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Research Article

Effect of Precooking and Superheated Steam Treatment on Quality of Black Glutinous Rice

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Consumption of glutinous rice has been increasing. Leum Pua rice (*Oryza sativa* Linn.) is black glutinous rice containing high nutrition, but its cooking process is time-consuming. This study aimed at decreasing cooking time by changing rice properties using superheated steam treatment. The black glutinous rice was subjected to pretreatment: uncooking and precooking before superheated steam treatment at 250°C and 300°C. Drying rate constant (k) of uncooked rice was 0.0301–0.0744 s^{-1}. Precooking rice prior to superheated steam treatment at 300°C reduced the kinetic rate constant to 0.0596 s^{-1}. From SEM, porosity of the treated rice was observed. However, superheated steam treatment reduced ferric reducing antioxidant power and total phenolic content, compared with control. From X-ray diffraction, A-type crystalline structure of the treated rice was disappeared. Cooking time of the superheated steam-treated rice was reduced to 1–5 min. Their hardness and overall liking scores were comparable to control.

1. Introduction

Rice is an important agricultural crop in the world particularly in Asia which had high consumption and production. In Southeast Asia especially in northern and northeastern of Thailand, Laos, and some parts of Vietnam, people consume glutinous or sticky rice as the main meal. In January–August 2017, Thailand exported the glutinous rice for 301,696 metric tons while total volume of rice exportation was 7,395,579 metric tons [1].

Leum Pua rice is one of the black glutinous rice varieties that was selected and purified by Phitsanulok Rice Research Center, Thailand, in 1991–1995. Its kernel pericarp has purple color containing cyanidin-3-O-glucoside and peonidin-3-O-glucoside. At outer layers of the rice grain, it contains high levels of phenolic acids. These bioactive compounds yielded high antioxidant activities in grain [2]. Therefore, it has the potential to be functional foods [3]. However, the cooking process is time-consuming. Therefore, many researches have been conducted to develop the quick-cooking rice as consumers need nowadays.

The process of quick-cooking rice involves heat and mass (water) transfer. Water is absorbed by starch in the rice, under high temperature, resulting in starch gelatinization. Degree of starch gelatinization is an important factor for development of the quick-cooking rice. When rice starch is heated and absorbed enough water, the starch granule was broken, resulting in amylose or amylopectin leaching from the starch granule. This phenomenon could be investigated by loss of birefringence and loss of crystallinity [4].

Superheated steam treatment is a thermal processing technology using superheated steam as a medium for heat transfer. After heating, water is evaporated from liquid to become steam above its boiling point at the absolute pressure. The steam can be generated by a boiler. Then, a heating device can be used to transfer additional heat to the steam. Finally, the steam becomes dried [5, 6]. The advantage of superheated steam is to destroy microorganisms and inactivate bacteria's activity. Compared to the hot air heating, the superheated steam treatment could be more effective to reduce a number of microorganisms in foods. In addition, energy consumption could be reduced by recycling the exhausted steam to the system which reduced pollution or odor emission to atmosphere [7].

Therefore, this study was aimed at developing quick-cooking glutinous rice using superheated steam treatment. Effect of pretreatment before superheated steam treatment was also investigated.

2. Materials and Methods

2.1. Materials. Black glutinous rice (*Oryza sativa* Linn.) or Leum Pua rice was brought from Phitsanulok Rice Research Center, Thailand. Initial moisture content of the black glutinous rice was determined by an oven method [8]. Then, it was kept in a vacuum package at 25°C until used.

2.2. Sample Preparation. Black glutinous rice with approximate initial moisture content of 13% w.b. was separated into 2 groups. The first group was pretreated by precooking rice with a rice : water ratio of 1 : 2 for 15 min. The second group was the uncooked black glutinous rice. Both groups were dried by superheated steam at 250°C and 300°C for 1 min in the superheated steam dryer of JSP, Ltd., Japan (United States of America Patent No. 8343422). The superheated steam dryer chamber was equipped with a 360° rotating vessel (Figure 1). The heating system began with a boiler to generate steam. Steam was then delivered to be heated in chamber containing a radio frequency generator (300 MHz) with 20 kW energy input and became the superheated steam. At this step, steam flow volume was controlled by pressure at 145 kPa. The superheated steam was transferred to a drying chamber which had the rotating vessel inside. To treat with superheated steam, rice sample (50 g) was placed in the rotating vessel and put into the drying chamber. The rotating speed of the vessel was set at 60 rpm.

