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Properties of Non-glutinous Thai Rice Flour: Effect of rice variety

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ABSTRACT

The purpose of this research was to investigate the effect of six non-glutinous Thai rice varieties namely Pathum Thani 1 (P1), Hawm Suphan Buri (HS), Suphan Buri 1 (S1), Suphan Buri 2 (S2), Suphan Buri 3 (S3), and Suphan Buri 60 (S60) on the physicochemical, functional, thermal, and pasting properties of flours. The results showed that the flours had different properties, i.e. amylose content 18.64 - 34.19 %, damaged starch 2.52 - 6.38 %, gelatinization temperature (T_{onset}) 70.48 - 77.72 ^{o}C and % crystallinity 23.14 - 31.30. Based on these properties the flour samples could be divided into 2 groups: Group 1 those having amylose content of 18 – 22 % (P1, HS, S2, and S60) had T_{onset} 70 ^{o}C, % retrogradation 32 - 40, and low final viscosity and setback, Group 2 those having amylose content of 28 – 33 % (S1 and S3) had T_{onset} 77 ^{o}C, % retrogradation 55 - 59, and high final viscosity and setback. The relationship among the properties of non-glutinous found that amylose leaching; gelatinization temperature, functional properties, and pasting properties of rice flour were correlated to amylose content.
Keywords: non-glutinous rice; thermal properties; functional properties; pasting properties; retrogradation; gelatinization

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INTRODUCTION

Rice (*Oryza sativa* L.) is the most important crop of Thailand. In 2009, rice flour was exported and earned around 129 million US dollar [1]. Rice flour is used to produce various food products such as traditional Asian foods, baked products, noodles, extruded products or as additive of other ingredients. The qualities of these products depended on the physicochemical properties of rice flour [2, 3]. Previous studies revealed that rice flour from different varieties were different in the amylose, amylopectin, starch, protein, lipid and ash contents [4-8]. The difference in chemical composition of rice flour affected the functional, thermal and pasting properties [6, 9, 10]. Starch, as main composition of rice flour, is composed of two glucose polymers: amylose and amylopectin [11]. Both amylose and amylopectin affected the functional, pasting, gelatinization and retrogradation properties of rice flour [12, 13]. Amylose acts as an inhibitor of swelling but it can create a gel network and sets the structure of flour gel in short-term (less than 1 day) changes, while amylopectin is responsible for the longer term structural changes [2]. Besides amylose and amylopectin, protein and lipids, which are minor components of rice flour, also affect the properties of rice flour such as restricting the expansion of starch granules during gelatinization or retarding amylopectin retrogradation [8, 11, 14]. Many Thai foods are made from rice flour, especially desserts. However, the information on properties of Thai rice flour from different varieties are still lacking. Thus, the objective of this study was to study the physicochemical, functional, thermal, pasting, and gel texture properties of rice flour from six non-glutinous rice varieties. The relationship among these properties was also investigated. This will be useful in selecting the appropriate variety of rice flour to suit the characteristics of food products.

MATERIALS AND METHODS

MATERIALS

Six varieties of non-glutinous Thai rice (*Oryza sativa* L.) namely Pathum Thani 1 (P1), Hawm Suphan Buri (HS), Suphan Buri 1 (S1), Suphan Buri 2 (S2), Suphan Buri 3 (S3) and Suphan Buri 60 (S60), were chosen to represent different ranges of amylose of non waxy rice. They were harvested during year 2006- 2007 from Pathum Thani Rice Research Institute and Suphan Buri Rice Research Institute, Thailand.

Flour was produced by wet milling at Cho Heng Rice Vermicelli Factory Co. Ltd., Thailand. Rice was steeped in water at the ratio of water: rice of 2:1 (w/w) for 4 h and ground by double-disk stone mill. The slurry was centrifuged by basket centrifuge for 10 min before drying in a hot-air oven at 40 ^{0}C for 12 h to reduce the moisture content to approximately 10%. The dried sample was ground using hammer mill with a 0.5-mm sieve and kept in Al-laminated (12µm PET/ 6.5µm Al/50µm LDPE) bag at 4^{0}C until used. The rice flour sample was sieved through a 100 mesh before using.

