results were comparable to parboiled rice using the traditional method. The reduction of water uptake with increase in NaCl concentration could be attributed to water absorption of proteins in the parboiled rice. This may be because at high concentration NaCl induced the reduction of hydrogen bonding at the protein surface. On the other hand, after the milling, cracking and breaking, the grain

Fig. 2 Elongation ratio (a) and water uptake (b) of parboiled rice and parboiled rice soaked with NaCl–VI

kernels also increased in water uptake and consequently increased in hardness in the parboiled rice (Sareepuang et al. 2008).

Effect of NaCl and VI on visual color

Color is an important quality attribute for consumer acceptability of parboiled rice, and dark color reduces market value in several countries (Bhattacharya, 1985). In this study, the parboiling conditions (VI levels and NaCl concentrations) had a significant effect ($P < 0.05$) on the visual color (a^* , b^* , L^* and ΔE) of the parboiled rice (Table 1). As NaCl concentration and levels of VI increased the L^* , b^* , and ΔE increased while the a^* value decreased. Parboiled rice at 4% NaCl concentration and all levels of VI during soaking showed the highest L^* and b^* , whereas the lowest value was observed in parboiled rice produced by the traditional method. This may be because at higher concentration NaCl was able to prohibit nonenzymatic browning (Maillard reaction). The discoloration of parboiled rice was mainly caused by Maillard type nonenzymatic browning reaction and parboiling conditions (Pillaiyar and Mohandass, 1981; Sareepuang et al. 2008). These findings were similar to Tian et al. (2014); they noted that vacuum soaking enhanced the reduction of enzymes and enzymatic browning occurred in rice with less oxygen. Niamnuy et al. (2007) reported that as the rate of the Maillard reaction at high temperature increased, L^* decreased and a^* increased. Lamberts et al. (2008), found that an increase in reducing sugar, free α -amino nitrogen and glucose isomerisation to fructose caused by non-enzymatic Maillard type of browning for color change in parboiled rice. Tian et al. (2014) reported that L^* and the color intensity of cooked waxy rice were improved by vacuum soaking and high hydrostatic pressure (HHP) soaking. In addition, the contribution of pigments in the husk and bran diffusing into the endosperm also occurred

during soaking (Subrahmanyam et al. 1938; Lamberts et al. 2006).

Effect of NaCl and VI on texture profiles of cooked parboiled rice

The cooked parboiled rice obtained from the different conditions significantly affected the texture profiles in terms of hardness and stickiness ($P < 0.05$; Table 2). As NaCl concentration and level of VI increased, the hardness increased and stickiness decreased. Parboiled glutinous rice prepared by NaCl concentration at 2% and VI at 150, 200, and 250 Pa showed the lowest values of hardness and stickiness. However, the parboiled rice was comparable to that produced by the traditional method. These results were related to the water uptake. The decreasing in water uptake of the parboiled rice (4% NaCl and all levels of VI) resulted in increasing the hardness of cooked grain. This may be due to some starch granules located in central part of the grain, soaked at high NaCl concentration (4%), did not fully gelatinize during steaming which resulting in a hard texture. On the other hands, the increasing in hardness may be related to the reduction of amylose and amylopectin leaching from the grain (Hu et al. 2011). Amylose content is considered to be one parameter amongst others positively correlated to cooked rice hardness (Sowbhagya et al. 1987). Changes in the properties of the rice starch depend upon not only amylose but also amylose–lipid complexes, the proportion of intermediate fractions, and short and long chains of amylopectin (Singh et al. 2007, 2014). By contrast, vacuum soaking using water medium did not show a significant effect on cooked grain hardness and cohesiveness compared to that of rice soaked at atmospheric pressure (Tian et al. 2014). However, the hardness in the cooked parboiled rice was dependent on several other factors including the chemical composition (moisture), balance of starch, gelatinization, soaking time

Table 1 Visual color parameter of parboiled rice and parboiled rice prepared by different levels of vacuum impregnation (VI) and NaCl concentration

