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Research Paper

The nutritional quality of indigenous brown rice flour from southern borderline provinces of Thailand physiochemical and functional properties for targeting food products

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Abstract. The physicochemical properties and gelatinization and pasting properties of indigenous brown rice flour from southern borderline provinces of Thailand were investigated. Protein and fat of rice kernel affected swelling power, water absorptivity index (WAI), and water solubility index (WSI). The protein content of GY variety (8.79 ± 0.39 g/100 g flour) interacted with amylose (23.38 ± 0.46 g/100 g flour), resulting in a higher swelling power and water absorptivity index with heat treatment. Moreover, intermediate amylose level in brown rice flour, like in CK, GY, CP and cv.RD varieties, was associated with high protein and fat contents, and restricted the gelatinization temperatures of flour granules. In particular, the amylose content of CK (23.20 ± 0.31 g/100 g flour) was greater than that of NMDL (15.04 ± 0.21 g/100 g flour), which impacted the gelatinization temperature of the NMDL variety (72.94°C) making it less than that of the CK variety (73.66°C). The crystalline structures in all rice flour varieties gave typical A-type X-ray diffraction patterns with peaks observed at 2θ 15.01°, 17.01°, 18.00° and 22.9°. The RVA viscosity profiles of SBK and NMDL varieties were different from others due to low amylose contents. Regarding pasting behavior, an increased amylose content to intermediate level could affect the final viscosity of the rice flours of CK, GY, CP, and cv.RD varieties. The GY variety with intermediate amylose level and high protein and fat contents had the least pasting temperature, and slightly elevated pasting viscosity, final viscosity and trough viscosity. It was therefore concluded that GY may be developed as rice flour ingredient with high nutritional value contributed by its pigmented bran.

Keywords: Brown rice flour in Thailand, physicochemical properties, gelatinization behavior, water absorptivity, amylose-lipid, amylose-protein, pasting properties, crystallinity.

INTRODUCTION

The Thai indigenous rice varieties play an important role in the local culture and traditions because these varieties were selected for their high nutrition and palatability. These rice cultivars have heritable insect and flood resistance, as well as drought endurance. However, due to the comparatively low yield of these varieties, the number of farmers using them has decreased as has their cultivated area. Therefore, the Thai Rice Department is conducting projects to restore abandoned fields that can cultivate rice, support the rice farmers and contribute added value to rice as food, and increase rice production by advancing the uses of science and technology in the cultivation and processing of rice. Meanwhile, the development of added-value food products from rice flour would expand the choices of rice products and contribute to sustainable food security, as well as to the overall rice industry in Thailand.

Thai rice (*Oryza sativa* L.) is a major export item in the global market, and more than 2,291,916 tons of rice from January to April 2022 were exported, worth USD 1.12 billion. In the whole year 2022, the amount of exported rice is expected to increase by 52.7% (Thai Rice Exporters Association, 2022). Recently, Thai indigenous rice varieties have been utilized as brown rice flour, due to specific functional properties and being a gluten-free flour, in several health food products in the consumer market such as flour tortillas, rice beverages, meat substitutes for vegetarians, rice puddings, low-fat salad dressings from pre-gelatinized rice flour, and gluten-free bread for the gluten intolerant (Kadan *et al*., 2001; Kadan *et al*., 2008; Falade and Christopher, 2015; Seetapan *et al*., 2019; Nespeca *et al*., 2021).

The varieties of indigenous brown rice in the Southern part of Thailand, particularly pigmented rice including Sang Yod, Khao Hom Kra Dang Nga, Niaw Dang Kram Rad, Khao Niaw Dam Moe and Khao Niaw Dam Chaw Mai Pi have abundant contents of bioactive phytochemicals (Seechamnanturakit, 2018), such as γ-oryzanol, α-tocopherol, α-tocotrienol, phenolic acids (ferulic acid, *p*-coumaric acids, gallic, vanillic, caffeic and syringic acids), flavonoids, and anthocyanins (cyaniding 3-*O*-glucoside, peonidin 3-*O*-glucoside). These bioactive substances have garnered much attention for their benefits to human health. Numerous studies have reported the biological activities of these different bioactive substances, including antioxidant effects (Choi *et al*., 2007), antiglycation and anticancer properties (Daiponmak *et al*., 2014). Due to a low glycemic index reflecting the slow starch digestibility of pigmented brown rice, epidemiological studies have shown that it could be associated with decreased risk of several non-communicable diseases, such as diabetes type II, hypertension, hyperlipidemia, cardiovascular disease, obesity, etc. In addition, the pigmented brown rice impacts the regulation of various biological functions, condoning it with anti-inflammatory, antimicrobial, antitumor and anti-allergic properties (Bhat and Riar, 2017). Therefore, pigmented brown rice has become an alternative source of functional foods for health-conscious people.

