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Original Article

Effects of drum drying on physical and antioxidant properties of riceberry flour

Porntip Wiriyawattana, Suntaree Suwonsichon,* Thongchai Suwonsichon

Department of Product Development, Faculty of Agro-Industry, Kasetsart University, Bangkok 10900, Thailand

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ABSTRACT

The effects of drum drying on the physical and antioxidant properties of pregelatinized riceberry flour were investigated. The drum drying temperature was varied (110 °C, 120 °C and 130 °C) and unheated riceberry flour was used as the control. The results showed that all pregelatinized riceberry flour samples had lower ($p \leq 0.05$) L* value, but higher ($p \leq 0.05$) a* and b* values than the control. The water absorption index and swelling power of all pregelatinized riceberry flour samples were also significantly ($p \leq 0.05$) higher than those of the control. The results from rapid visco analysis indicated that the pasting time, pasting temperature, peak viscosity, trough viscosity, final viscosity and set back of riceberry flour decreased ($p \leq 0.05$) after drum drying. Moreover, the total phenolic content and antioxidant capacity, as measured using 2,2-diphenylpicrylhydrazyl and 2,2′azinobis (3-ethylbenzothiozoline-6-sulfonic acid) disodium salt radical assays, respectively, also decreased ($p \leq 0.05$) after drum drying. Such changes were more evident with increased drum drying temperature in the range 110–130 °C. In addition, increasing the drum drying temperature led to poorer stability to withstand the thermal treatment and stress than in pregelatinized riceberry flour. The results suggested that special attention should be given to the drum drying temperature as it affects not only the physical but also the antioxidant properties of the pregelatinized riceberry flour. Pregelatinized riceberry flour produced using drum drying at 110 °C could be applied to formulate an instant soup product because it had high values for water absorption capacity, total phenolic content and antioxidant activity and was completely gelatinized and stable against thermal treatment and stress.

Introduction

Riceberry, a black purple rice variety (*Oryza sativa* L.), is a new strain of cross-bred rice between Khoa Dawk Mali 105 (hommali rice) and JaoHom Nin (non-glutinous purple rice). Riceberry, especially its bran part, contains antioxidants and other significant bioactive constituents, such as anthocyanins, vitamin E complex (tocopherols and tocotrienols), β-carotene, γ-oryzanol and folic acid (folate) which possess anticancer activity and other chemo-preventive properties (Leardkamolkarn et al., 2011; Min et al., 2011). Prangthip et al. (2013) reported that dietary supplement formulated with riceberry bran as a major ingredient had properties to improve hyperglycemia and to ameliorate hyperlipidemia. Moreover, riceberry bran supplement could also reduce oxidative stress and inflammation.

Pregelatinization is one of the methods commonly used to modify starch/flour to improve its water absorption, solubility, pasting property and storage stability to make it suitable for various food applications. The process involves the use of heat from a drum dryer, spray dryer and, less commonly, an extruder (Lai, 2001). After pregelatinization, the physicochemical and functional properties of starch/flour change dramatically. For instance, pregelatinized starch/flour often has better water absorption and solubility in cold water than its native form. Such changes have been attributed to the loss of crystallinity, disruption of starch granule structure and molecular depolymerization (Patindol et al., 2012).

Amongst the pregelatinization methods available, drum drying is the easiest and most economical method (Majzoobi et al., 2011). Anastasiades et al. (2002) found that maize starch had excellent wettability and was easy to reconstitute after drum drying. The physicochemical properties of the obtained pregelatinized flour depended not only on the source of raw material but also on drum drying process parameters (Lai, 2001). Those parameters included feed rate, thickness of film, drum speed and gap as well as drum

* Corresponding author.
E-mail address: fagisrsu@ku.ac.th (S. Suwonsichon).