Treatment	Color value			
	L^*	a^*	b^*	ΔE
Parboiled rice	60.42 $\pm$ 0.32 ^c	8.89 $\pm$ 0.07 ^a	26.97 $\pm$ 0.12 ^d	–
2% NaCl + VI-150	66.47 $\pm$ 0.63 ^{bc}	8.71 $\pm$ 0.21 ^b	28.46 $\pm$ 0.37 ^c	5.99 $\pm$ 0.55 ^{bc}
2% NaCl + VI-200	66.44 $\pm$ 0.69 ^{bc}	8.57 $\pm$ 0.28 ^{bc}	28.61 $\pm$ 0.23 ^{cd}	5.92 $\pm$ 0.72 ^{bc}
2% NaCl + VI-250	65.52 $\pm$ 0.59 ^{cd}	8.43 $\pm$ 0.17 ^{bc}	29.05 $\pm$ 0.25 ^{abc}	4.79 $\pm$ 0.71 ^{cd}
2% NaCl + VI-300	64.34 $\pm$ 0.85 ^d	8.26 $\pm$ 0.10 ^{cd}	29.11 $\pm$ 0.19 ^{abc}	3.45 $\pm$ 0.86 ^e
4% NaCl + VI-150	68.65 $\pm$ 0.97 ^a	8.21 $\pm$ 0.11 ^{cd}	29.41 $\pm$ 0.95 ^{ab}	7.91 $\pm$ 0.98 ^a
4% NaCl + VI-200	67.54 $\pm$ 0.53 ^{ab}	8.31 $\pm$ 0.17 ^{cd}	29.42 $\pm$ 0.54 ^{ab}	6.78 $\pm$ 0.61 ^{ab}
4% NaCl + VI-250	67.46 $\pm$ 0.83 ^{ab}	8.13 $\pm$ 0.23 ^d	29.51 $\pm$ 0.48 ^{ab}	6.64 $\pm$ 0.37 ^{ab}
4% NaCl + VI-300	67.40 $\pm$ 0.85 ^{ab}	8.15 $\pm$ 0.31 ^d	29.85 $\pm$ 0.09 ^a	6.47 $\pm$ 0.88 ^{ab}

Values are mean $\pm$ SD of triplicate samples (n = 3)

Values with the same letter in the same columns are not significantly different ($P < 0.05$)

Table 2 Texture characteristics of parboiled rice and parboiled rice prepared by different levels of vacuum impregnation (VI) and NaCl concentration

Treatment	Texture profiles	
	Hardness (N)	Stickiness (N)
Parboiled rice	71.86 ± 0.97 ^c	0.89 ± 0.014 ^a
2% NaCl + VI-150	71.35 ± 0.63 ^c	0.51 ± 0.024 ^c
2% NaCl + VI-200	72.25 ± 0.69 ^c	0.57 ± 0.033 ^d
2% NaCl + VI-250	72.62 ± 0.39 ^c	0.64 ± 0.012 ^c
2% NaCl + VI-300	71.98 ± 0.74 ^c	0.65 ± 0.018 ^c
4% NaCl + VI-150	78.57 ± 0.91 ^b	0.86 ± 0.031 ^b
4% NaCl + VI-200	82.56 ± 0.48 ^{ab}	0.85 ± 0.037 ^b
4% NaCl + VI-250	84.38 ± 0.54 ^a	0.87 ± 0.023 ^{ab}
4% NaCl + VI-300	84.96 ± 0.66 ^a	0.91 ± 0.013 ^a

Values are mean ± SD of triplicate samples (n = 3)

Values with the same letter in the same columns are not significantly different ($P < 0.05$)

and temperature, and soaking methods (Rabiul et al. 2000; Sareepuang et al. 2008).

Effect of NaCl and VI on tocots and γ -oryzanol

Tocots (tocopherols and tocotrienols) and γ -oryzanol are naturally occurring phytochemicals which are mainly distributed in the bran layer and are removed along with into the bran fraction during the milling process (Qureshi et al. 2002; Loypimai et al. 2009, 2016). These compounds exhibit positive health benefits for the prevention of cardiovascular disease, atherosclerosis, osteoporosis, and ischemic heart disease (Tiwari and Cummins 2009). Tocots including α -tocopherol, δ -tocopherol, γ -tocopherol, γ -tocotrienol and γ -oryzanol in the parboiled rice prepared from different NaCl–VI soaking conditions are illustrated in Table 3. Significantly different concentrations