In southern Thailand, the varieties of indigenous brown rice differ by the contents, types, and biological activities of bioactive substances located in the aleuron layer of rice bran. Among indigenous brown rice varieties, the non-pigmented varieties in the three borderline provinces of Thailand were studied for the physicochemical and functional properties of brown rice flour. Since the sensory characteristics of brown rice, including its taste and texture, are unpalatable, rice flour is more acceptable from an industrial perspective because of its functional characteristics (Kaushal *et al*., 2012; Reddy *et al*., 2016) and it is free from gluten (Kaushal *et al*., 2012; Tran *et al*., 2004) as well as available in the local market. Both the flour from unpolished rice and the starch are important ingredients for developing new food products with specific physical and functional properties involving bioactive substances (Mohan *et al*., 2014; Singthong and Meesit, 2017). Rice flour-based products are available in the market, such as cakes, cookies, muffins, nutrition supplementing bars, bread, beverages, and vinegar (Gujral and Rosell, 2004; Kim, 2013; Murakami *et al.*, 2016; Sasaki *et al*., 2014). The food component interactions, like starch-protein and starch-lipid interactions, could influence the physicochemical properties. Then, these attributes are among the determinants of the characteristics of food products, affecting both appearance and nutritional benefits (Kraithong *et al*., 2018).

Therefore, the purpose of this study was to investigate the physiochemical and thermal properties associated with bioactive phytochemicals in Thai indigenous brown rice flour, particularly in varieties from the southern borderline provinces of Thailand, such as Ma Ja Nu (MJN), Chaew Khing (CK), Si Bu Kantang (SBK), Cheang Phatthalung (CP), Gam Yarn (GY), Nok Med Dang Lek (NMDL), and Ra Dang (cv. RD). The results of the investigation support further studies to develop value-added products in food applications.

MATERIALS AND METHODS

Materials

Indigenous brown rice flours representing the varieties Ma Ja Nu, Si Bu Kuntang, Gam Yarn, Nok Med Dang Lek, Chaew Khing, and cv.Ra Dang were obtained from Pattani Rice Research Center, Khok Pho district, Pattani province, Thailand. The Cheang Phatthalung variety was obtained from Pak Roa Tumbon, Singhanakhon district, Songkhla province, Thailand. All chemical reagents used in the study were of analytical grade and were obtained from Sigma-Fluka and Aldrich.

Sample preparation

All indigenous paddy rice samples were dehusked on a household paddy husker to obtain the brown rice. The brown rice was dried in a hot air oven to moisture below 12.5%, and ground with a household blender to produce rice flour. The flour was passed through a 60 to 80 mesh sieve to ensure uniform particle size. Finally, the flour was kept in Ziplock bags and stored in the refrigerator at 4°C for further use.

Chemical composition analysis of brown rice flours

The proximate analysis of moisture, ash, crude fat, and crude fiber contents in the brown rice flours was done according to standard methods of analysis of the

Association of Official Analytical Chemists (AOAC, 2012). The determination of crude protein content was performed by combustion technique (Carbon/Nitrogen Analyzer, CN-628, LECO Instruments (Thailand) Ltd.) using Nitrogen-Protein conversion factor 5.95. Total carbohydrate content (% dry basis) was calculated by subtracting from 100 the sum of moisture, ash, crude fat, crude protein, and crude fiber contents. Mineral contents were determined by using ICP-OES (PerkinElmer, Optima8000).

Water hydration properties

Water absorption index (WAI), water solubility (WS) and swelling power (SP) were determined following the method of Heo *et al.* (2013). The brown rice flour was accurately weighed for a 100 mg sample and dispersed in 10 ml of distilled water. The obtained slurry was incubated at specific temperatures (27, 50, 85 and 100°C) for 30 min. Then, each suspension was left to cool down to room temperature and centrifuged at 7,500 rpm for 30 min. The supernatant was transferred into a Petri dish and dried at 105°C until constant weight. The wet sediment was weighed. WAI, WS and SP were obtained from the following equations and were measured in triplicate:

WAI (g/g) = wet sediment weight/sample weight (1)

WS (%) = (dry supernatant weight/sample weight) × 100 (2)

SP (g/g) = (wet sediment weight/sample weight) × (1 – WS/100) (3)

Analysis of amylose contents

Accurately sampled 100.00 mg of defatted and deproteinized rice flour was added to 1 ml of 95%EtOH and 9 ml of 1 M NaOH. The aliquot was vigorously shaken and heated in a water bath at 100°C for 10 min. It was left at room temperature for 10 min and the volume was adjusted with distilled water to 100 ml. Subsequently, 5 ml of the solution was transferred to a 100 ml volumetric flask and pH was adjusted with 1 ml of 1 N Aq.CH_3COOH. Then, 2 ml of 0.2% I_2 solution ((I_2 2 g + KI 20 g)/L) and distilled water were added until 100 ml volume was reached. Spectrophotometer measurement was made at 620 nm. The relation of absorbance to apparent amylose content was based on simple linear regression as follows (Avaro, *et al*., 2011):

Amylose content (%) = $(6.2335 + 1.8305 \times \ln(Abs620))^2$ (4)

Thermal properties

Gelatinization temperatures and enthalpy of flours were investigated with a differential scanning calorimeter (DSC, PerkinElmer Inc., Norwalk, CT, USA.) according to the method of Reddy *et al.* (2016). Flour was accurately weighed to 3 mg (dry basis), mixed with 7 µl distilled water to make a slurry, and added to a DSC pan. Flour sample pans were allowed to stand for 2 h at 4°C before testing. An empty aluminum pan was used as a reference. The scanning temperature and the heating rates were 50°C to 150° and 5°C/min, respectively. The onset temperature (T_0) and the enthalpy change (ΔH) of the glass transition of starch gelatinization were determined (Wang *et al*., 2019).