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surface temperature. It was crucial to maintain a uniform film on the drum surface to ensure maximized throughput and consistent final moisture content of the obtained pregelatinized flour (Heldman, 2003). Supprung and Noomhorm (2003) studied the effects of varying the drum drying temperature (115–135 °C), holding time (14–84 s) and solid content of the slurry (20–40%) on various physicochemical properties of rice (KDML105) flour and starch. They found that as solid content of the slurry increased, degree of gelatinization, water absorption index and initial peak viscosity of rice flour and starch decreased while the moisture content and water solubility index of the samples increased. Longer holding times led to an increase in the degree of gelatinization whereas the drum drying temperature had no significant effect on any of the characteristics studied. Another study by Ruttarattanamongkol et al. (2016) revealed the effects of speed (3 revolutions per minute (rpm), 5 rpm, 7 rpm) and drum drying temperatures (80 °C, 95 °C, 110 °C) on the quality of orange-fleshed and purple-fleshed sweet potato flours. They found that moisture content of the sweet potato flour of both cultivars decreased with decreased drum speed and increased drum drying temperature. Potato flour samples that were drum dried at 95 °C and a drum speed of 3 rpm had the highest phenolic content and antioxidant activity. As the drum drying temperature increased from 95 °C to 110 °C, the phenolic content and antioxidant activity of the samples decreased significantly. This was attributed to the degradation of phenolic compounds at high temperature.

The present study was a part of research aiming to develop instant soup from riceberry flour for the elderly. Riceberry was milled into flour and the flour was then subjected to a pregelatinization process using drum drying. The obtained pregelatinized riceberry flour was intended to be used in the instant soup formulation. Heat during drum drying could have various impacts on the physical and antioxidant properties of riceberry flour depending on the drying temperature being used. As such information is still lacking, the present study was conducted to determine the effects of drum drying at various drying temperatures on the physical and antioxidant properties of riceberry flour.

Materials and methods

Materials

Riceberry was obtained from the Rice Science Centre & Rice Gene Discovery Unit, Kasetsart University, Kamphaengsaen Campus, Nakhon Pathom, Thailand. Riceberry flour was prepared using the dry-milling method (Suksomboon and Naivikul, 2006). Dehusked riceberry grains were ground in a hammer mill (Yor Yong Hah Heng Part. Ltd; Bangkok, Thailand) fitted with a 0.5 mm sieve. Then, the flour was milled twice in an electric miller (Newin, HK-04B; China) and passed through a 100-mesh sieve. The flour was packaged in polyethylene bags and kept at room temperature until used within 1 wk.

Pregelatinized riceberry flour preparation

Pregelatinized riceberry flour was prepared by passing riceberry flour solution through a double drum dryer (Unique Tool Co. Ltd; Bangkok, Thailand). Sriroth and Piyachomkwan (2007) suggested that the solid content of the flour solution used in drum drying should not exceed 42–44%; thus, riceberry flour solution of 40% solids was used for drum drying in the present study. The drum dryer speed and gap were set at 0.72 rpm and 0.01 inches, respectively (Wadchararat et al., 2006). Preliminary testing was carried out at four drying temperature levels (100 °C, 110 °C, 120 °C, 130 °C) and the moisture content of the obtained flour was determined. Since the pregelatinized riceberry flour obtained from this study was to be used as a main ingredient in an instant soup formulation, its moisture content could not exceed 7% level in order to comply with the Thai Industrial Standard for instant soup product (TIS 462-2548). Preliminary results indicated that drum drying at 110 °C, 120 °C and 130 °C yielded flour samples with less than 7% moisture content, while drum drying at 100 °C yielded the flour with moisture content that slightly exceeded the limit (about 7.18%). Therefore, drum drying at 100 °C was excluded from the study and the actual test was carried out only at three drying temperature levels (110 °C, 120 °C, 130 °C). After drum drying, pregelatinized riceberry flour was milled twice in an electric miller and passed through a 100-mesh sieve. The moisture contents of the riceberry flour samples that had been drum-dried at 110 °C, 120 °C and 130 °C were 6.18%, 5.78% and 5.67%, respectively. The flour samples were packaged in polyethylene bags and kept at room temperature until further analysis within1 wk. Unheated riceberry flour served as the control sample. All flour samples were subjected to analyses of various physical and antioxidant properties as described below.

Color measurement

The color of the flour samples was measured using a spectrophotometer (Minolta CM-3500d; Konica Minolta Holdings Inc.; Tokyo, Japan). Each sample was placed in a transparent glass Petri dish and its surface color was measured using a D65 illuminant at 10° observation. The CIE color values of each sample were reported as L^* (0 = black, 100 = white), a^* ($-a^*$ = greenness, $+a^*$ = redness) and b^* ($-b^*$ = blueness, $+b^*$ = yellowness).