For superheated steam treatment, moisture contents of glutinous rice samples (treated with superheated steam for 0, 5, 10, . . ., 90, 95, and 100 s) were determined by the oven method [8]. Moisture ratio (MR) was calculated using the following equation:

$$\mathrm{MR} = \frac{X_i - X_\mathrm{e}}{X_\mathrm{o} - X_\mathrm{e}}, \tag{1}$$

where X_i is the moisture content (kg water·kg dry solid^{-1}) of black glutinous rice at drying time i, X_o is the initial moisture content (kg water·kg dry solid^{-1}) of black glutinous rice, and X_e is equilibrium moisture content (kg water·kg dry solid^{-1}) of black glutinous rice.

According to Lewis model [9], kinetic rate constant could be estimated using the following equation:

$$\mathrm{MR} = e^{-k\Delta t}, \tag{2}$$

where MR is the moisture ratio, k is kinetic rate constant (s^{-1}), and Δt is time interval (s).

Coefficient of determination (r^2) and root-mean-square error (RMSE) between the observed values and the estimated values were used to evaluate performance of the model.

2.3. Determination of Black Glutinous Rice Properties

2.3.1. Determination of Microstructure of Black Glutinous Rice. Microstructure of all rice samples was determined by a scanning electron microscopy (SEM), using the method modified from [10]. The dried rice was placed on a specimen holder using a silver plate and coated with a thin film of gold (10 nm) in a vacuum evaporator. The obtained specimens were observed in a scanning electron microscope (JSM-5600LV, JEOL Company, Tokyo, Japan) with an accelerating voltage of 10 kV. Magnification was adjusted to 2000x.

2.3.2. Thermal Properties of Black Glutinous Rice. Superheated steam treated rice and control samples were ground by a rice miller (NW 1000 turbo-model, Natavee Technology Ltd., Thailand) for determination of thermal properties using a differential scanning calorimeter DSC (DSC1, METTLER–TOLEDO, USA). The rice flour (2–4 mg) was added with water (a flour/water ratio approximately 1 : 3) in aluminum sample pan, sealed and equilibrated at 20°C for 3 h and then heated from 20 to 100°C at a rate of temperature 10°C·min^{-1} [10].

2.3.3. Crystalline Structure of Black Glutinous Rice. The X-ray diffractometer (Bruker AXS Model D8 Discover, Karlsruhe, Germany) was used to determine the crystalline structure of black glutinous rice. The superheated steam treated rice and control samples were ground by a rice miller (NW 1000 turbo-model, Natavee Technology Ltd., Thailand) and then was put into a sample holder in the machine operated at 40 kV and 40 mA with Cu-anode source (Cu-Ka radiation of wavelength $k = 1.54$ A). The scanning range of diffraction angle was started from 5° to 40° and detected every 0.02 diffraction angle (2Θ) [11].

2.3.4. Determination of Minimal Cooking Time of Black Glutinous Rice. Minimal cooking time (MCT) was used to compare the cooking time of black glutinous rice before and after treatment with superheated steam treatment. The rice grains (4 g) were added into boiled water (135 mL) for 10 min. A few grains were sampled every minute and removed to a glass plate pressed with another plate. The MCT was determined when the grains no longer presented an opaque center [12].

2.3.5. Determination of Texture of Black Glutinous Rice. A texture analyzer (TA.XT plus, Stable Micro Systems Ltd., Godalming, UK) was used to determine texture of all rice samples after cooking using MCT. Cooked rice (10 g) was placed inside the test cylinder (6 cm diameter). During the measurement, test speed was set at 0.5 mm/s while control force was set at 10 g. Deformation level was set at 60% of sample height. Measurement was repeated at least 10 times for each sample. Hardness, adhesiveness, springiness, and cohesiveness of the cooked rice were recorded for statistical analysis [13].

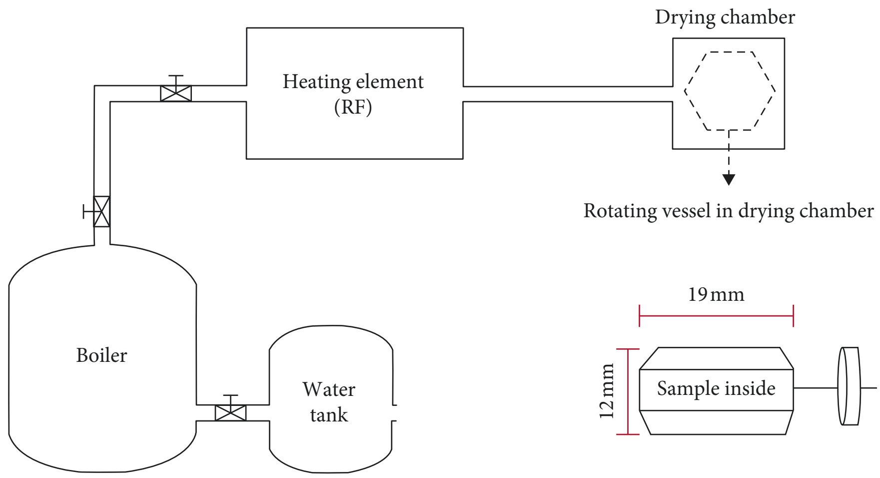

Figure 1: Schematic diagram of superheated steam system.