METHODS

Physicochemical properties

Chemical composition, granule morphology, particle size distribution and crystallinity of the rice flour samples were analyzed as follows:

Chemical composition

The samples were analyzed for moisture (AACC method 44-15A) [15], crude Protein (AACC method 46-13A, 1995), crude fat (AOAC method 920.39) [16], ash (AACC method 08-01), starch (Glucoamylase method, AACC), appearance amylose [17], and damaged starch (AACC method 76-31).

Granule morphology

The granule morphology of the samples was examined under Scanning Electron Microscope (SEM JEOL model JSM-6480 LV, Tokyo, Japan) with a magnification of 5,000 X at accelerating voltage of 20kV.

Particle size distribution

Two hundred gram of rice flour was passed through a series of 4 sieves with mesh size ranging from 63 to 200 μm. The sieve shaker (Retsch, Germany) was operated at speed # 50 (150 rpm) for 30 min. The particle collected on each sieve was weighed and percentage of each particle size range was calculated.

Crystallinity

The crystallinity of rice flour granules was determined using the X-ray diffractometer (XRD) (Bruker AXS, model D8 Advance, Germany). The X-ray source was Cu radiation (wavelength = 1.5406 nm) and operating conditions were 40 kV and 30 mA. About 0.1 mg rice flour was put into the XRD sample slide, and placed on the sample holder. Data was collected over the 2θ range from 5^0 to 40^0 at a scanning speed of 0.1 deg / min, and a step size of 0.02^0 [18]. The % crystallinity was calculated as the ratio of area of the crystalline shape peak, as double helices of polymer in starch, over the total area [19].

Amylose leaching

The apparent amylose leaching was determined by the blue-value method [20]. Accurately 1.000 g rice flour sample in centrifuge tube was suspended in 15 ml of deionized water and shaken in water-bath at 80 ^{0}C for 30 min. The content was centrifuged at 2,500 rpm (Universal 32R, Hettich Zentrigugen, Germany) for 10 min. The supernatant was carefully poured into an aluminum dish (of known weight) and accurately weighed. 1 ml of supernatant was pipette into 100 ml volumetric flask. Then 1 ml of 1 M acetic acid and 2 ml of 2% (w/v) iodine solution were added to the supernatant and the volume was adjusted to 100 ml by deionized water. The solution was placed into dark room for 30 min. The blue color was measured colorimetrically by using spectrophotometer (Spectronic 20 genesys, Model 4001/4, Spectronic Unicam, USA) at 620 nm. Potato amylose (Fluka, Switzerland) was used as standard. The amylose leaching was calculated from amylose standard curve. The measurement was done in triplicate.

Functional properties

Water absorption index (WAI), water solubility index (WSI), and swelling power (SP) of flour samples were analyzed as follows:

Water absorption index and water solubility index

The WAI and WSI of rice flour samples were determined following the method described by Kadan et al [21]. One gram (1.0000 g) of dried flour sample was accurately weighed and suspended in 6 ml of distilled water and shaken in water- bath at 80 ^{0}C for 30 min. The content was centrifuged at 2,500 rpm (Universal 32R, Hettich Zentrigugen, Germany) for 10 min. The supernatant was carefully poured into an aluminum dish (of known weight) before drying at 105 ^{0}C for 10 h and weighing. The sediment was collected and weighed. The WAI and WSI were calculated from equations (1) and (2).

$$\text{WAI} = \frac{\text{weight of wet sediment}}{\text{Dry weight of flour}} \qquad (1)$$

$$\text{WSI (\%)} = \frac{\text{weight of dried solids in supernatant x 100}}{\text{Dry weight of flour}} \qquad (2)$$

Swelling power (SP)

The SP of rice flour samples was determined by measuring water uptake of the samples [22]. The 500 mg of rice flour was weighed into centrifuge tube and 15 ml of distilled water was added. The suspension was heated in water bath at 80 ^{0} C for 30 min and then centrifuged at 4,000 rpm for 20 min. The supernatant was carefully poured into aluminum dish (of known weight) before drying at 105 ^{0}C to constant weight and weighing. The sediment was collected and weighed. SP was calculated using equation (3).

$$\text{SP} = \frac{\text{weight of sediment}}{\text{Weight of flour – weight of dried solids in supernatant}} \qquad (3)$$