Gel hydration properties

The gel hydration properties of the flour samples were determined as described by Lai (2001) and consisted of: the water absorption index (WAI), water solubility index (WSI) and swelling power (SP). Briefly, riceberry flour (about 2.5 g dry basis) was weighed (Wi) and then distilled water (30 mL) was added. The mixture was agitated at 30 °C for 30 min, followed by centrifugation at 5000×*g* for 15 min. The supernatant was decanted into an evaporating dish and the weight of the residue (Wr) in the centrifuge tube was recorded. The supernatant then was dried at 105 °C until constant weight (Ws) was obtained. WAI, WSI and SP values were calculated according to Equations (1)–(3), respectively.

$$\mathrm{WAI}\left(\frac{g}{g}\right) = \frac{\mathrm{Wr}}{\mathrm{Wi}} \quad (1)$$

$$\mathrm{WSI}(\%) = \frac{\mathrm{Ws}}{\mathrm{Wi}} \times 100 \quad (2)$$

$$\mathrm{SP}\left(\frac{g}{g}\right) = \frac{\mathrm{WAI}}{1 - \frac{\mathrm{WSI}}{100}} \quad (3)$$

Pasting properties

The pasting properties of the flour samples were studied using a Rapid Visco Analyzer (RVA-4; Newport Scientific; Warriewood, NSW, Australia) and Approved Method 61-02 (American Association of Cereal Chemists, 1995) as described by Lai (2001) with some modifications. A 12% (w/v) flour suspension was prepared by placing 3 g riceberry flour in an aluminum canister, then

25 mL distilled water was added. Each flour suspension sample was subjected to a programmed heating regime at a constant shear rate where the sample was equilibrated at 35 °C for 2 min, then heated to 95 °C at a rate of 11.8 °C/min and held at this temperature for 2.5 min. After heating, the sample was cooled to 35 °C at the same rate. Paste viscosity plotted in arbitrary RVA units (RVU) versus time was recorded and various parameters were determined: initial viscosity, peak viscosity (PV), temperature at PV (P_{temp}), final viscosity (FV), breakdown viscosity (BKD = PV-trough) and total setback viscosity (TSB = FV-trough). The onset temperature of gelatinization (Tg) of the samples was determined as the first point at which the viscosity increased at the rate of 1 RVU/s or faster.

Thermal properties

A differential scanning calorimeter (DSC; DSC822e; Mettler-Toledo GmbH; Switzerland) was used to investigate thermal characteristics of the flour samples. The instrument was calibrated with indium before analysis and an empty aluminum pan was used as a reference (Lai, 2001). The flour sample (5.0 ± 0.5 mg on a dry basis) was loaded into an aluminum sample pan. Deionized water was then added into the sample using a microsyringe to give a water content of 70% (w/w). The sample pan was sealed, reweighed and allowed to equilibrate at room temperature for 1 h. Subsequently, the sample was heated to 140 °C at a rate of 5 °C/min. The DSC curve parameters were determined consisting of onset temperature (To), peak temperature (Tp), conclusion temperature (Tc) and transition enthalpy (ΔH).

Total phenolic content and antioxidant properties

Each flour sample (1.5 g) was extracted with 15 mL of 85% aqueous methanol at room temperature under agitation using a magnetic stirrer for 30 min (Sompong et al., 2011). The mixture was centrifuged for 10 min at 2500×g and the supernatant was decanted. The residue was re-extracted twice using the same conditions. The supernatant samples collected from the three extractions were combined and the total volume was then made up to 50 mL by adding 85% aqueous methanol (Merck; Darmstadt, Germany). The extract was used for the determinations of total phenolic content (TPC) and antioxidant properties using diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay and 2,2-azinobis 3-ethylbenzthiazoline-6-sulphonic acid (ABTS) radical scavenging assay.

Total phenolic content

The TPC was measured using the Folin-Ciocalteu colorimetric method (Iqbal et al., 2005). Riceberry flour extract (0.2 mL) was mixed with 0.8 mL of freshly prepared diluted (10% v/v) Folin-Ciocalteu's phenol reagent (Loba Chemie Pvt. Ltd; Mumbai, India) and 2 mL of 7.5% sodium carbonate (Ajax Finechem Pty Ltd; Taren Point, NSW, Australia). The volume of the mixture was adjusted to 7 mL by adding deionized water. The mixture was then stored in the dark for 2 h to allow the completion of the reaction. An absorbance value of the blue-colored mixture was measured at 765 nm using a spectrophotometer (sigma Helios; Thermo Fisher Scientific; Waltham, MA, USA). Gallic acid (Fluka Chemical, Buchi, Switzerland) was used as the calibration standard and the TPC was reported as milligrams gallic acid equivalent (GAE) per 100 g dry weight.