2.3.6. Determination of Color of Black Glutinous Rice. After superheated stream treatment, uncooked and precooked rice were ground by a rice miller (NW 1000 turbo-model, Natavee Technology Ltd., Thailand) to measure the color by HunterLab (MiniScan, XE Plus model, USA). Measurement was based on the HunterLab system of L^* (lightness/darkness), a^* (redness/greenness), and b^* (yellowness/blueness) using D65 light source and 10° standard observer.

2.3.7. Determination of Antioxidant Activity of Black Glutinous Rice. All rice samples were ground by a rice miller (NW 1000 turbo model, Natavee Technology Ltd., Thailand) and extracted with 100 mL acetone (70% v/v). The extraction was done twice in shaking water bath at 32°C for 4 h. Then, it was centrifuged at $1250 \times g$ for 15 min to separate supernatant and pellet. The supernatant of twice extraction was combined and evaporated to obtain crude extract. The volume of the crude extract was adjusted to 40 mL using acetone (70% v/v) kept at −18°C in brown bottles until use [3, 5].

To determine DPPH radical scavenging activity, each sample was prepared at different dilutions (10–150 mg·mL^{-1}). Then, each dilution (1 mL) was added to 2, 2-Diphenyl-1-picrylhydrazyl (DPPH radical scavenging capacity assay) (0.1 mmol·mL^{-1}) in 95% ethanol (1 mL), mixed, and rested at ambient temperature for 30 min. Light absorption was determined by a spectrophotometer (DYNEX Technologies, Inc., VA, USA) at 517 nm. Butylated hydoxytoluene (BHT), α-Tocopherol, and ascorbic acid were used as standard. DPPH radical scavenging activity (%) was calculated by the following equation:

$$\text{DPPH radical scavenging activity}\,(\%) = \frac{[(A_0 - A_1) \times 100]}{A_0}, \tag{3}$$

where A_0 = absorbance of standard and A_1 = absorbance of sample.

Then, IC_{50} (dilution that can inhibit the free-radical DPPH by 50%) was estimated by plot graph using % DPPH radical scavenging activity at each dilution.

To determine ferric reducing antioxidant power (FRAP), FRAP reagent was prepared by mixing 300 mmol acetate buffer, 20 mmol $FeCl_3 \cdot 6H_2O$, and 10 mmol tripyridyltriazine TPTZ (2,4,6-tris(2-pyridyl)-s-triazine) in HCL solution at a ratio of 10 : 1 : 1 and distilled water. Sample (60 μL) and distilled water (180 μL) were added to the FRAP reagent (1.8 mL) in a cuvette at 37°C for 4 min before measuring the absorbance by the spectrophotometer (DYNEX Technologies, Inc., VA, USA) at 595 nm. The antioxidant activity was reported as μmol of Fe (ll)·g^{-1} sample [14].

Total phenolic content was determined by the modified Folin–Ciocalreu colorimetric method [15]. Sample (125 μL) and deionized water (500 μL) in a test tube was mixed with Folin's reagent (125 μL) for 6 min. Then, 7% sodium carbonate (1250 μL) and deionized water (1000 μL) was added and kept for 90 min, and spectrophotometer (DYNEX Technologies, Inc., VA, USA) was used for measuring absorbance at 760 nm. The result was compared with the standard curve of Gallic acid solutions and reported as micrograms of Gallic acid equivalents per 1 g sample.

2.3.8. Determination of Sensorial Quality of Black Glutinous Rice. All rice samples were cooked by a steamer with a ratio of rice : water = 1 : 2 using the minimal cooking time. Serving size was set at 50 g per sample; as well as, serving temperature was set at 55–60°C for sensory evaluation. Only one sample was served per time to ensure the evaluation of rice quality at 55–60°C. Untrained panelists (n = 100) were involved to evaluate liking scores of appearance, color, texture, flavor, and overall of cooked glutinous rice at Kasetsart University Sensory and Consumer Research Center (KUSCR) using 9-point Hedonic Scale (1 = dislike very much while 9 = like very much).

2.4. Statistical Analysis. All data were subjected to the analysis of variance (ANOVA) using SPSS® software version 12 for window and presented as mean values with standard deviations. Duncan's multiple range tests were used to determine significant difference among means of each treatment at 95% confidential level ($P \leq 0.05$).