Pasting properties

The pasting properties of brown rice flour were measured by using a Rapid Visco Analyzer (Newport Scientific Pvt. Ltd., Australia) according to the method of Reddy *et al*. (2016). Flour slurry in the RVA canister was prepared by mixing 3.5 g flour with 25 ml distilled water. Then, it was heated at 50°C with continuous stirring for 10 s and held for 1 min. The temperature was elevated to 95°C (heating rate 6°C/min) over 7.5 min and held for 5 min, and finally cooled to 50°C (cooling rate 6°C/min). The paddle speed was maintained at 160 rpm throughout the process. Samples were analyzed in triplicates. The results are represented by the parameters pasting temperature (PT), peak viscosity (PV), breakdown (BD), final viscosity (FV), and set back (SB).

X-ray powder diffraction (XRD)

The crystallite characteristics of starch granules in brown rice flour were analyzed by using an X-ray powder diffractometer (Bruker, Germany). The samples were left in a sealed container containing saturated lithium chloride solution (30°C) to reach 10 % moisture content prior to XRD analysis (Lin *et al.*, 2021). The wavelength of Cu-Kα radiation from the X-ray source was 0.1542 nm at 40 kV and 40 mA, and the scanning range of the diffractometer was from 5° to 45° of 2θ angle of diffraction at the rate of 10°/min, with logging at 0.02° scanning step width. The relative crystallinity is assessed from X-ray powder diffractograms. The patterns of diffractograms were compared with reference patterns from the literature review.

Statistical analysis

All measurements were carried out in triplicate and are presented as mean value ± standard deviation. Each parameter was analyzed in one-way analysis of variance (ANOVA) for the determination of significant differences between samples at 95% confidence.

Table 1. Chemical proximal compositions of brown rice flours.

Variety of flour	Moisture (g/ 100g)	Crude fat (g/100 g)	Crude protein (g/100 g)	Ash (g/100 g)	Crude dietary fiber (g/100 g)	Carbohydrate (g/100 g)
SBK	9.38±0.09[a]	0.58±0.24[a]	5.60±0.57[a]	2.73±0.26[a]	21.05±1.45[a]	65.83±2.99[a]
CK	10.30±0.22[ab]	1.43±0.31[ab]	6.34±0.55[ab]	2.03±0.30[a]	20.79±0.95[a]	64.70±2.51[a]
GY	11.74±0.41[c]	2.30±0.16[ab]	8.79±0.39[b]	2.34±0.26[a]	16.72±3.73[a]	66.62±2.97[a]
NMDL	11.67±0.36[c]	2.38±0.59[b]	6.93±0.38[ab]	4.72±0.13[b]	22.48±3.36[a]	57.67±3.28[a]
cv. RD	9.67±0.54[a]	1.38±0.09[ab]	6.90±0.54[ab]	2.21±0.54[b]	21.05±3.20[a]	65.61±3.53[a]
MJN	11.47±0.37[bc]	1.85±0.37[ab]	7.52±0.91[ab]	3.41±0.14[a]	16.46±0.25[a]	66.11±1.92[a]
CP	12.24±0.47[c]	2.07±0.16[ab]	6.77±0.47[ab]	2.30±0.06[ab]	24.15±2.73[a]	58.58±2.32[a]

Mean ± SD, each value in the table is the mean of three replications (n=3).
Different superscripts in the same column indicate that the means differ significantly at the 0.05 level.
SBK: Si Bu Kantang brown rice flour, CK: Chaew Khing brown rice flour, GY: Gam Yarn brown rice flour, NMDL: Nok Med Dang Lek brown rice flour, cv.RD: cv. Ra Dang brown rice flour, MJN: Ma Ja Nu brown rice flour, and CP: Cheang Phatthalung brown rice flour.