DPPH radical scavenging assay

The radical scavenging activity of riceberry flour extracts on the DPPH radicals was measured as described by Samchai et al. (2009) with some modifications. Riceberry flour extracts (3 mL) were mixed with 2 mL of 0.2 mM DPPH solution (Ajax Finechem Pty Ltd; Taren Point, NSW, Australia). The mixture was vigorously shaken and kept in the dark for 30 min. Subsequently, an absorbance value of the mixture was measured at 517 nm using a UV–visible spectrophotometer (sigma, Helios; Thermo Fisher Scientific; Waltham, MA, USA). The free radical scavenging activity (%) was calculated using Equation (4). Subsequently, DPPH radical scavenging activity was expressed as milligrams gallic acid equivalent (GAE) per 100 g dry weight.

$$DPPH\ \ radical\ scavenging\ activity\ (\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \quad (4)$$

where $A_{control}$ is the absorbance of the control (DPPH solution with no test sample) and A_{sample} is the absorbance of the test sample (DPPH solution with test sample).

ABTS radical scavenging assay

ABTS assay was performed as described by Kambli et al. (2014). To prepare the stock solution, equal volumes of 7 mM ABTS solution (Ajax Finechem Pty Ltd; Taren Point, NSW, Australia) and 2.45 mM potassium persulfate solution (Ajax Finechem Pty Ltd; Taren Point, NSW, Australia) were mixed. The mixture was incubated at room temperature in the dark for 12 h to yield a dark-colored solution containing ABTS radicals. The working solution was freshly prepared for each assay by diluting the stock solution with ethanol (Merck; Darmstadt, Germany) (16 mL stock solution diluted to 100 mL). The absorbance value at 745 nm of the working solution should fall in the range of 0.70 ± 0.02 at30 °C. Riceberry flour extract (1 mL) was mixed with 2 mL of the ABTS working solution and the absorbance of the mixture was recorded at 734 nm using a UV–visible spectrophotometer (sigma Helios; Thermo Fisher Scientific; Waltham, MA, USA). Gallic acid was used as a positive control. The scavenging activity was estimated based on the percentage of ABTS radicals scavenged according to Equation (5). Then, the ABTS radical scavenging activity was converted to milligrams gallic acid equivalent (GAE) per 100 g dry weight.

$$ABTS\ radical\ scavenging\ activity\ (\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \quad (5)$$

where $A_{control}$ is the absorbance of the control (ABTS solution with no test sample) and A_{sample} is the absorbance of the test sample (ABTS solution with test sample).

Statistical design and analysis

The experiment followed a completely randomized design with three replications. For each analysis, triplicate measurements were performed. Data were subjected to analysis of variances using the SPSS software (version 12.0; SPSS (Thailand) Co., Ltd; Bangkok, Thailand). Duncan's multiple range tests were performed to determine if differences among treatment means were significant at the 95% confidence level ($p \leq 0.05$).

Results and discussion

Color values

The results showed significant changes in the color values of all pregelatinized riceberry flours compared to the control (Table 1). All pregelatinized riceberry flour samples were darker (lower L* value), redder (higher a* value) and yellower (higher b* value) than

Table 1
Effect of drum drying on physical and antioxidant properties of riceberry flour.