3. Results and Discussion

3.1. Change in Moisture Content of Black Glutinous Rice during Superheated Steam Treatment. According to Figure 2, initial moisture content of uncooked rice and precooked rice was around 13% (d.b.) and 30% (d.b.), respectively. During superheated steam treatment, moisture content of all samples was continually decreased. Change in moisture content could be simulated by the Lewis model. Root-mean-square error (RMSE) was in the range of 0.0501–0.0980 while coefficient of determination (r^2) between the actual moisture content and the predicted model was in the range of 0.9273–0.9834.

At 250°C, a drying rate constant of precooked rice (0.0449 s^{-1}) was higher than that of uncooked rice (0.0301 s^{-1}). It is due to the higher initial moisture content of precooked rice than uncooked rice, resulting in the possible high mass diffusion. The rate constants were in the similar range to superheated steam drying of Jasmine rice (0.0332–0.0465 s^{-1} at 300–400°C) previously reported by [5]. In addition, the rate constant could be increased by increasing the superheated steam drying temperature to 300°C (Table 1). This is because high temperature enhanced the high heat-transferring rate and subsequent high mass-transferring rate [16]. Therefore, the rate constant of uncooked rice drying was increased to 0.0744 s^{-1}. Although the rate constant of precooked rice drying could be enhanced to 0.0596 s^{-1} with the increase in the superheated temperature to 300°C, the degree of enhancement was less than the case of uncooked rice. It is possible that precooking caused partial starch gelatinization in the glutinous rice. Moreover, the further treatment by superheated steam at a high temperature may increase the degree of starch gelatinization. This would reduce the moisture transferring rate during the superheated steam treatment. Consequently, the rate constant of the precooked rice drying became less than the rate constant of the uncooked rice drying, at high superheated steam temperature treatment.

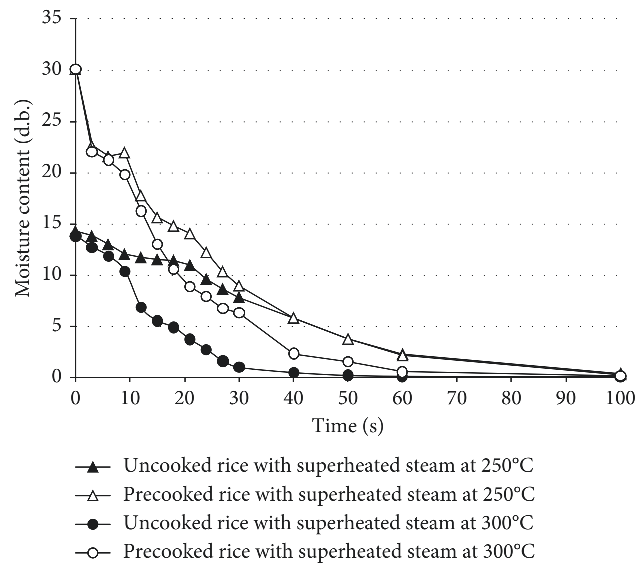

Figure 2: Change in moisture content of uncooked and precooked glutinous rice during superheated steam treatment.

Table 1: Drying kinetic rate constant of black glutinous rice during superheated steam treatment.

Rice sample	Temperature of superheated steam (°C)	k (s^{-1})	RMSE	r^2
Uncooked	250	0.0301 ± 0.00^{d}	0.0806	0.9273
Uncooked	300	0.0744 ± 0.00^{a}	0.0980	0.9745
Precooked	250	0.0449 ± 0.00^{c}	0.0501	0.9602
Precooked	300	0.0596 ± 0.00^{b}	0.0508	0.9834

[a–d]Means with different letters in each column are significantly different ($P \leq 0.05$).

3.2. Effect of Pretreatment and Superheated Steam on Microstructure of Black Glutinous Rice. Microstructure of black glutinous rice before superheated stream treatment showed clear rice granule and rough surface (Figure 3). When the glutinous rice was treated with superheated steam, the rice granule was lost. Granule of starch was possibly changed from crystalline to amorphous structure [17]. Moreover, the rough surface was changed to smooth surface, due to gelatinization effect. High heating rate and the steam media during superheated steam caused quick evaporation of free water in the glutinous rice. Vapor pressure was increased; as a result, porous structure was generated. An increase in superheated steam temperature from 250°C to 300°C raised the vapor pressure. Uncooked rice treated at 300°C (which had a significant higher drying rate constant than superheated steam treatment at 250°C) had higher porosity than the sample treated at 250°C. This was coincided with the previous study [6] that observed a positive correlation between porosity and drying rate constant.

Considering the effect of precooking before superheated steam treatment, SEM of the precooked sample showed the melting of starch granules while porosity of the precooked sample was not clearly observed. It is possible that pretreatment by cooking generated starch gelatinization before entering superheated steam treatment. Water was absorbed by some starch. Consequently, the structure of the precooked rice was different from the uncooked rice, whose water was free to evaporate quickly.