RESULTS AND DISCUSSION

Chemical compositions of brown rice flours

Brown rice is utilized in the forms of starch and flour, as a food ingredient in desserts throughout Asia (Yang *et al*., 2019; Wang *et al*., 2019). The chemical composition of brown rice grains affects their physicochemical properties both in starch and flour forms and is associated with characterizations of the X-ray diffraction pattern, crystallinity, starch chain involving amylose-lipid and amylose-protein interactions, viscosity, and gelatinization temperature (Bae and Lee, 2018; Sun *et al*., 2013). Fat and protein contents in rice kernels affect the hydrophilic and hydrophobic parts of amylose and amylopectin chains in the starch granules of brown rice flour. This impacts the physical characteristics, gelatinization temperature, pasting and rheological properties of rice flour. The proximate compositions of rice flour are compiled in Table 1. Crude fat of NMDL (2.38 ± 0.59 g/100 g) was greater than that of GY (2.30 ± 0.16 g/100 g), CP (2.07 ± 0.16 g/100 g), MJN (1.85 ± 0.37 g/100 g), CK (1.43 ± 0.31 g/100 g), cv. RD (1.38 ± 0.09 g/100 g) and SBK (0.58 ± 0.24 g/100 g). Generally, NMDL is used for feeding Zebra Dove, and this rice variety is more expensive than rice for human consumption. The pigment in brown rice flour is red and cv.RD is a naturally breeding cultivar among Maw Arun (white rice). In contrast, the color of the rice kernel of cv.RD is slightly reddish. The moisture, crude fat, crude protein, ash, crude dietary fiber and carbohydrate contents were 9.67 ± 0.54, 1.38 ± 0.09, 6.90 ± 0.54, 2.21 ± 0.54, 21.05 ± 3.20 and 65.61 ± 3.53 g/100 g, respectively. The fat component interacts with amylose by complexation in starch granules, impacting the thermal properties (gelatinization and enthalpy) and X-ray diffraction pattern. Lipids can rotate the hydrocarbon portion to interact with the helical amylose cavity. Amylose-lipid complexes have induced changes in swelling power, water-solubility index, and pasting properties (Kaur and Singh, 2000). Crude protein of GY was the highest (8.79 ± 0.39 g/100 g) among the varieties tested. The water absorptivity of rice flour is disturbed by crude protein, resulting in a prolonged cooking time. The protein component affects the gelatinization and gelling properties of starch granules. When gelatinization occurs, the expansion of starch granules is inhibited by disulfide bonds on the surface of protein structures (Hamaker and Griffin, 1993; Xie *et al*., 2008). Protein fractions found in brown rice grain include albumin (30.9%), globulin (24.9%), glutenin (32.5%) and prolamin (11.6%) (Chanput *et al*., 2009). Amino acids contained in brown rice include arginine, cysteine, histidine, methionine, valine, and trace amounts of lysine, isoleucine, phenylalanine, and tyrosine (Singh *et al*., 2016). Due to the high nutrition, true digestibility (SD), and biological value (BV) of rice protein (Eggum, 1979), it has been recommended as a supplement to infant formula milk and in rations for the elderly (Helm and Burks, 1996). High contents of lysine as a hypoallergenic are suitable for human consumption (Amgliani *et al.*, 2017). Numerous studies have demonstrated that the biological properties of rice protein include antioxidant (Li *et al*., 2021; Phongthai *et al*., 2018), anti-hypertension (Li *et al.*, 2007), anti-cancer (Kannan *et al*., 2010) and anti-obesity activities (Kannan *et al.*, 2012; Zhang *et al*., 2011). All varieties in the current study had high amounts of essential amino acids like leucine, isoleucine, lysine, threonine, valine, tyrosine, phenylalanine, and histidine, but only small amounts of methionine (data not shown). Particularly, the essential and non-essential amino acid contents in GY brown rice flour are most abundant. It could be used as a raw material of flour for pastries and steamed desserts, and GY brown rice could further be improved to make germinated rice flour. Because of a high amount of L-glutamic acid in GY and CK, the L-glutamic acid can transform into glutamic acid decarboxylase enzyme for catalyzing the reaction of irreversible α-decarboxylation reaction to produce γ-aminobutyric acid (GABA). GABA has multiple health benefits including the prevention of neurological disorders (Hepsomali *et al*., 2020), and anti-diabetic (Rezazadeh *et al*., 2021) and anti-hypertensive activities (Nishimura *et al*., 2016;

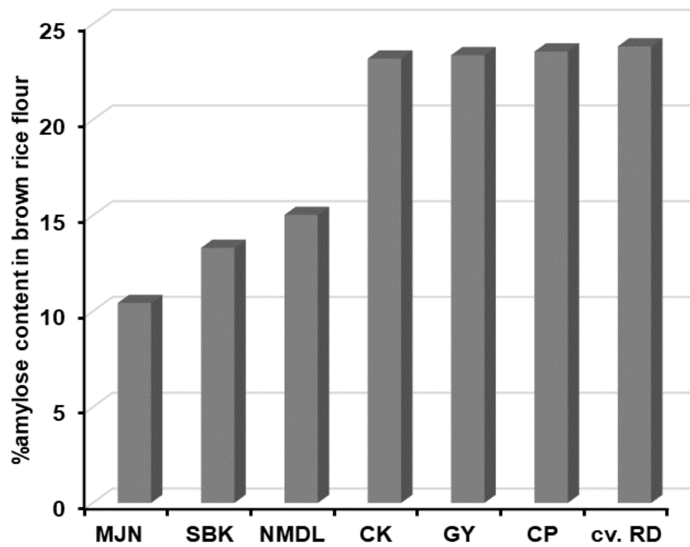

Figure 1. Amylose content in starches of the studied flour varieties (dry basis).
MJN: Ma Ja Nu brown rice flour, SBK: Si Bu Kantang brown rice flour, NMDL: Nok Med Dang Lek brown rice flour, CK: Chaew Khing brown rice flour, GY: Gam Yarn brown rice flour, CP: Cheang Phatthalung brown rice flour, and cv.RD: cv. Ra Dang brown rice flour. Data shown are means of five replicates (n = 5).