Parameter	Control*	D110	D120	D130
Color				
L^*	59.81 ± 0.17^a	50.12 ± 0.39^b	49.83 ± 0.18^{bc}	49.49 ± 0.43^c
a^*	4.52 ± 0.06^c	8.64 ± 0.07^b	8.75 ± 0.13^{ab}	8.85 ± 0.07^a
b^*	3.83 ± 0.06^c	4.81 ± 0.10^b	5.04 ± 0.07^a	5.11 ± 0.06^a
Water absorption index	2.03 ± 0.15^c	5.64 ± 0.03^b	5.88 ± 0.09^a	6.02 ± 0.04^a
Water solubility index (%)	6.99 ± 0.07^a	6.36 ± 0.12^b	6.33 ± 0.12^b	6.16 ± 0.15^b
Swelling power	2.19 ± 0.16^c	6.03 ± 0.04^b	6.28 ± 0.10^a	6.42 ± 0.04^a
Total phenolic content (mg gallic acid equivalent/100 g)	119.19 ± 2.33^a	91.90 ± 2.32^b	84.83 ± 2.07^c	83.89 ± 2.05^c
Antioxidant activity				
DPPH assay (mg gallic acid equivalent/100 g)	75.76 ± 0.94^a	60.80 ± 0.94^b	56.95 ± 0.74^c	54.06 ± 0.93^d
ABTS assay (mg gallic acid equivalent/100 g)	101.18 ± 1.56^a	69.40 ± 1.86^b	59.90 ± 1.84^c	48.41 ± 1.27^d

Results are shown as mean ± SD; D110, D120 and D130 = pregelatinized riceberry flour samples drum dried at 110 °C, 120 °C and 130 °C, respectively; DPPH = diphenyl-1-picrylhydrazyl; ABTS = 2,2-azinobis 3-ethylbenzthiazoline-6-sulphonic acid.
[a,b] values in the same row followed by different lowercase superscript letters are significantly different ($p \leq 0.05$).
*Unheated riceberry flour used as the control.

the control. As the drum drying temperature increased, L* tended to decrease while a* and b* values tended to increase.

The color changes in the riceberry flour samples were possibly caused by the alteration of material surface characteristics when exposed to high temperature during the drum drying process. In addition, thermal treatment induced non-enzymatic browning which led to the formation of a brown color (Dao, 2015). This browning reaction was enhanced by the increased temperature level and heating time. Thus, the color of pregelatinized riceberry flour tended to become darker with increasing drum drying temperature. In addition, anthocyanin pigments in colored rice readily degrade during thermal processing and this provides a red-blue color which can affect the color quality and nutritional properties of the rice (Patrasa et al., 2010).

Gel hydration properties

After drum drying, the WAI and SP of the riceberry flour samples significantly increased by about three times compared to those of the control sample, while the WSI of the samples decreased slightly but significantly (Table 1). An increase in the WAI in the pregelatinized riceberry flour samples could be attributed to the destruction of starch granules during drum drying, resulting in a porous structure of the flour samples (Majzoobi et al., 2011). It was also observed that increasing the drum drying temperature in the range 110–120 °C resulted in significant increases in the WAI and SP (Table 1). However, the WAI and SP of pregelatinized riceberry flour did not increase further as the drum drying temperature increased from 120 °C to 130 °C.

Pasting behavior

Viscographs of pregelatinized riceberry flour samples and the unheated control are shown in Fig. 1. The results showed that the pasting time, pasting temperature, peak viscosity, trough viscosity, final viscosity and setback were significantly lower for the pregelatinized riceberry flours than for the control. Pregelatinization caused starch granule disruption when the pregelatinized riceberry flour was reheated during the RVA measurement and this caused a decrease in the paste viscosity, leading to “thinning” of the slurry (Wadchararat et al., 2006). Yadav et al. (2006) also reported that the high temperature used in pregelatinization process was conductive to amylolytic hydrolysis and starch breakdown, resulting in a decrease in viscosity.

In addition, the results showed that increasing the drum drying temperature had no significant effect on the peak viscosity, pasting time and pasting temperature. However, the trough viscosity, final viscosity and setback decreased significantly and the breakdown viscosity increased significantly with increased drum drying temperature. The increase in the breakdown viscosity indicated poorer ability of the pregelatinized samples to endure heating and stress during thermal treatment (Patindol et al., 2012). Lai (2001) reported that rice flour with a high amylose content had a tendency to retrograde rapidly during gelatinization and the drying process. In addition, the amylose molecules of gelatinized rice flour could re-associate strongly, leading to a lower peak viscosity but a higher final viscosity. Debet and Gidley (2006) also reported that the pasting behavior of rice flour depended not only on the ratio of amylose and amylopectin but also on the minor components such as proteins and lipids.