3.3. Effect of Pretreatment and Superheated Steam on Thermal Properties and Crystalline Structure of Black Glutinous Rice. According to DSC analysis, control rice sample had onset temperature (T_o) of 59.57 ± 0.4°C, peak temperature (T_p) of 73.67 ± 0.6°C, conclusion temperature (T_c) of 91.45 ± 0.6°C, and gelatinization enthalpy (ΔH) of 1.016 ± 0.58 J/g. With superheated steam treatment, both cooked and uncooked rice samples did not detect the enthalpy of gelatinization. In the case of cooked rice, gelatinization could be completed during pretreatment. In the case of uncooked rice, it could be

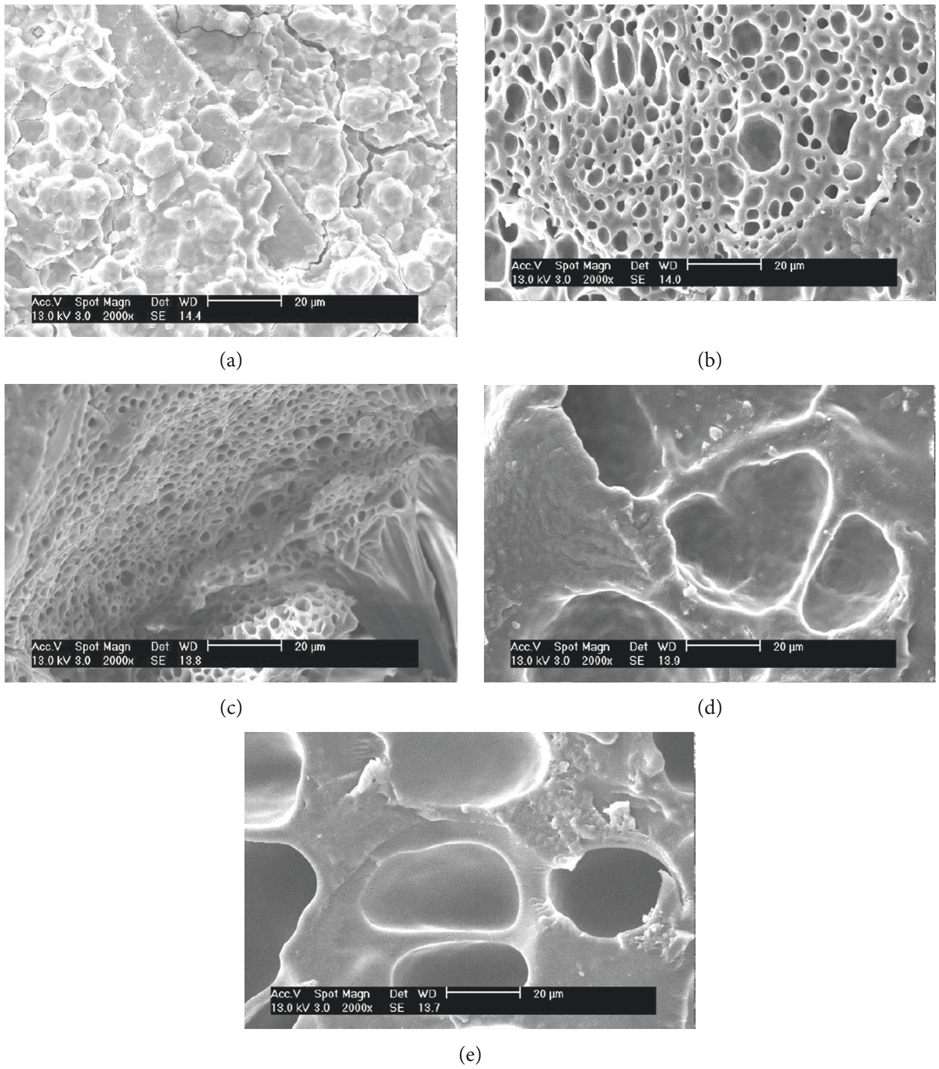

Figure 3: Scanning electron micrographs (2000x) of black glutinous rice with/without superheated steam treatment. (a) Uncooked rice without superheated steam treatment (control). (b) Uncooked rice with superheated steam at 250°C. (c) Uncooked rice with superheated steam at 300°C. (d) Precooked rice with superheated steam at 250°C. (e) Precooked rice with superheated steam at 300°C.

explained that there was enough heat and moisture content during superheated treatment to promote the completed starch gelatinization to black glutinous rice [18].