Thermal properties

A differential scanning calorimeter (Perkin Elmer, DSC Pyris, USA) was employed to measure the gelatinization and retrogradation of rice flour samples according to the method described by Thirathumthavorn and Trisuth [23]. The sample (about 6 mg) and distilled water (about 24 mg) were accurately weighed into a stainless steel DSC pan and hermetically sealed. The content was equilibrated overnight at room temperature. The sample was heated from 25 ^{0}C to 110 ^{0}C at 10^{0}C/min. An empty pan and indium were used as reference and calibration standard, respectively. The gelatinization temperature (T_{onset}) and the gelatinization enthalpy (ΔH_{gel}) of samples were obtained from thermogram.

The samples were kept at 4^{0}C for 7 days to allow them to retrograde, and then rescanned from 25 ^{0}C to 110 ^{0}C at 10^{0}C/min for retrogradation studies. The onset temperature ($T_{onset\text{-}retro}$) and the enthalpy of regelatinization (ΔH_{retro}) were obtained from thermogram. All measurements were done in triplicate. The percentage of retrogradation was calculated from equation (4).

$$\%\ \text{Retrogradation} = \frac{\Delta H_{retro} \times 100}{\Delta H_{gel}} \qquad (4)$$

Pasting properties

A Rapid Visco-Analyzer (Newport Scientific model RVA-4C, Sydney, Australia) was employed to evaluate the pasting characteristics of rice flour samples according to the AACC 76-21 method [15]. About 3.50 g of rice flour was weighed and poured into 25 g distilled water in aluminum RVA canister. The content was quickly stirred using a plastic paddle for 10 times before insertion into Rapid Visco-Analyzer. The temperature profile consisted of equilibrating the flour suspension at 50 ^{0}C for 1 min, then heated to 95^{0}C within 3 min 42 s at 12.2^{0}C/min, and held at 95^{0}C for 2 min 30 s. It was subsequently cooled to 50 ^{0}C within 3 min 48 s at 11.8^{0}C/min, and held at 50 ^{0}C for 2 min. The rotation speed was maintained at 160 rpm. The pasting characteristics: peak viscosity (PV), trough (T), breakdown (BD), final viscosity (FV), and setback from trough (SB) were determined from Newport Scientific's Thermo Cline for Windows software. All measurements were done in triplicate.

Data analysis

The data were statistically analyzed using SPSS software version 17. The Analysis of variance (ANOVA) and Duncan's New Multiple Range Test [24] were used to determine effect of main parameters and compare difference between means. Pearson correlation analysis was used to determine the correlation between physicochemical properties and functional properties. The significant level was established at the 95% confidence limit.

RESULTS AND DISCUSSION

Table 1 Chemical composition of rice flour from different rice varieties

Varieties	Proximate content (% db)			
	Moisture^{ns}	Protein (N x 5.95)	Fat^{ns}	Ash^{ns}
P1	5.67$\pm$0.09	6.83$\pm$ 0.08^{a}	0.28$\pm$0.04	0.32$\pm$0.02
HS	5.88$\pm$0.60	6.90$\pm$0.17^{a}	0.28$\pm$0.05	0.37$\pm$0.01
S2	5.82$\pm$0.72	5.98$\pm$0.08^{b}	0.30$\pm$0.03	0.36$\pm$0.03
S60	5.81$\pm$0.55	5.64$\pm$0.07^{c}	0.27$\pm$0.08	0.32$\pm$0.03
S1	5.86$\pm$0.23	5.85$\pm$0.09^{b}	0.30$\pm$0.01	0.36$\pm$0.03
S3	5.74$\pm$0.53	5.28$\pm$0.08^{d}	0.29$\pm$0.03	0.33$\pm$0.04

a, b, c,… means with different letters in each column were significantly different ($p \leq 0.05$).
ns means in the same column were not significantly different ($p > 0.05$).

The proximate compositions of non-glutinous rice flour from six varieties were shown in Table 1. It was found that variety significantly affected only protein content ($p \leq 0.05$). Rice flour from Hawm Suphan Buri (HS) variety contained the highest protein content (6.90%), while Suphan Buri 3 (S3) variety contained the lowest protein content (5.28%). The moisture content, fat content and ash content were found to be 5.67 - 5.88 %, 0.27 - 0.30% and 0.32 - 0.37%, respectively.