Thermal properties

The effect of drum drying on the thermal properties of riceberry flour measured using the DSC is shown in Fig. 2. The unheated riceberry flour (control) had an onset temperature (To) of 62.0 °C, a peak temperature (Tp) of 75.84 °C and a conclusion temperature (Tc) of 75.84 °C and was endothermic with a gelatinization enthalpy (ΔH) of 8.49 J/g of dry flour (Fig. 2A). During heating, starch granules swelled and ruptured and the flour sample was gelatinized. Generally, the degree of gelatinization increases with increasing heating time and temperature (Lai, 2001; Rohaya et al., 2013). In the present study, no endothermic peak was found with any riceberry flour samples after drum drying (Fig. 2B), indicating that all these samples had already completely gelatinized because the drum drying temperatures being used (110–130 °C) were much higher

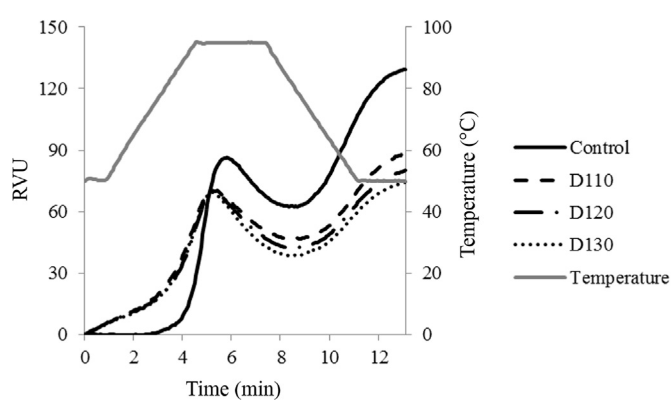

Fig. 1. Viscographs of riceberry flour samples, where unheated riceberry flour was the control, D100, D120 and D130 are pregelatinized riceberry flour samples drum dried at 110 °C, 120 °C and 130 °C, respectively, and RVU is arbitrary Rapid Visco Analyzer units.

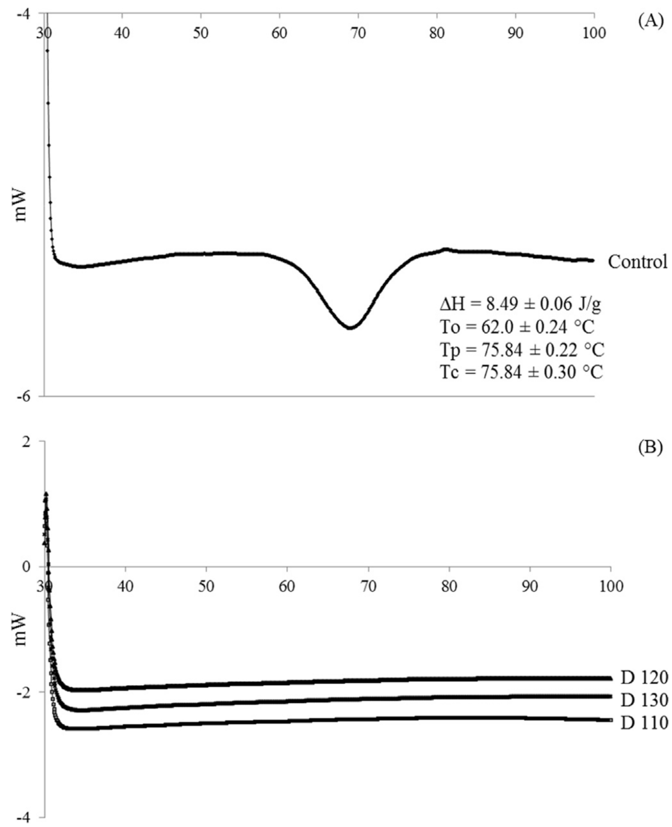

Fig. 2. Differential scanning calorimeter thermal graphs: (A) unheated riceberry flour (control); (B) pregelatinized riceberry flours produced by drum drying, where To, Tp, Tc and ΔH are the onset temperature, peak temperature, conclusion temperature and transition enthalpy, respectively, and D100, D120 and D130 are pregelatinized riceberry flour samples drum dryied at 110 °C, 120 °C and 130 °C, respectively.

than the gelatinization temperature range (62.0–75.84 °C) of riceberry flour. In the early stage of gelatinization, amorphous regions in the starch granules absorbed water, resulting in a rapid expansion of the granules (Miah et al., 2002). This was followed by the disruption of starch granule structures (Aini and Purwiyatno, 2010). The present results were consistent with those of Rohaya et al. (2013) who reported that rice flour that was heated at 80 °C for 90 min was fully gelatinized; therefore no endothermic peak was found when the sample was analyzed using the DSC. Moongngarm et al. (2015) indicated that full or partial gelatinization of starch granules could result in decreased viscosity. Therefore, studies on flour properties as influenced by thermal treatments are essential to achieve suitable properties for specific food products.