X-ray diffraction pattern of control rice sample presented A-type crystalline structure with diffraction angle (2Θ) of 15°, 17.3°, 18°, and 23° (Figure 4). The A-type structure was typically formed in the cereal starch. With superheated steam treatment, the A-type crystalline structure of the black glutinous rice was disappeared, regardless of pretreatment condition. This confirmed the result of DSC analysis showing undetected enthalpy of starch gelatinization in all superheated steam-treated samples. The positive relationship between the A-type crystallinity and the enthalpy of starch gelatinization was previously reported in [11].

3.4. Effect of Pretreatment and Superheated Steam on Texture Profile of Black Glutinous Rice. Superheated steam treatment caused a reduction of cooking time from 15 min (control sample) to 1 min (Table 2). This was because of porosity found in the treated black glutinous rice. The porous structure enhanced water absorption [19]. In addition, precooking could generate pregelatinization and cause a faster water absorption rate. Then minimal cooking time could be decreased. At the same superheated steam temperature, the minimal cooking time of the cooked rice samples was less than that of the uncooked rice. This could be from variation of rice structure as shown in Figure 3.

Using the minimal cooking time, hardness of the cooked glutinous rice treated with only superheated steam (70.05–83.28 N) was not different from the cooked control sample (85.39 N). When precooking was used prior to superheated steam treatment at high temperature (300°C), hardness of the cooked rice (43.03 N) was significantly less than the cooked control sample. This is due to structural change from heat damage and high degree of gelatinization before cooking. During cooking, the precooked rice treated

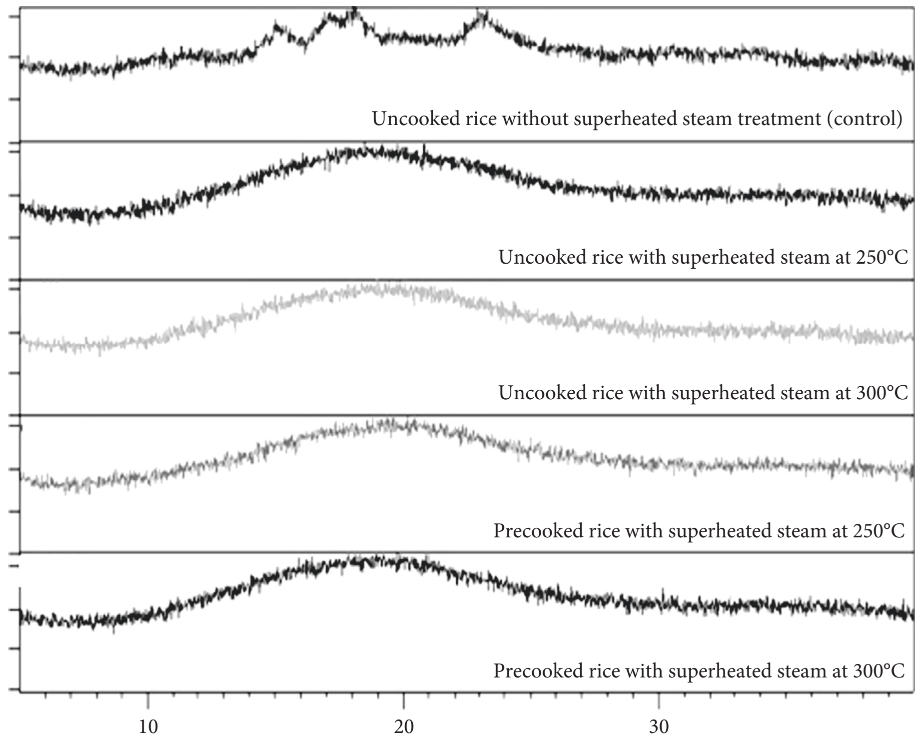

FIGURE 4: X-ray diffraction patterns of black glutinous rice with/without superheated steam treatment.

TABLE 2: Texture profile of cooked black glutinous rice with/without superheated steam treatment.

Rice sample	Temperature of superheated steam (°C)	MCT (min)	Hardness (N)	Adhesiveness (N·s)	Springiness	Cohesiveness
Uncooked	—	15	85.39 ± 13.98^{a}	-20.88 ± 12.45^{b}	0.73 ± 0.11^{a}	0.44 ± 0.03^{a}
Uncooked	250	5	83.28 ± 10.17^{a}	-6.74 ± 5.42^{a}	0.74 ± 0.17^{a}	0.53 ± 0.04^{a}
Uncooked	300	3	70.05 ± 10.41^{a}	-7.34 ± 1.67^{a}	0.72 ± 0.07^{a}	0.54 ± 0.03^{a}
Precooked	250	3	75.57 ± 5.05^{a}	-14.72 ± 2.67^{ab}	0.66 ± 0.01^{a}	0.58 ± 0.01^{a}
Precooked	300	1	43.03 ± 2.26^{b}	-10.08 ± 2.39^{ab}	0.67 ± 0.15^{a}	0.49 ± 0.03^{a}

$^{a\text{–}d}$Means with different letters in each column are significantly different ($P \leq 0.05$).

with superheated steam at high temperature (300°C) was quickly rehydrated and required less water and time to complete starch gelatinization. Then, cooking this rice with the same amount of water may cause softer texture than other rice samples. To maintain the same hardness as the control sample, the precooked rice should be treated with superheated steam at lower temperature (250°C). This condition yielded the cooked rice with hardness of 75.57 N.