of α -tocopherol, δ -tocopherol, γ -tocopherol, γ -tocotrienol and γ -oryzanol were found in the parboiled rice samples ($P < 0.05$). Overall, the parboiled rice obtained by soaking with NaCl concentration at 2% and VI of 300 Pa, and NaCl concentration at 4% and all levels of VI (150, 200, 250, and 300 Pa) showed significantly high values of both tocots and γ -oryzanol ($P < 0.05$). Among the tocots, α -tocopherol was the major homolog in all parboiled rice. Interestingly, all parboiled rice prepared by NaCl–VI soaking provided significantly higher levels of either tocots or γ -oryzanol than the parboiled rice obtained by the traditional process. This may be due to the bioactive compounds in rice grain such as tocots and γ -oryzanol mainly locate in the outer layer of the rice grain and effectively contribute to the endosperm under NaCl–VI soaking by diffusion. On the other hand, less oxygen concentration induced by vacuum soaking reduced both the oxidative and enzymatic reactions, resulting in the loss of active substance compounds such as tocots and γ -oryzanol. These results were supported by Thammapat et al. (2016) who reported that rough rice soaked in 3% (w/v) NaCl solution to give parboiled waxy rice showed significantly higher concentrations of polyunsaturated fatty acids (PUFA), total vitamin E, and γ -oryzanol compared to parboiled rice by the traditional method. Thammapat et al. (2015) reported that as NaCl concentration and soaking temperature increased the γ -oryzanol content also increased. Vacuum soaking is an effective process to inactivate enzymes such as catalase and polyphenol oxidase which are present in waxy rice (Knorr et al. 2006; Mabashi et al. 2009; Tian et al. 2014). Nevertheless the digestible vitamins and high molecular weight polymers like bioactive compounds are degraded by hydrolytic enzymes during soaking (Ohtsubo et al. 2005). In this study, all the parboiled rice prepared by NaCl–VI soaking reduced soaking time by sixfold compared with the traditional method (data not show). Therefore, soaking rice

Table 3 Bioactive compounds of parboiled rice and parboiled rice prepared by different levels of vacuum impregnation (VI) and NaCl concentration

Treatment	(±)- α -tocopherol (μg/g)	(+)- γ -tocopherol (μg/g)	δ -tocopherol (μg/g)	d-(+)- γ -tocotrienol (μg/g)	γ -oryzanol (μg/g)
Parboiled rice	63.44 ± 2.12 ^b	28.12 ± 0.17 ^d	29.71 ± 0.25 ^d	11.11 ± 0.46 ^d	169.7 ± 42.4 ^c
2% NaCl + VI-150	63.49 ± 3.51 ^b	33.35 ± 1.48 ^c	30.31 ± 0.10 ^c	15.33 ± 0.25 ^c	172.9 ± 13.6 ^c
2% NaCl + VI-200	63.66 ± 2.47 ^{ab}	34.63 ± 1.85 ^b	30.83 ± 0.98 ^{abc}	16.42 ± 0.33 ^b	175.7 ± 32.5 ^c
2% NaCl + VI-250	64.05 ± 3.15 ^a	35.33 ± 2.51 ^a	30.64 ± 0.19 ^{bc}	16.81 ± 0.34 ^b	197.5 ± 9.51 ^a
2% NaCl + VI-300	64.22 ± 2.07 ^a	35.38 ± 1.63 ^a	32.59 ± 0.24 ^a	17.68 ± 0.16 ^a	198.9 ± 36.1 ^a
4% NaCl + VI-150	63.91 ± 3.27 ^{ab}	35.12 ± 1.38 ^{ab}	30.41 ± 0.23 ^{bc}	17.63 ± 0.79 ^a	176.8 ± 23.2 ^{bc}
4% NaCl + VI-200	67.12 ± 4.16 ^a	35.51 ± 1.82 ^a	31.27 ± 0.54 ^{ab}	17.88 ± 0.91 ^a	183.7 ± 14.6 ^b
4% NaCl + VI-250	66.26 ± 3.11 ^a	35.47 ± 1.47 ^a	33.71 ± 0.43 ^a	18.01 ± 0.28 ^a	202.6 ± 11.5 ^a
4% NaCl + VI-300	67.09 ± 3.29 ^a	35.43 ± 1.37 ^a	33.62 ± 0.78 ^a	18.97 ± 1.11 ^a	196.9 ± 9.43 ^a