Total phenolic content and antioxidant properties

The TPC and antioxidant activity of riceberry flour decreased significantly after drum drying (Table 1). Moreover, increasing the drum drying temperature generally resulted in greater decreases in the TPC and antioxidant activity of the flour. Riceberry is known to contain high amounts of compounds with antioxidant activity such as phenols and anthocyanins (Leardkamolkarn et al., 2011). Hou et al. (2013) reported that anthocyanins degraded more quickly as the heating temperature and pH increased, especially at 100 °C and pH 5.0. In addition, Nayak et al. (2011) reported that degradation of anthocyanins could be due to the formation of browning compounds via the Maillard reaction at high temperatures. Their findings supported the results of the present study. Therefore, attention should be given to the processing conditions to minimize the loss of antioxidant activity. In the present study, pregelatinized riceberry flour produced by drum drying at 110 °C was considered the most valuable material due to its significantly highest TPC and antioxidant activity among the pregelatinized flour samples.

In conclusion, pregelatinized riceberry flours produced using drum drying were darker in color, had higher WAI and SP values but lower viscosity than the unheated riceberry flour. Such changes were more evident with increased drum drying temperatures (110–130 °C). Increasing drum drying also led to poorer stability to withstand thermal treatment and stress in pregelatinized riceberry flour. Additionally, losses in the TPC and antioxidant activity of riceberry flour were lower at drum drying of 110 °C than at 120 °C and 130 °C. Since the pregelatinized riceberry flour obtained from this study was intended to be used in instant soup formulation for the elderly, it was desirable that the flour had the following characteristics: 1) completely gelatinization, 2) high water absorption capacity to enable instant reconstitution, 3) stability against thermal treatment and stress and 4) high total phenolic content and antioxidant activity. Pregelatinized riceberry flour produced using drum drying at 110 °C met all of these criteria better than native riceberry flour and flour being drum dried at 120 °C and 130 °C. Therefore, pregelatinized riceberry flour produced using drum drying at 110 °C was selected to be used in the instant soup formulation for the elderly.

Conflict of interest

The authors declare that there was no conflict of interest.

Acknowledgements

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References

American Association of Cereal Chemists, 1995. Approved Methods of the American Association of Cereal Chemists, ninth ed. American Association of Cereal Chemists, St. Paul, MN, USA.
Aini, N., Purwiyatno, H., 2010. Gelatinization properties of white maize starch from three varieties of corn subject to oxidized acetylated-oxidized modification. IFRJ 17, 961–968.
Anastasiades, A., Thanou, S., Loulis, D., Stapatoris, A., Karapantsios, T.D., 2002. Rheological and physical characterization of pregelatinized maize starches. J. Food Eng. 52, 57–66.
Dao, V.T.T., 2015. Optimization of drum drying process parameters for pumpkin powder production and its substitution in rice noodles. JOS 3, 149–160.
Debet, M.R., Gidley, M.J., 2006. Three classes of starch granule swelling: influence of surface proteins and lipids. Carbohydr. Polym. 64, 452–465.
Heldman, D.R., 2003. Encyclopedia of agricultural, food, and biological engineering. In: Tang, J., Feng, H., Shen, G. (Eds.), Drum Dryers. Marcel Dekker, Inc., New York, NY, USA, pp. 211–214.
Hou, Z., Qin, P., Zhang, Y., Cui, S., Ren, G., 2013. Identification of anthocyanins isolated from black rice (*Oryza sativa* L.) and their degradation kinetics. Food Res. Int. 50, 691–697.
Iqbal, S., Bhanger, M.I., Anwar, F., 2005. Antioxidant properties and components of some commercially available varieties of rice bran in Pakistan. Food Chem. 93, 265–272.
Kambli, J., Patil, A.C., Keshava, R., 2014. Phytochemical screening and evaluation of antibacterial, antioxidant and cytotoxic activity of Ficusracemosa Linn. Int. J. Pharm. Pharmaceut. Sci. 6, 464–468.
Lai, H.M., 2001. Effects of hydrothermal treatment on the physicochemical properties of pregelatinized rice flour. Food Chem. 72, 455–463.
Leardkamolkarn, V., Thongthep, W., Suttiarporn, P., Kongkachuichai, R., Wongpornchai, S., Wanavijitr, A., 2011. Chemopreventive properties of the bran extracted from a newly-developed Thai rice: the riceberry. Food Chem. 125, 978–985.
Majzoobi, M., Radi, M., Farahnaky, A., Jamalian, J., Tongdang, T., Mesbahi, G., 2011. Physicochemical properties of pre-gelatinized wheat starch produced by a twin drum drier. J. Agric. Sci. Technol. 13, 193–202.
Miah, M.A.K., Haque, A., Douglass, M.P., Clarke, B., 2002. Parboiling of rice. Part II: effect of hot soaking time on the degree of starch gelatinization. IJFST 37, 539–545.
Min, B., McClung, A.M., Chen, M.H., 2011. Phytochemicals and antioxidant capacities in rice brans of different color. J. Food Sci. 76, 117–126.