Superheated steam treatment caused variation of adhesiveness of cooked rice. Significant change ($P \leq 0.05$) in adhesiveness from −20.88 N·s to −6.74 N·s and −7.34 N·s after glutinous rice grain was treated with superheated steam at 250°C and 300°C, respectively, was observed. It is possible that rice starch was gelatinized during precooking and superheated steam treatment, and then it was retrograded during cooling down. When the treated rice grain was cooked, adhesiveness of cooked rice became reduced, compared with the control sample which was fully gelatinized in one step during cooking. Sareepuang et al. [20] reported that a higher drying temperature could increase adhesiveness, relating to the gelatinization degree. The increase in adhesiveness of cooked brown rice caused a firm gel structure of rice and a lower water-uptake ratio [21]. However, in the current study of superheated steam treatment, an increase in temperature from 250°C to 300°C did not affect adhesiveness of the cooked rice. This might be because both temperatures used in this study were in high temperature range.

To reduce the change in adhesiveness, precooking prior to superheated steam treatment could be used, and cooking time should be shortened. This condition yielded adhesiveness of the cooked rice in a range from −10.08 N·s to −14.72 N·s, which was not significantly different from the cooked control sample ($P > 0.05$). Nonetheless, precooking and superheated steam treatment did not significantly affect springiness and cohesiveness of the cooked rice ($P > 0.05$).

3.5. Effect of Pretreatment and Superheated Steam on Color of Black Glutinous Rice. Lightness (L^* value), redness (a^* value), and yellowness (b^* value) of black glutinous rice (control sample) were 49.72, 2.36, and 2.33, respectively (Table 3). After superheated steam treatment, lightness was

Table 3: Color of black glutinous rice with/without superheated steam treatment.

Rice sample	Temperature of superheated steam (°C)	L^*	a^*	b^*
Uncooked	—	49.72 ± 0.01^{c}	2.36 ± 0.01^{d}	2.33 ± 0.07^{e}
Uncooked	250	66.32 ± 0.02^{a}	2.05 ± 0.05^{e}	6.68 ± 0.07^{a}
Uncooked	300	54.93 ± 0.03^{b}	2.74 ± 0.03^{c}	6.47 ± 0.10^{b}
Precooked	250	41.40 ± 0.03^{e}	4.38 ± 0.04^{b}	2.45 ± 0.03^{d}
Precooked	300	44.32 ± 0.01^{d}	4.58 ± 0.01^{a}	4.81 ± 0.07^{c}

$^{a–e}$Means with different letters in each column are significantly different ($P \leq 0.05$).

Table 4: Antioxidant activity of black glutinous rice with/without superheated steam treatment.

Rice sample	Temperature of superheated steam (°C)	DPPH assay IC_{50} ($mg \cdot mL^{-1}$)	FRAP value (μmol of Fe(II))·(1 g sample^{-1})	Total phenolic (μg GAE)·(1 g sample^{-1})
Uncooked	—	34.26 ± 0.14^{e}	4.99 ± 0.19^{a}	912.72 ± 64.38^{a}
Uncooked	250	108.43 ± 1.39^{d}	2.55 ± 0.11^{b}	742.04 ± 83.85^{b}
Uncooked	300	119.57 ± 3.20^{c}	1.79 ± 0.26^{c}	592.98 ± 12.45^{c}
Precooked	250	137.32 ± 3.18^{a}	1.55 ± 0.32^{cd}	436.46 ± 22.69^{d}
Precooked	300	129.95 ± 2.27^{b}	1.25 ± 0.12^{d}	130.50 ± 16.78^{d}

$^{a–d}$Means with different letters in each column are significantly different ($P \leq 0.05$).

significantly increased to 54.93–66.32 while yellowness was significantly increased to 6.47–6.68. This was because heat treatment caused degradation of anthocyanin [22].

By precooking prior to superheated steam treatment, redness of the treated rice was increased to 4.38–4.58. An increase in superheated steam temperature from 250°C to 300°C seemed to increase the redness. It is possible because Millard reaction is enhanced by the high temperature treatment [16]. In addition, precooking prior to superheated steam treatment allowed color pigment to migrate from the outer layer to inner layer. These possibly reduced loss of color pigment during superheated steam treatment. Therefore, lightness of the precooked and superheated steam treated rice was not increased (41.40–44.32), compared with the control.