Diana *et al*., 2014). Numerous reviews have reported on the nutrition and digestibility of rice protein in using rice flour to replace gluten-containing wheat in bakery and pasta products (Gao *et al*., 2017; Khatun *et al*., 2020). In principle, ash level is an indicator of the inorganic matter content in brown rice flour, such as minerals, Cl^- and SO_4^{2-}. In the results, the ash content of NMDL flour was higher than those of the other varieties, including macro-minerals K, Ca, and Mg; and micro-minerals Zn and Fe. These essential minerals are located in the rice kernel and starch endosperm. They have important roles in balancing and maintenance of human functions (Akhtar *et al.*, 2011; Peña-Rosas *et al.*, 2014), and in enzyme and hormone production.

Amylose content, swelling power and water hydration properties of brown rice flour

Amylose content is an important factor impacting water hydration, gelatinization, and pasting properties. In principle, amylose content in rice grain ranges from 0 to 30% of the starch endosperm. That range is categorized as low amylose for 0 to 20%, intermediate amylose for 20 to 25% and high amylose for more than 25% (Biselli *et al.*, 2014). The amylose contents of the studied brown rice flours are seen in Figure 1 and Table 2. The amylose contents for the varieties of CK, GY, cv.RD and CP (that is, 23.20 ± 0.31%, 23.38 ± 0.46%, 23.84 ± 0.35% and 23.57 ± 0.86%) are greater than those of NMDL, SBK and MJN (that is, 15.04 ± 0.21%, 13.32 ± 0.63% and 10.44 ± 1.52). Consequently, CK, GY, cv.RD and CP have intermediate amylose levels while the other varieties (MJN, SBK and NMDL) have low amylose. When considering the contents of fat and protein in rice kernel and starch endosperm, they could contribute to forming complexes with amylose, thereby affecting swelling power, water absorptivity, and solubility of amylose during heating with water. These parameters can impact the crystalline structures in starch granules. The amylose complexes (amylose-fat and amylose-protein complexes) interact with water via hydrogen bonding, favoring hydration that is measured by the water absorption index. The results in Table 2 reveal that the intermediate amylose varieties (CK, GY and CP) with network formation involving fat and protein, had water absorptivity index for brown rice flour elevated, with increased swelling power. However, the insufficient heat energy that cleaves the amylose-protein and amylose-fat bonds in rice kernel, allowed the amylose to leach out from the inner part of the flour granule. Thus, water solubility indexes had low values, due to the complexation of amylose. However, the parameters: amylose content, crosslinking of amylose and fat, protein content, swelling power, water hydration properties, and crude dietary fiber, could be used to predict the glycemic index. The complexation of amylose with lipid or protein in starch granules would inhibit the accessibility of granules to the gastrointestinal enzymatic system (Annison and Topping, 1994). The granule is only swollen by water hydration (Singthong, 2018). Hence, the flour resisted

Table 2. The different parameters affect the physical properties.

Variety of flour	Amylose content g/100 g flour	Fat g/100 g flour	Protein g/100 g flour	Swelling Power$_{100^{\circ}C}$ g/g	WAI$_{100^{\circ}C}$ g/g	WSI$_{100^{\circ}C}$ g/g
MJN	10.44±1.52[a]	1.85±0.37[ab]	7.52±0.91[ab]	13.18±1.71[a]	9.86±0.42[a]	0.02±0.00
SBK	13.32±0.63[ab]	0.58±0.24[a]	5.60±0.57[a]	10.73±0.54[a]	10.15±0.02[a]	0.05±0.01
NMDL	15.04±0.21[b]	2.38±0.59[b]	6.93±0.38[ab]	11.39±0.40[a]	10.25±0.92[a]	0.02±0.00
CK	23.20±0.31[c]	1.43±0.31[ab]	6.34±0.55[ab]	9.71±1.00[a]	8.95±0.12[a]	0.03±0.00
GY	23.38±0.46[c]	2.30±0.16[ab]	8.79±0.39[b]	12.34±0.94[a]	11.28±0.74[a]	0.09±0.01
CP	23.57±0.86[c]	2.07±0.16[ab]	6.77±0.47[ab]	8.99±0.28[a]	9.11±0.27[a]	0.02±0.00
cv.RD	23.84±0.35[c]	1.38±0.09[ab]	6.90±0.54[ab]	11.50±0.25[a]	11.18±0.10[a]	0.04±0.01

Mean ± SD, each value is the mean of three replications (n=3).
WAI$_{100^{\circ}C}$ = water absorption index at heating temperature, WSI$_{100^{\circ}C}$ = water solubility index at heating temperature. MJN: Ma Ja Nu brown rice flour, SBK: Si Bu Kantang brown rice flour,
NMDL: Nok Med Dang Lek brown rice flour, CK: Chaew Khing brown rice flour, GY: Gam Yarn brown rice flour, CP: Cheang Phatthalung brown rice flour, and cv.RD: cv. Ra Dang brown rice flour.

Table 3. The protein in flour granule affects swelling power and gelatinization temperature of studied varieties of brown rice flour.