Values are mean ± SD of triplicate samples (n = 3) based on dry weight

Values with the same letter in the same columns are not significantly different ($P < 0.05$)

Table 4 Phenolic compounds of parboiled rice and parboiled rice prepared by different levels of vacuum impregnation (VI) and NaCl concentration

Treatment	Gallic ($\mu\text{g/g}$)	Syrinic ($\mu\text{g/g}$)	Caffeic ($\mu\text{g/g}$) ns	<i>p</i> -Coumaric ($\mu\text{g/g}$)	Ferulic ($\mu\text{g/g}$)
Parboiled rice	6.49 $\pm$ 0.34 ^d	6.32 $\pm$ 0.20 ^d	31.91 $\pm$ 0.14	24.63 $\pm$ 0.15 ^f	40.46 $\pm$ 1.55 ^e
2% NaCl + VI-150	9.04 $\pm$ 0.26 ^c	6.34 $\pm$ 0.15 ^c	31.94 $\pm$ 0.46	45.89 $\pm$ 0.48 ^e	142.11 $\pm$ 3.42 ^d
2% NaCl + VI-200	9.86 $\pm$ 0.19 ^c	6.89 $\pm$ 0.07 ^b	31.96 $\pm$ 0.22	49.13 $\pm$ 0.80 ^d	157.55 $\pm$ 5.15 ^c
2% NaCl + VI-250	10.84 $\pm$ 0.17 ^b	6.96 $\pm$ 0.09 ^{ab}	32.21 $\pm$ 0.17	51.63 $\pm$ 0.55 ^c	166.72 $\pm$ 4.69 ^{ab}
2% NaCl + VI-300	11.32 $\pm$ 0.29 ^b	7.05 $\pm$ 0.16 ^{ab}	32.20 $\pm$ 0.35	54.24 $\pm$ 0.34 ^b	169.79 $\pm$ 7.98 ^a
4% NaCl + VI-150	12.53 $\pm$ 0.33 ^a	7.18 $\pm$ 0.13 ^a	31.89 $\pm$ 0.35	56.45 $\pm$ 0.23 ^{ab}	171.51 $\pm$ 5.05 ^a
4% NaCl + VI-200	13.28 $\pm$ 0.42 ^a	7.22 $\pm$ 0.06 ^a	31.81 $\pm$ 0.52	56.96 $\pm$ 0.52 ^a	172.01 $\pm$ 3.56 ^a
4% NaCl + VI-250	12.98 $\pm$ 0.33 ^a	7.26 $\pm$ 0.03 ^a	31.97 $\pm$ 0.81	58.19 $\pm$ 0.48 ^a	179.97 $\pm$ 2.86 ^a
4% NaCl + VI-300	12.91 $\pm$ 0.15 ^a	7.19 $\pm$ 0.12 ^a	31.92 $\pm$ 0.32	57.47 $\pm$ 0.87 ^a	189.63 $\pm$ 3.47 ^a

Values are mean $\pm$ SD of triplicate samples ($n = 3$) based on dry weight

Values with the same letter in the same columns are not significantly different ($P < 0.05$)

ns Not significantly different at $P < 0.05$

grains in NaCl–VI for parboiling may inhibit the decomposition of valuable bioactive compounds such as tocopherols and γ -oryzanol.

Effect of NaCl and VI on phenolic compounds

Phenolic acids (both soluble and insoluble) found in cereal grains are bound with polysaccharides at the cell wall (Thammapat et al. 2016). The parboiling process significantly ($P < 0.05$) affected phenolic compounds (gallic, syringic, *p*-coumaric and ferulic acids) in the parboiled rice (Table 4). The parboiled rice obtained by soaking with NaCl at 2% and VI at 250 and 300 Pa, and NaCl at 4% and at all levels of VI had significantly high concentrations of syringic acid (ranging 6.96–7.26 $\mu\text{g/g}$) and ferulic acid (ranging 166.72–189.63 $\mu\text{g/g}$; $P < 0.05$). The parboiled rice from these combinations showed a fourfold increase in ferulic acid compared with rice parboiled by the traditional method. The highest concentrations of gallic and *p*-coumaric acids were found in parboiled rice with NaCl concentration at 4% and all levels of VI, while the concentration of caffeic acid showed no significant difference. The results were consistent with Thammapat et al. (2016) who found that parboiling using NaCl during the soaking step enhanced the concentrations of protocatechuic, syringic, ferulic and *p*-coumaric acids. This may be because NaCl-vacuum soaking accelerated water penetration and contributed free phenolic acids from the outer layer of the grain into the inner layer or endosperm. On the other hand, the NaCl–VI soaking reduced the enzymatic reactions occurring in the rice by generating low oxygen concentration as reported by Tian et al. (2014). These factors are a major reason for the increase in phenolic acids using NaCl–VI soaked parboiled rice.