3.6. Effect of Pretreatment and Superheated Steam on Antioxidant Activity of Black Glutinous Rice. With superheated steam treatment, DPPH assay IC_{50} was significantly ($P \leq 0.05$) increased from 34.26 to 108.43–137.32 $mg \cdot mL^{-1}$ (Table 4). This meant concentration of antioxidant was decreased, compared with the control, due to degradation by heat treatment. The loss of antioxidant depended on heat, oxygen level, and process time [23]. Precooking prior to superheated steam treatment even increased DPPH assay IC_{50} to be higher than the one without precooking. This might be explained by interaction between the gelatinized starch during precooking and some phenolic compounds that could reduce extractabilities of antioxidant activity [24].

The ferric reducing antioxidant power and total phenolic content of black glutinous rice were 4.99 μmol of Fe(II)·(1 g·sample^{-1}) and 912.72 μg GAE·(1 g·sample^{-1}), respectively. With superheated steam treatment, FRAP values and total phenolic compound were significantly ($P \leq 0.05$) decreased to 1.79–2.55 μmol of Fe(II)·(1 g·sample^{-1}) and 592.98–742.04 μg GAE·(1 g·sample^{-1}), respectively. The degree of loss of FRAP and total phenolic compound was increased by precooking prior to superheated steam treatment and an increase in superheated steam temperature from 250°C to 300°C. The variation in antioxidant power was due to the combination of thermal degradation of antioxidant compounds and possible leaching of water soluble compounds during precooking [25, 26].

3.7. Effect of Pretreatment and Superheated Steam on Sensorial Quality of Black Glutinous Rice. Superheated steam treatment at high temperature (300°C) reduced the liking score on color and appearance of the cooked glutinous rice, regardless of pretreatment. With superheated steam treatment at lower temperature (250°C), the liking score on appearance could be maintained to the same range as the control sample (Table 5). However, precooking and superheated steam treatment did not affect the liking score of texture. In fact, the treatment could increase the liking score on the flavor of rice. Superheated steam heating may cause cooked flavor and special odor from 2-acetyl-1-pyrroline, guaiacol, indole, and *p*-Xylene that were preferred by consumers [27]. Therefore, overall liking scores of all treated rice were not different from that of the control sample ($P > 0.05$). All cooked glutinous rice had overall liking score in the range of slightly liked and moderately liked (6.3–6.9 from 9-point Hedonic Scale).

4. Conclusion

Superheated steam treatment could improve porous structure of black glutinous rice that could be benefit water absorption during rice cooking. However color pigment was degraded, resulting in lighter color and more yellowness of rice. Precooking rice prior to superheated steam treatment could increase redness and reduce lightness of the black glutinous rice. Nonetheless, both precooking and

Table 5: Liking scores of cooked black glutinous rice with/without superheated steam treatment.

Rice sample	Temperature of superheated steam (°C)	Appearance	Color	Texture	Flavor	Overall
Uncooked	—	7.4 ± 1.3^{a}	7.5 ± 0.9^{a}	5.9 ± 1.6^{a}	6.0 ± 1.3^{b}	6.3 ± 1.1^{a}
Uncooked	250	6.3 ± 1.1^{ab}	6.7 ± 0.8^{a}	6.3 ± 1.3^{a}	6.7 ± 0.9^{ab}	6.3 ± 1.3^{a}
Uncooked	300	5.1 ± 1.2^{b}	5.4 ± 1.6^{b}	6.3 ± 1.1^{a}	6.9 ± 0.9^{ab}	6.3 ± 1.5^{a}
Precooked	250	6.3 ± 1.3^{ab}	6.3 ± 1.2^{ab}	6.7 ± 1.1^{a}	6.9 ± 0.7^{ab}	6.8 ± 0.8^{a}
Precooked	300	5.9 ± 1.7^{b}	6.5 ± 1.6^{ab}	7.0 ± 1.3^{a}	7.2 ± 0.8^{a}	6.9 ± 1.3^{a}

[a,b]Means with different letters in each column are significantly different ($P \leq 0.05$).

superheated steam treatment reduced antioxidant activity, FRAP and total phenolic content. From x-ray diffraction and DSC analysis, all treated rice was completely gelatinized. Therefore, the minimum cooking time of the black glutinous rice was reduced from 15 min to 1–5 min with comparable hardness to the control sample. Moreover their overall liking scores were not different from that of the control sample. Therefore, superheated steam treatment could be a potential method to develop quick cooking glutinous rice. However, the loss of antioxidant activity was a drawback of this method that needs further study.

Data Availability

We declare that all data supporting the findings of this study are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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