Variety of flour	Amylose content g/100 g flour	Protein content g/100 g flour	Swelling Power$_{27^{\circ}C}$ g/g	Gelatinization temperature (T_{onset}) °C
MJN	10.44±1.52[a]	7.52±0.91[ab]	1.78±0.15[a]	75.18
SBK	13.32±0.63[ab]	5.60±0.57[a]	1.71±0.46[a]	74.66
NMDL	15.04±0.21[b]	6.93±0.38[ab]	1.54±0.08[a]	72.94
CK	23.20±0.31[c]	6.34±0.55[ab]	1.77±0.29[a]	73.66
GY	23.38±0.46[c]	8.79±0.39[b]	1.65±0.21[a]	74.79
CP	23.57±0.86[c]	6.77±0.47[ab]	1.93±0.42[a]	74.01
cv.RD	23.84±0.35[c]	6.90±0.54[ab]	1.32±0.17[a]	73.91

MJN: Ma Ja Nu brown rice flour, SBK: Si Bu Kantang brown rice flour, NMDL: Nok Med Dang Lek brown rice flour, CK: Chaew Khing brown rice flour, GY: Gam Yarn brown rice flour,
CP: Cheang Phatthalung brown rice flour, and cv.RD: cv. Ra Dang brown rice flour.
All data were measured in triplicates (n=3), except for the gelatinization temperature that was measured in duplicate (n=2).

digestion that produces glucose in the bloodstream, affecting a low glycemic index (Meera *et al*., 2019).

Thermal properties

Because of the hindering of the access by water molecules, affected by protein in starch granules, Hamaker and Griffin suggested that the disulfide bonds of protein structure in starch granules could limit the swelling during gelatinization, making the swollen starch particles rigid and less susceptible to disruption by shear (Hamaker and Griffin, 1993). Furthermore, Lim *et al.* (1999) demonstrated that gelatinization temperature was positively correlated with protein content in rice starch. As can be seen from Table 3, the high protein content in the amylose complex could restrict the migration of water into the rice grain, reducing the swelling power at room temperature, as well as decreasing the gelatinization temperature. Similarly, the quantity of protein in amylose complexes could influence the temperature characteristics of gelatinization. Thus, the studied brown rice flour with high amylose-protein complexes is inappropriate for making rice bread, rice noodles, or pasta, because of the textural characteristics of rice flour including hardness, firm texture and low porosity. Moreover, the high protein content in starch significantly affects the retrogradation of rice flour gel (Wang *et al*., 2020). It is concluded that the protein in amylose complexes could inhibit water migration to the starch granule, causes swelling of rice grains, and decelerate starch retrogradation.

Pasting properties

Both amylose and amylopectin in starch granules influence the final texture and nutritional characteristics of starchy foods, as seen in functional properties (Li *et al*., 2017; Li *et al*., 2020). Pasting properties are used to characterize cereal food ingredients. Moreover, pasting

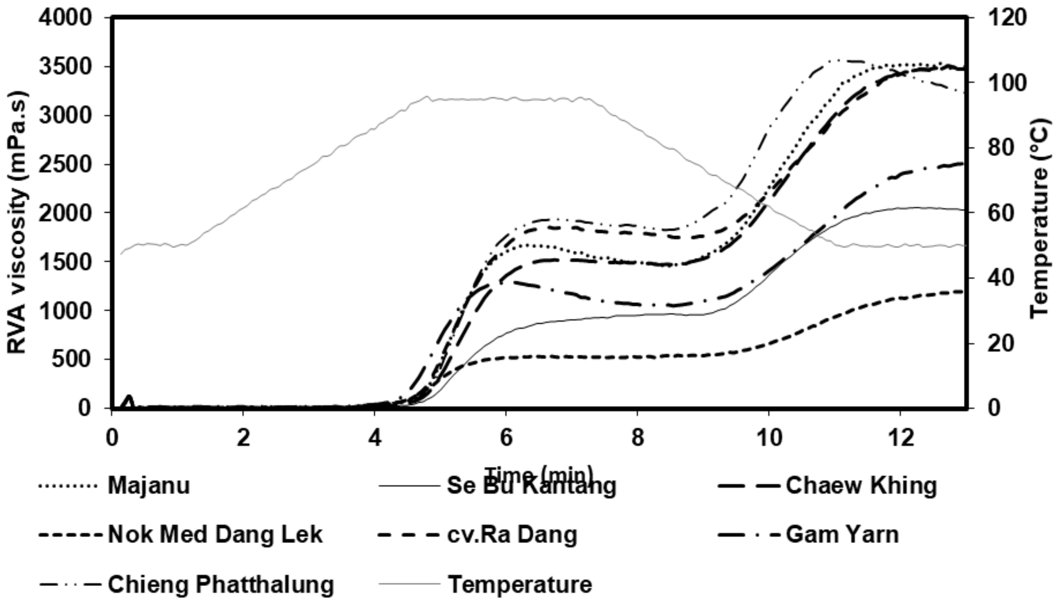

Figure 2. Viscoamylographs from Brabender equipment for characterizing the pasting properties of different varieties of brown rice flour in standard heating mode (95°C 13 min).

Table 4. Effects of RVA viscosity parameters on pasting parameters of different varieties of brown rice flour.