Conclusion

NaCl and VI significantly affected the quality and bioactive compounds of parboiled glutinous rice. This study demonstrated that the application of NaCl–VI soaking increased L^* and ΔE of parboiled rice. The application of NaCl–VI soaking could reduce the soaking time and improved the concentrations of bioactive compounds compared to parboiled rice obtained by the traditional method. The highest concentrations of tocopherols, γ -oryzanol, syringic acid, and ferulic acid were obtained from parboiled rice with NaCl concentration at 2% (w/v) and VI at 250 and 300 Pa. Moreover, the hardness of cooked rice and water uptake obtained from these conditions were also comparable to that produced by the traditional method. These findings suggest that the NaCl–VI soaking is an effective technique for parboiled rice production. However, further studies are required concerning consumer acceptability.

Acknowledgments The authors gratefully acknowledge the Research and Development Institute, Bansomdejchaopraya Rajabhat University, Thailand for financial support and Mahasarakham University for HPLC equipment and laboratory support.

References

- Ahmad U, Alfaro L, Yeboah-Awudzi M, Kyereh E, Dzandu B, Bonilla F, Chouljenko A, Sathivel S (2017) Influence of milling intensity and storage temperature on the quality of Catahoula rice (*Oryza sativa* L.). LWT Food Sci Technol 75:386–392. doi:10.1016/j.lwt.2016.09.014
- Ali N, Ojha TP (1976) Parboiling technology. In: Araullo EV, Depadua DB, Grahm M (eds) Rice postharvest technology. International Development and Research Center, Ottawa, pp 163–201 (ISBN 0-88936-067-7)