Table 2 Amylose content, starch content, damaged starch, crystallinity and amylose leaching of rice flour from different rice varieties

Rice Varieties	Amylose content (% db)	Starch content ^{ns} (% db)	Damaged starch (% db)	Crystallinity (%)	Amylose leaching at 80^{0}C (mg/100ml)
P1	18.64$\pm$0.57^{e}	84.44$\pm$ 2.87	5.44$\pm$ 0.06^{b}	24.04$\pm$0.15^{e}	0.053$\pm$0.003^{d}
HS	19.46$\pm$0.57^{de}	84.80$\pm$ 2.89	6.38$\pm$ 0.07^{a}	23.15$\pm$0.22^{f}	0.060$\pm$0.005^{d}
S2	21.58$\pm$1.23^{c}	85.16$\pm$ 1.93	4.18$\pm$0.03^{d}	24.39$\pm$0.16^{d}	0.058$\pm$0.003^{d}
S60	20.73$\pm$0.93^{cd}	85.33$\pm$ 2.75	4.62$\pm$0.05^{c}	25.75$\pm$0.14^{c}	0.418$\pm$0.006^{b}
S1	28.22$\pm$1.07^{b}	85.08$\pm$ 1.54	2.52$\pm$0.06^{e}	30.56$\pm$0.34^{b}	0.375$\pm$0.009^{c}
S3	33.05$\pm$1.00^{a}	86.14$\pm$ 1.38	4.52$\pm$ 0.08^{c}	31.31$\pm$0.24^{a}	1.222$\pm$0.025^{a}

a, b, c,… means with different letters in each column were significantly different ($p \leq 0.05$).
ns means in the same column were not significantly different ($p > 0.05$).

From Table 2 the amylose content, starch content, damaged starch and % crystallinity were found to be 18.64 - 33.05% db, 84.44 - 86.14% db, 2.52 - 6.38% db, and 23.15 - 31.31%, respectively. This rice flour could be classified into three groups according to its amylose content [25], as follows

- Low amylose rice flour having amylose content of less than 20%
- Intermediate amylose rice flour having amylose content of 20 – 25 %
- High amylose rice flour having amylose content of more than 25%