Varieties of flour	Pasting temp. (°C)	Peak time (min)	Viscosity (cP)					Amylose (g/100 g flour)
			Peak (PV)	Final (FV)	Breakdown (BDV)	Trough (TV)	Setback (SV)	
MJN	92.80±0.4[a]	6.27	1672.0±11.8[c]	3437.3±30.0[b]	210.7±9.7[a]	1461.3±5.0[c]	1976.0±35.0[b]	10.44±1.52[a]
SBK	93.30±0.8[a]	7.00	911.0±12.1[f]	2034.3±18.0[e]	100.3±15.0[b]	810.7±3.1[e]	1223.7±15.0[e]	3.32±0.63[ab]
NMDL	92.2±0.7[b]	6.33	538.0±5.6[g]	1181.7±13.7[f]	18.7±2.1[c]	519.3±5.8[f]	662.3±19.1[f]	15.04±0.21[b]
CK	93.10±0.4[a]	6.67	1522.3±35.6[d]	3465.7±29.1[b]	107.0±12.1[b]	415.3±26.6[c]	2050.3±3.2[a]	23.20±0.31[c]
GY	89.35±0.3[c]	5.93	1290.3±2.5[e]	2536.0±38.6[d]	223.3±14.5[a]	1067.0±16.6[d]	1469.0±30.4[d]	23.38±0.46[c]
CP	93.75±0.6[a]	6.67	1929.7±7.1[a]	3229.7±5.7[c]	116.7±3.8[b]	1813.0±7.9[a]	1416.67±11.6[d]	23.57±0.86[c]
cv. RD	91.55±0.5[b]	6.53	1875.7±25.7[b]	3542.0±39.0[a]	108.67±8.7[b]	1767.0±22.6[b]	1775.00±16.7[c]	23.84±0.35[c]

MJN: Ma Ja Nu brown rice flour, SBK: Si Bu Kantang brown rice flour, NMDL: Nok Med Dang Lek brown rice flour, CK: Chaew Khing brown rice flour, GY: Gam Yarn brown rice flour, CP: Cheang Phatthalung brown rice flour, and cv.RD: cv. Ra Dang brown rice flour. All RVA parameters were measured in triplicate (n=3). Different superscripts in the same column indicate significant differences at $P \leq 0.05$.

behavior was also used to assess the digestibility in the enzymatic gastrointestinal system, and to assess the hardness of cooked rice noodle and pasta products (Wu *et al.*, 2019). Tao *et al.* (2019) studied the influences of pasting and retrogradation on starch fine structure, suggesting that the short-term retrogradation of starch fine structure was predominantly impacted by amylose content, while the amylopectin influenced long-term retrogradation. After the gelatinization of starch has been induced by heating with water, the pasting behavior reflects the swollen starch granules that also rupture, the amylose leaching, and the gel formation (Zhu *et al.*, 2020).

The pasting properties of the studied brown rice flours are presented in Figure 2 and Table 4. The recorded viscoamylographic (VAG) parameters were peak temperature (PT), peak viscosity (PV), final viscosity (FV), breakdown (BD), and setback (SB) viscosity, and the eight rice varieties had significantly different viscosities in terms of these. The lipid and protein on granule surfaces are important along with the amylose content, in their effects on the pasting viscosity. From Figure 2, the RVA amylographs of CP, cv.RD, MJN, CK, and GY varieties had similar viscosity profiles, while the SBK and NMDL varieties behaved differently. In Table 4, the pasting profiles reveal that the high amylose content combined with high lipid and protein contents of CK, GY, CP and cv.RD varieties exhibited high PV, as did the MJN variety. The crosslinking of protein and lipid with amylose starch plays a dominant role for PV: the peak viscosity does not only reflect the amylose level. Regarding high PV of CK,

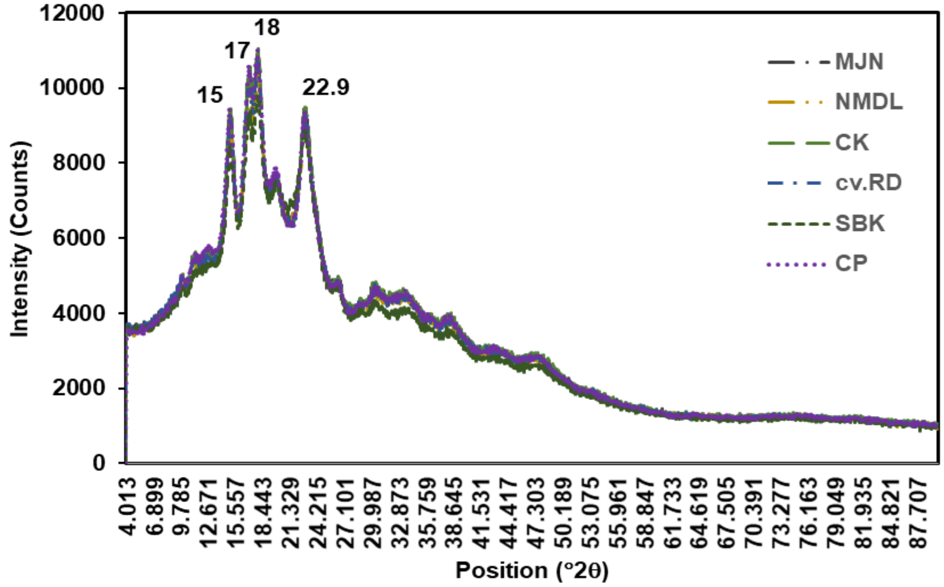

Figure 3. XRD diffractograms of starch crystallites in studied varieties of brown rice flours: MJN (Ma Ja Nu), SBK (Si Bu Kantang), NMDL (Nok Med Dang Lek), CK (Chaew Khing), GY (Gam Yarn), CP (Cheang Phatthalung), and cv.RD (cv.Ra Dang).