- Alzamora SM, Castro MA, Vidales SL, Nieto AB, Salvatori D (2000) The role of tissue microstructure in the textural characteristics of minimally processed fruits. Minimally processed fruits and vegetables fundamental aspects and applications. Aspen Publishers Inc, Maryland, pp 153–172
- AOAC (2000) Official methods of analysis, 17th edn. Association of Official Analytical Chemical, Washington
- Ayamdoo AJ, Demuyakor D, Dogbe W, Owusu R, Ofosu MA (2013) Effect of varying parboiling conditions on physical qualities of jasmine 85 and nerica 14 rice varieties. *Am J Food Technol* 8:31–42. doi:[10.3923/ajft.2013.31.42](https://doi.org/10.3923/ajft.2013.31.42)
- Bello M, Tolaba M, Suárez C (2008) Hydration kinetics of rice kernels under vacuum and pressure. *Int J Food Eng* 4:1556–3758. doi:[10.2202/1556-3758.1363](https://doi.org/10.2202/1556-3758.1363)
- Betoret E, Betoret N, Rocculi P, Rosa MD (2015) Strategies to improve food functionality: structure-property relationships on high pressures homogenization, vacuum impregnation and drying technologies. *Trends Food Sci Technol* 46:1–12. doi:[10.1016/j.tifs.2015.07.006](https://doi.org/10.1016/j.tifs.2015.07.006)
- Bhattacharya KR (1985) Parboiling of rice. In: Juliano BO (ed) rice chemistry and technology. American Association of Cereal Chemists Inc, Minnesota, pp 289–348
- Erihemu Hironaka K, Oda Y, Koaze H (2014) Iron enrichment of whole potato tuber by vacuum impregnation. *LWT Food Sci Technol* 59:504–509. doi:[10.1016/j.lwt.2014.04.043](https://doi.org/10.1016/j.lwt.2014.04.043)
- Fito P (1994) Modelling of vacuum osmotic dehydration of food. *J Food Eng* 22(1–4):313–328
- Gimeno E, Castellote AI, Lamuela-Raventó RM, de la Torre-Boronat MC, López-Sabater MC (2001) Rapid high-performance liquid chromatographic method for the simultaneous determination of retinol, alpha-tocopherol and beta-carotene in human plasma and low-density lipoproteins. *J Chromatogr B Biomed Sci Appl* 758(2):315–322
- González C, Fuentes C, Andrés A, Chiralt A, Fito P (1999) Effectiveness of vacuum impregnation brining of Manchego-type curd. *Int Dairy J* 9:143–148. doi:[10.1016/S0958-6946\(99\)00035-7](https://doi.org/10.1016/S0958-6946(99)00035-7)
- Heinemann RJB, Fagundes PL, Pinto EA, Penteadó MVC, Lanfer-Marquez UM (2005) Comparative study of nutrient composition of commercial brown, parboiled and milled rice from Brazil. *J Food Compos Anal* 18(4):287–296. doi:[10.1016/j.jfca.2004.07.005](https://doi.org/10.1016/j.jfca.2004.07.005)
- Hironaka K, Kikuchi M, Koaze H, Sato T, Kojima M, Yamamoto K, Yasuda K, Mori M, Tsuda S (2011) Ascorbic acid enrichment of whole potato tuber by vacuum-impregnation. *Food Chem* 127:1114–1118. doi:[10.1016/j.foodchem.2011.01.111](https://doi.org/10.1016/j.foodchem.2011.01.111)
- Hu XT, Xu XM, Jin ZY, Tian YQ, Bai YX, Xie ZJ (2011) Retrogradation properties of rice starch gelatinized by heat and high hydrostatic pressure (HHP). *J Food Eng* 106:262–266. doi:[10.1016/j.jfoodeng.2011.05.021](https://doi.org/10.1016/j.jfoodeng.2011.05.021)
- Knorr D, Heinz V, Buckow R (2006) High pressure application for food biopolymers. *Biochim Biophys Acta* 1764(3):619–631. doi:[10.1016/j.bbapap.2006.01.017](https://doi.org/10.1016/j.bbapap.2006.01.017)
- Lamberts L, Brijs K, Mohamed R, Verhelst N, Delcour JA (2006) Impact of browning reactions and bran pigments on color of parboiled rice. *J Agric Food Chem* 54:9924–9929
- Lamberts L, Rombouts I, Brijs K, Gebruers K, Delcour JA (2008) Impact of parboiling conditions on Maillard precursors and indicators in long-grain rice cultivars. *Food Chem* 110:916–922. doi:[10.1016/j.foodchem.2008.02.080](https://doi.org/10.1016/j.foodchem.2008.02.080)
- Loypimai P, Moongngarm A, Chottanom P (2009) Effects of ohmic heating on lipase activity, bioactive compounds and antioxidant activity of rice bran. *Aust J Basic Appl* 3(4):3642–3652
- Loypimai P, Moongngarm A, Chottanom P (2016) Phytochemicals and antioxidant capacity of natural food colorant prepared from black waxy rice bran. *Food Biosci* 15:34–41. doi:[10.1016/j.fbio.2016.04.003](https://doi.org/10.1016/j.fbio.2016.04.003)