Moongngarm, A., Srijinda, P., Paseephol, T., Samana, S., Martphutorn, N., 2015. Effect of heat moisture treatment using different solvents and incubation times on resistant starch formation of rice flour. Am. J. Appl. Sci. 12, 560–566.
Nayak, B., Berrios, J.J., Powers, J.R., Tang, J., 2011. Effect of extrusion on the antioxidant capacity and color attributes of expanded extrudates prepared from purple potato and yellow pea flour mixes. J. Food Sci. 76, 874–833.
Patindol, J., Shih, F., Ingber, B., Champagne, E., Boue, S., 2012. Porous rice powder from the precipitation of gelatinized flour or starch paste with ethanol. Starch Staerke 65, 296–303.
Patrasa, A., Brunton, N.P., O'Donnell, C., Tiwari, B.K., 2010. Effect of thermal processing on anthocyanin stability in foods; mechanisms and kinetics of degradation. Trends Food Sci. Technol. 21, 3–11.
Prangthip, P., Surasiang, R., Charoensiria, R., et al., 2013. Amelioration of hyperglycemia, hyperlipidemia, oxidative stress and inflammation in steptozotocin-induced diabetic rats fed a high fat diet by riceberry supplement. J. Funct. Food. 5, 195–203.
Rohaya, M.S., Maskat, M.Y., Ma'aruf, A.G., 2013. Rheological properties of different degrees of pregelatinized rice flour batter. Sains Malays. 42, 1707–1714.
Ruttarattanamongkol, K., Chittrakorn, S., Weerawatanakorn, M., Dangpium, N., 2016. Effect of drying conditions on properties, pigments and antioxidant activity retentions of pretreated orange and purple-fleshed sweet potato flours. J. Food Sci. Technol. 53, 1811–1822.
Samchai, S., Seephonkai, P., Sangdee, A., Puntumchai, A., Klinhom, U., 2009. Antioxidant, cytotoxic and antimalarial activities of crude extracts of mushroom *Phellinus linteus*. J. Biol. Sci. 9, 778–783.
Sompong, R., Siebenhandl-Ehn, S., Linsberger-Martin, G., Berghofer, E., 2011. Physicochemical and antioxidative properties of red and black rice varieties from Thailand, China and Sri Lanka. Food Chem. 124, 132–140.
Sriroth, K., Piyachomkwan, K., 2007. Technology of Flour, fourth ed. Kasetsart University Press, Bangkok, Thailand.
Suksomboon, A., Naivikul, O., 2006. Effect of dry- and wet-milling processes on chemical, physicochemical properties and starch molecular structures of rice starch. Kasetsart J. (Nat. Sci.) 40, 125–134.
Supprung, P., Noomhorm, A., 2003. Optimization of drum drying parameters for low amylose rice (KDML105) starch and flour. Dry. Technol. 21, 1781–1795.
Wadchararat, C., Thongngam, M., Naivikul, O., 2006. Characterization of pregelatinized and heat moisture treated rice flours. Kasetsart J. (Nat. Sci.) 40, 144–153.
Yadav, A.R., Guha, M., Tharanathan, R.N., Ramteke, R.S., 2006. Changes in characteristics of sweet potato flour prepared by different drying techniques. Lebensm-Wiss Technol. 39, 20–26.