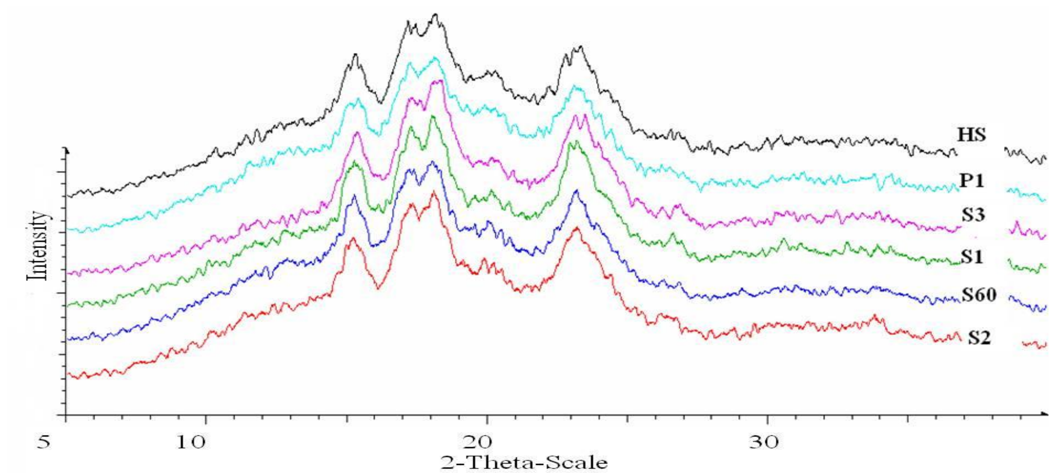

Fig 1: The crystalline patterns of rice flour from different rice varieties

The crystallinity patterns of rice flour samples (Fig. 1) showed a typical A-type diffraction pattern with strong peaks at 15.2^0, 17.1^0, 18.2^0, and $23.2^0(2\theta)$ as observed by other reports [26, 27, 28, 29]. Table 2 showed that % crystallinity of the samples were separated into 2 groups corresponding to their amylose contents, i.e. % crystallinity of 23.15 – 25.75 for those having amylose content of 18.63 - 21.58% (P1, HS, S2, and S60) and % crystallinity of 30.56 – 31.31 for those having amylose content of 28.22 - 33.05 % (S1 and S3). This may be because amylose chain either linear or slightly branched can easily form double helices in amorphous zone resulting in higher % crystallinity [30]. Besides amylose, protein in flour may influence granule structure and crystallinity [8]. Therefore, flours from P1 and HS, which had higher protein and lower amylose content, had lower % crystallinity.

For damaged starch, it was found that damaged starch ranged from 2.5 – 6.4 %. Normally the damaged starches occurred from milling process. In this experimental, the rice flour samples made from wet milling and the level of damaged starch of rice flour was lower than 6.5%, which was low value [31].

For amylose leaching, it was found that amylose leaching of the samples ranged from 0.0513 – 1.222 mg/100 ml. The S3 flour had higher amylose leaching than the others. This difference may be because the amount of amylose in high amylose rice flour will leak out over than that of low amylose rice flour at high temperature (80^0C).

Table 3 Particle size distribution of rice flour from different rice varieties

Varieties	Particle size distribution (weight %)				
	> 200 µm^{ns}	126-200 µm^{ns}	91-125 µm^{ns}	63-90 µm^{ns}	< 63 µm^{ns}
P1	6.56± 1.11	24.12± 1.16	47.42± 0.60	18.24± 1.30	3.64± 0.37
HS	6.47± 1.13	21.86± 0.51	49.48± 0.08	18.48± 1.81	3.71± 0.26
S2	7.02± 0.71	24.56± 1.80	48.41± 0.09	16.57± 1.00	3.44± 0.17
S60	6.58± 1.11	23.79± 0.75	46.65± 0.78	19.38± 0.93	3.59± 0.19
S1	6.26± 1.21	23.63± 0.21	47.99± 0.56	18.38± 1.02	3.72± 0.16
S3	6.45± 0.86	23.09± 0.85	47.59± 1.14	18.54± 0.27	4.31± 0.84

ns means in the same column were not significantly different ($p > 0.05$).

Table 3 shows that the distribution of flour particle size from different rice varieties ranged from less than 63 to more than 200 µm. About 50% flour particle size of rice flour samples was in range from 91 to 125 µm. The granule morphology of rice flour samples showed angular polyhedral shape (Fig. 2).