GY, CP and cv.RD varieties, it revealed that the interactions within these starches are strong, resisting swelling and rupture of the granules. Peak times of these rice varieties ranged from 5.90 to 7.01 min during heating at 95°C. The complexes of amylose - lipid and/or - protein and amylose-amylopectin led to the formation of a gel network, and heating had a cooking effect. The breakdown of the gel structure in starch granules is quantitatively represented by the breakdown viscosity (BDV). Hence, it is viewed as the heat stability of starch at 95°C (Inglett *et al.*, 2015). The RVA profiles indicated that BDV of GY variety was higher than those of MJN, CP, cv.RD, CK, SBK and NMDL. It was concluded that the heat stabilities of NMDL and SBK varieties were better than those of the other varieties. Then, the rates of retrogradation of NMDL and SBK varieties were also lower. After swelling at an elevated temperature, gel is formed by amylose leached from the starch granules due to its interactions with non-starch polymers, and amylose chains are cleaved, subsequently, retrogradation upon cooling of cooked rice flour pastes occurred. This is quantitated by the setback viscosity. In summary, CK, MJN, cv. RD, GY, CP, SBK and NMDL varieties had varied setback viscosities, which may be caused by the degradation of interactions between amylose and non-starch polymers. Likewise, SBK and NMDL varieties could be used at a comparatively low temperature to form a gel by amylose leached from the granules, indicating weak interactions in the network. It can be seen that also the PV of SBK and NMDL was low. Final viscosity reflects the ability of starch to form a thick paste. The different amylose contents and variations of lipid and protein in rice flour varieties led to variations in the final viscosity (Devi and Badwaik, 2022).

XRD profile

In Figure 3, all the varieties display similar X-ray diffraction patterns typical of A-type starch, with two single diffraction peaks at around 15.01° (15°) and 22.9° (23°), and overlapping peaks at 17.01° and 18.00°. This agrees with Nawaz *et al.* (2016) and Zhang *et al.* (2017). There is a small reflection peak at 20° typical in V-type, indicating the amylose-lipid complexes (Zhu *et al.*, 2020). The existence of a lipid peak in the XRD pattern corresponds to the chemical composition of rice grains having high contents of lipids. Lee *et al*. (2017) suggested that the presence of lipids enhanced the intermolecular interactions of amylose and amylopectin, affecting the physicochemical properties, including thermal properties, swelling power, water hydration, and digestibility. The results of this current work agree with Zhu *et al*. (2011), who studied the crystallinity of four rice starches, and found that the four starches had crystallinity of A type in the X-ray diffraction pattern, with diffraction peaks at 2θ 15°, 17°, 18° and 23°. In addition, the crystallinity of rice starch and flour depended on the content of amylose. Furthermore, Singh *et al.* (2007) suggested that the variation in the proportions of amylose and chain length distribution in amylopectin were the dominant parameters influencing the crystallinity of rice starch (Singh *et al*., 2007).

CONCLUSION

The production of brown rice flour is garnering much attention for enabling diverse flour-based products like tortillas, beverages, puddings, children's food, etc. (Chen *et al*., 2017;

Wani *et al.*, 2012; Wu *et al*., 2010). Brown rice flour is rich in bioactive substances located on the bran and in the rice kernel. However, fat and protein in the rice kernel influence the physicochemical properties of non-waxy rice varieties, including water hydration, swelling power, gelatinization, pasting, and crystallinity. Compared with prior literature, the crystalline pattern of these rice flours was typical A-type according to X-ray diffraction; closely similar to other such starches. Major diffraction peaks were observed at 2θ 15.01°, 17.01°, 18.00°, and 22.9°. For the development of rice flour-based products, broken mill brown rice of GY among the studied varieties may be parboiled as instant porridge for children, due to the high crude fat and protein contents, high water absorptivity and swelling power under hydrothermal processing of rice grains, a quite high gelatinization temperature, peak viscosity, and setback viscosity, and slightly high final viscosity. As suggested by the reddish color of brown rice flour, the GY variety is rich in carotenoids and polyphenols that have health benefits for human consumers. Besides rice instant porridge, as a result of high protein, water absorptivity, swelling power, and a quite high peak viscosity, setback viscosity, breakdown viscosity and final viscosity, GY rice flour may be developed into a rice pudding or a rice milk dessert, which are popular in the United States, and in Northern and Central Europe (Mukhekar *et al*., 2017). Rice pudding is made from rice flour mixed with other ingredients, such as sucrose, dried fruits, additives, flavor agents, and added milk. Subsequently, this rice milk is cooked until it turns into a semi-solid paste. Normally, the consumption is after cooling, and the texture is characterized as a soft gel (Arora and Patel, 2017; Suttireung *et al.*, 2019).

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