- Mabashi Y, Ookura T, Tominaga N, Kasai M (2009) Characterization of endogenous enzymes of milled rice and its application to rice cooking. *Food Res Int* 42:157–164. doi:[10.1016/j.foodres.2008.09.012](https://doi.org/10.1016/j.foodres.2008.09.012)
- Niamnuy C, Devahastin S, Soponronnarit S (2007) Effects of process parameters on quality changes of shrimp during drying in a jet spouted bed dryer. *J Food Sci* 72(9):553–563. doi:[10.1111/j.1750-3841.2007.00516.x](https://doi.org/10.1111/j.1750-3841.2007.00516.x)
- Ohtsubo K, Suzuki K, Yasui Y, Kasumi T (2005) Bio-functional components in the processed pre-germinated brown rice by a twin-screw extruder. *J Food Compos Anal* 18(4):303–316. doi:[10.1016/j.jfca.2004.10.003](https://doi.org/10.1016/j.jfca.2004.10.003)
- Pillaiyar P, Mohandass R (1981) Hardness and colour in parboiled rice produced at low and high temperature. *J Food Sci Technol* 18:7–9
- Qureshi A, Mo H, Packer L, Peterson DM (2000) Isolation and identification of novel tocotrienols from rice bran with hypocholesterolemic, antioxidant, and antitumor properties. *J Agric Food Chem* 48(8):3130–3140
- Qureshi A, Sami SA, Salser WA, Khan FA (2002) Dose-dependent suppression of serum cholesterol by tocotrienol-rich fraction (TRF25) of rice bran in hypercholesterolemic humans. *Atherosclerosis* 161(1):199–207
- Rabiul IM, Shimizu N, Kimura T (2000) Quality evaluation of parboiled rice with physical properties. *Food Sci Technol Res* 7(1):57–63. doi:[10.3136/fstr.7.57](https://doi.org/10.3136/fstr.7.57)
- Saif SMH, Suter DA, Lan Y (2004) Effects of processing conditions and environmental exposure on the tensile properties of parboiled rice. *Bioprocess Biosyst Eng* 89(3):321–330. doi:[10.1016/j.biosystemseng.2004.08.010](https://doi.org/10.1016/j.biosystemseng.2004.08.010)
- Sareepuang K, Siriamornpun S, Wiset L, Meeso N (2008) Effect of soaking temperature on physical, chemical and cooking properties of parboiled fragrant rice. *World J Agric Sci* 4(4):409–415
- Singh N, Nakaura Y, Inouchi N, Nishinari K (2007) Fine structure, thermal, viscoelastic properties of starch separated from indica rice cultivars. *Starch-Stärke* 59:10–20. doi:[10.1002/star.20060527](https://doi.org/10.1002/star.20060527)
- Singh N, Paul P, Virdi AS, Kaur P, Mahajan G (2014) Influence of early and delayed transplantation of paddy on physicochemical, pasting, cooking, textural, and protein characteristics of milled rice. *Cereal Chem* 94(4):389–397. doi:[10.1094/CCHEM-09-13-0193-R](https://doi.org/10.1094/CCHEM-09-13-0193-R)
- Sowbhagya CM, Ramesh BS, Bhattacharya KR (1987) The relationship between cooked-rice texture and the physicochemical characteristics of rice. *J Cereal Sci* 5(3):287–297. doi:[10.1016/S0733-5210\(87\)80029-2](https://doi.org/10.1016/S0733-5210(87)80029-2)
- Subrahmanyam V, Sreenivasan A, Dasgupta HP (1938) Studies on quality of rice (I). Effect of milling on the chemical composition and commercial qualities of raw and parboiled rice. *Indian J Agric Sci* 8:459–486
- Thammapat P, Meeso N, Siriamornpun S (2015) Effects of NaCl and soaking temperature on the phenolic compounds, α -tocopherol, γ -oryzanol and fatty acids of glutinous rice. *Food Chem* 175:218–224. doi:[10.1016/j.foodchem.2014.11.146](https://doi.org/10.1016/j.foodchem.2014.11.146)
- Thammapat P, Meeso N, Siriamornpun S (2016) 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* 194:230–236. doi:[10.1016/j.foodchem.2015.08.014](https://doi.org/10.1016/j.foodchem.2015.08.014)
- Tian Y, Zhao J, Xie Z, Wang J, Xu X, Jin Z (2014) Effect of different pressure-soaking treatments on color, texture, morphology and

- retrogradation properties of cooked rice. *LWT Food Sci Technol* 5:368–373. doi:[10.1016/j.lwt.2013.09.020](https://doi.org/10.1016/j.lwt.2013.09.020)
- Tiwari U, Cummins E (2009) Nutritional importance and effect of processing on tools in cereals. *Trends Food Sci Technol* 20:511–520. doi:[10.1016/j.tifs.2009.06.001](https://doi.org/10.1016/j.tifs.2009.06.001)
- Uzelac DV, Pospišil J, Levaj B, Delonga K (2005) The study of phenolic profiles of raw apricots and apples and their purees by HPLC for the evaluation of apricot nectars and jams authenticity. *Food Chem* 91:373–383. doi:[10.1016/j.foodchem.2004.09.004](https://doi.org/10.1016/j.foodchem.2004.09.004)