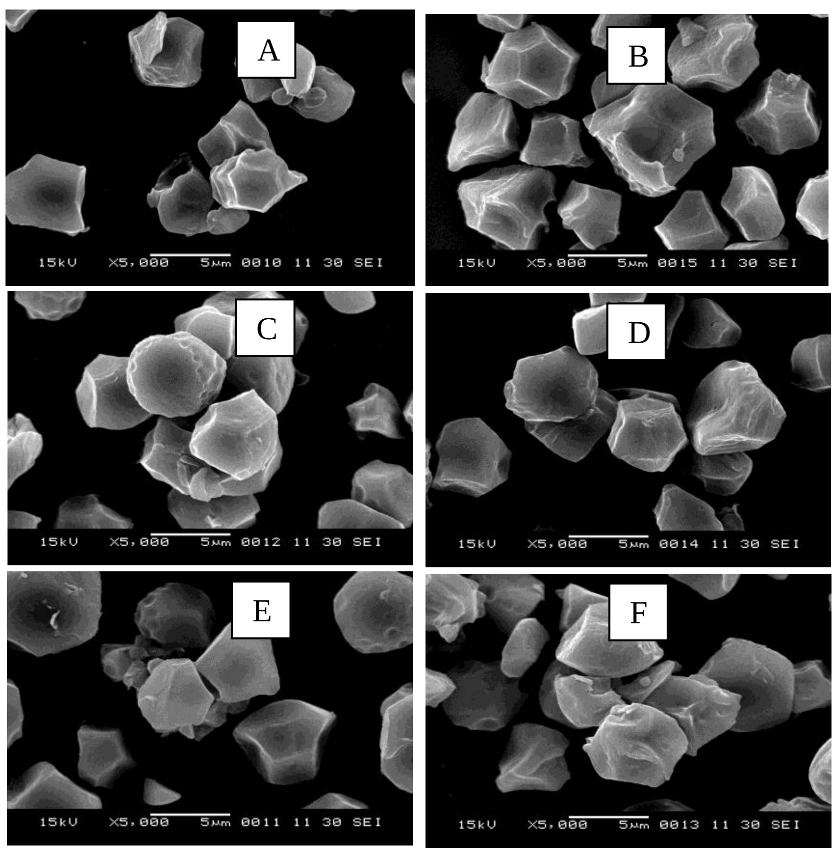

Fig 2: SEM micrographs (x5000) of rice flour granules from different rice varieties; P1 (A), HS (B), S2 (C), S60 (D), S1 (E) and S3 (F)

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Functional properties of rice flour

The WAI, WSI and swelling power of rice flour from different rice variety at 80 ^{0}C were significantly different ($p \leq 0.05$) (Table 4). It was found that rice flour from S3 variety had higher WAI, WSI and swelling power than the others. This difference may be because S3 flour had the highest amylose content.

Table 5 showed the correlation coefficients between amylose content, % crystallinity, protein content, damaged starch and amylose leaching with functional properties of rice flour. It was found that the correlation between amylose content, % crystallinity or amylose leaching was positively correlated with WSI of flour ($r > 0.6$) and stronger than that of WAI and swelling power, while the correlation coefficient of protein and WSI was negatively weaker correlated ($r = -0.545$). It may be because disulfide bond in rice protein restricted starch granule from swelling [11].

Table 4 Water absorption index, water solubility index, and swelling power of rice flour from different rice varieties

Varieties	WAI	WSI (%)	SP
P1	6.838 ± 0.365^{b}	0.787 ± 0.063^{b}	6.892 ± 0.368^{b}
HS	6.909 ± 0.220^{ab}	0.748 ± 0.108^{b}	6.962 ± 0.216^{b}
S2	6.684 ± 0.694^{b}	0.727 ± 0.104^{b}	6.734 ± 1.008^{b}
S60	6.477 ± 0.451^{b}	0.897 ± 0.181^{ab}	6.535 ± 0.451^{b}
S1	7.100 ± 0.709^{ab}	0.909 ± 0.211^{ab}	7.165 ± 0.821^{ab}
S3	8.008 ± 0.317^{a}	1.068 ± 0.098^{a}	8.095 ± 0.315^{a}

a, b, c,… means with different letters in each column were significantly different ($p \leq 0.05$).

Table 5 Correlation coefficients of physicochemical and functional properties of rice flour different rice varieties

	Amylose content	% Crystallinity	Protein	Damaged starch	Amylose leaching
WAI	0.593^{**}	0.516^{*}	ns	ns	0.588^{**}
WSI	0.666^{**}	0.664^{**}	-0.545^{*}	ns	0.694^{**}
SP	0.600^{**}	0.523^{*}	ns	ns	0.595^{**}

* Significant at α = 0.05 level, ** Significant at α = 0.01 level, ns not significant at α = 0.05 level

Thermal properties

Table 6 Gelatinization and retrogradation parameters of rice flour from different rice varieties

Varieties	ΔH_{gel} (J/g)	T_{onset} (^{0}C)	ΔH_{retro} (J/g)	$T_{onset-retro}$ (^{0}C)	% retrogradation
P1	9.50 ± 0.12^c	70.48 ± 0.12^b	3.08 ± 0.13^b	43.94 ± 3.33^b	32.42 ± 0.32^e
HS	9.37 ± 0.26^d	70.68 ± 0.12^b	3.37 ± 0.27^b	41.50 ± 3.23^c	35.97 ± 2.88^d
S2	9.58 ± 0.3^c	70.50 ± 0.27^b	3.84 ± 0.36^b	39.59 ± 1.82^d	40.08 ± 3.47^c
S60	9.61 ± 0.13^c	70.15 ± 0.05^b	3.47 ± 0.20^b	40.47 ± 2.99^c	36.34 ± 2.80^{cd}
S1	10.47 ± 0.12^a	77.72 ± 0.67^a	5.78 ± 0.36^a	43.02 ± 2.64^b	55.21 ± 1.07^b
S3	9.94 ± 0.21^b	77.54 ± 0.46^a	5.74 ± 0.23^a	45.33 ± 3.56^a	59.73 ± 1.84^a

a, b, c,… means with different letters in each column were significantly different ($p \leq 0.05$).
ΔH_{gel} means enthalpy of gelatinization.
ΔH_{retro} means enthalpy of regelatinization after left to retrograde at 4 ^{0}C for 7 days.

Table 6 shows the effect of rice varieties on gelatinization and retrogradation properties of flour. The gelatinization parameters (ΔH_{gel} and T_{onset}) of flour from different rice varieties were significantly different ($p \leq 0.05$). Flours containing high amylose content and % crystallinity (S1 and S3 flours) had higher gelatinization parameters. This may be due to the rigid amorphous regions of the starch granule by the interaction among amylose chains. The stability of amorphous region may be increased, resulting in higher energy for gelatinization and gelatinization temperature [32, 33].

The retrogradation parameters in term of enthalpy, temperature and % retrogradation of rice flour from different rice varieties were significantly different ($p \leq 0.05$). ΔH_{retro} and % retrogradation of rice flour samples increased with increasing amylose content and % crystallinity (Tables 2 and 6). The ΔH_{retro} reflected the melting of recrystallized amylopectin and amylose [34, 35]. The S1 and S3 had higher % retrogradation than those of S2, S60, HS and P1. It may be because amylose could associate more easily resulting in more crystal nuclei and hence faster retrogradation [34, 36].

Table 7: Correlation coefficients of physicochemical and thermal properties of rice flour from different rice varieties

	Amylose content	Crystallinity	Protein	Damaged starch	Amylose leaching
ΔH_{gel}	ns	ns	ns	-0.533^{*}	ns
T_{onset}	0.931^{**}	0.942^{**}	-0.559^{*}	-0.632^{**}	0.712^{**}
ΔH_{retro}	0.939^{**}	0.940^{**}	-0.672^{**}	-0.708^{**}	0.710^{**}
T_{onset_retro}	ns	ns	ns	ns	ns
% Retrogradation	0.970^{**}	0.937^{**}	-0.701^{**}	-0.629^{**}	ns

* Significant at $\alpha = 0.05$ level, ** Significant at $\alpha = 0.01$ level, ns not significant at $\alpha = 0.05$ level

Table 7 shows the Pearson correlation coefficients between amylose content, % crystallinity, protein content, damaged starch and amylose leaching with thermal properties of rice flour. It was found that amylose content or % crystallinity was highly positive correlated with T_{onset}, ΔH_{retro} and % retrogradation (r > 0.9) and stronger than that of protein content, damaged starch and amylose leaching. The protein content and damaged starch were negatively correlated with T_{onset}, ΔH_{retro} and %retrogradation. This may be because linear branched of amylose can easily form double helices, which required greater thermal temperature to dissociate [8, 9, 37]. Besides amylose, different chemical composition in rice flour, storage time, and growth condition may influence granule structure and crystallinity [11, 14, 38-40].

Pasting properties

Table 8 shows that variety significantly affected pasting properties of rice ($p \leq 0.05$). The high amylose rice flours (S1 and S3) were found to have higher setback, final viscosity and pasting temperature than those of low amylose rice flours (S60, S2, HS and P1), while low amylose rice flours had higher breakdown. This may be because amylose content in starch structure increased setback viscosity, final viscosity and pasting temperature of rice flour [6, 41]. Flour having low amylose would swell easier indicating a weaker binding force in that starch granule and upon heating its viscosity could increase at lower temperature [42]. S1 and S3 flours had higher setback which corresponded to higher % retrogradation from DSC (Table 6). This may be because the starch granules of S1 and S3 flour (high amylose rice flour) swelled less when the granules were destroyed by heat and had more amylose leached out to cause the higher final viscosity.

Table 9 shows that most of the pasting parameters were highly correlated with amylose content and amylose leaching of rice flour samples. Almost all correlation between amylose content and pasting parameters agreed with previous report [6] except peak viscosity. It was also found that the correlation coefficient values between % crystallinity and pasting parameters were about the same order as that of amylose content, while the correlation coefficient values of protein content were also significant but in opposite direction.

Table 8: Pasting properties of rice flour from different rice varieties

Varieties	PV (cP)	trough (cP)	BD (cP)	FV (cP)	SB (cP)	Peak time (min)	Pasting temperature
P1	3611.6 $\pm$26.9^{d}	1713.6 $\pm$ 34.6^{e}	1898.0 $\pm$ 50.7^{c}	2607.3 $\pm$ 43.7^{f}	892.7 $\pm$ 10.3^{e}	5.96$\pm$0.07^{b}	74.47 $\pm$ 0.06^{c}
HS	4356.0 $\pm$16.0^{b}	1987.0 $\pm$ 12.5^{b}	2371.7 $\pm$ 29.0^{a}	3252.0 $\pm$ 35.8^{c}	1265.0 $\pm$ 23.6^{d}	6.03$\pm$0.04^{b}	74.58 $\pm$ 0.90^{c}
S2	3800.7 $\pm$18.0^{c}	1650.3 $\pm$ 26.5^{f}	2147.0 $\pm$ 23.1^{b}	2994.0 $\pm$ 26.6^{d}	1344.3$\pm$ 20.1^{c}	5.77$\pm$0.06^{d}	81.21 $\pm$ 0.98^{b}
S60	3376.3 $\pm$11.0^{e}	1887.7$\pm$14.5^{c}	1489.0 $\pm$ 16.1^{d}	2845.3 $\pm$ 37.5^{e}	1841.3$\pm$ 15.0^{b}	6.05$\pm$0.04^{b}	80.08 $\pm$ 0.48^{b}
S1	3381.7 $\pm$ 9.0^{e}	1839.0 $\pm$20.8^{d}	1542.3 $\pm$ 36.7^{d}	4404.7 $\pm$ 10.9^{b}	2568.3$\pm$ 17.2^{a}	5.88$\pm$0.04^{c}	85.27 $\pm$ 0.73^{a}

PV means peak viscosity., BD means breakdown viscosity., FV means final viscosity., SB means setback viscosity.

Table 9: Correlation coefficients of physicochemical and pasting properties

	Amylose content	Crystallinity	Protein	Damaged starch	Amylose leaching
peak viscosity	ns	ns	ns	ns	ns
Trough	0.784**	0.657**	-0.563*	ns	0.935**
Breakdown	-0.752**	-0.847**	0.815**	ns	-0.858**
final viscosity	0.964**	0.891**	-0.640**	ns	0.888**
Setback	0.892**	0.945**	-0.808**	-0.704**	0.775**
peak time	0.576*	0.520*	ns	ns	0.856*
pasting temperature	0.847**	0.849**	-0.898**	-0.789**	0.699**

* Significant at α = 0.05 level., ** Significant at α = 0.01 level.,ns not significant at α = 0.05 level

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CONCLUSION

Variety of rice affected physicochemical properties, i.e. protein content, amylose content, and % crystallinity of flour; functional properties, i.e. WAI and SP; thermal properties, i.e. T_{onset}, ΔH_{gel} and % retrogradation; pasting properties, i.e. final viscosity, setback, and pasting temperature. Six non-glutinous rice flour used in this study could be divided into 2 groups by their amylose content, thermal and pasting properties as:

- Rice flour having intermediate amylose content (18 - 20%), i.e. P1, HS, S2 and S60, had T_{onset} around 70 ^{0}C, low final viscosity (< 3,300 cP), setback (< 2,000 cP), and % retrogradation (< 40%).

- Rice flour having high amylose content (28 - 33%), i.e. S1 and S 3, had T_{onset} around 77 ^{0}C, high final viscosity (> 4,000 cP), setback (> 2,500 cP), and % retrogradation (> 40 %).

The % crystallinity, WAI, WSI, SP, thermal and pasting properties of non-glutinous Thai rice flour from 6 varieties were related to amylose content. Furthermore, protein content significantly influenced the gelatinization temperature, %retrogradation and pasting properties of non-glutinous Thai rice flour, which will consequently affect quality of rice products.

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