Production and Characterization of Fermented Rice Flour from Mali Nil Surin Rice Variety and Effect of Partial Substitution of Fermented Rice Flour on The Rice Noodle Qualities

Piranit Loblom, Teeraporn Kongbangkerd, Sugeewan Detyotin, and Sasivimon Chittrakorn*

Department of Agro-Industry, Faculty of Agriculture, Natural Resources and Environment,
Naresuan University, Phitsanulok, Thailand
*Corresponding Author, E-mail: sasivimonc@nu.ac.th

Abstract

This research was conducted to study the effect of fermentation on the physicochemical, rheological properties, and bioactive compounds of Chai Nat (CHI) and Mali Nil Surin (SU) rice flour and the effect of fermented Mali Nil rice flour substitution on rice noodle qualities. Production of fermented rice flour was modified from the traditional method by using a tray dryer to control fermentation temperature at 40°C. Fermented rice noodles were produced by substitution of fermented Chai Nat flour (FCHI) with fermented Mali Nil Surin flour (FSU) at the level of 0, 10, 20, and 30%. The results indicated that moisture, protein content, and pH value of fermented Chai Nat and Mali Nil Surin rice flours decreased after fermentation, while the amount of amylose and total starch content increased ($p<0.05$). An increase in lightness (L*) and redness (a*) and decrease in yellowness (b*) values were observed after rice fermentation. The setback value of FSU flour was lower than SU flour and this value was higher in FCHI flour compared to CHI flour. Substitution of FSU flour to FCHI flour at 10 to 30% showed a significant decrease in pH values of rice noodles. The lightness (L*) values, hardness, and adhesiveness of rice noodles decreased, while a* and b* values increased with increasing levels of FSU flour replacement. High level of FSU flour substitution decreased storage (G′) and loss modulus (G″) of rice noodle paste. Storage modulus (G′) was higher than loss modulus (G″) over the tested frequency, indicating elastic properties of rice noodle pastes. All sample exhibited tan δ (loss tangent) lower than 1 indicated an elastic component that a solid-like. Partial substitution of FCHI flour with FSU flour tended to increase the antioxidants and total phenolic content of rice noodles.

Keywords: *Rice, Colored rice, Fermented rice flour, Fermented rice noodle, Antioxidant activity, Rheological behaviors*

1. Introduction

Rice (*Oryza sativa* L.) is a staple food of over 65% of the global population, especially in Asian countries. it contains many nutrients and a rich source of carbohydrates. Rice can be classified by color as white rice and colored rice. Colored rice contains reddish, purple, or black pigmentation. Consumption of colored rice is becoming more popular in many Asian countries. Black rice is often mixed with non-colored rice before cooking to enhance its flavor and act as antioxidant substances having a health-promoting activity (Yoshida, Tomiyama & Mizushina, 2010; Chakuton, Puangpronpitag, & Nakornriab, 2012). Besides, black and red rice is commonly used as a functional food and food colorant in bread, ice cream, liquor, drinks, and noodles (Frank, Reichardt, Shu, & Engel, 2012). Colored rice such as black rice and red rice contains several antioxidant compounds including phenolics, anthocyanins, flavonoids, tannin, and γ-oryzanols (Deng et al., 2013). Anthocyanins are major phenolic compounds found in black and red rice and are considered as one of the flavonoids although they have a positive charge at the oxygen atom of the C-ring of basic flavonoid structure (Laleh, Frydoonfar, Heidary, Jameei, & Zara, 2006). The most abundant anthocyanins in colored rice were identified as cyanidin-3-glucoside and peonidin-3-glucoside (Abdel-Aal, Young & Rabalski, 2006; Laokuldilok, Shoemaker, Jongkaewwattana, & Tulyathan, 2010). A high content of antioxidants in colored rice prevents the growth of intestinal cancer cells, anti-oxidative, anti-inflammatory effects (Shipp & Abdel-Aal, 2010).

Mali Nil Surin rice (*Oryza sativa* L.), a non-glutinous rice variety, is colored rice grown by a breeding program in 2003 at Surin Rice Research Center by collecting a traditional line; Mali Dam (SRNC03053) from Surin province in Thailand until obtained new Mali Nil Surin rice variety (Mali Dam 2). Mali Nil Surin rice has a dark purple pericarp with good cooking and eating qualities due to low amylose content (13.2%) and its aroma. Total phenolic content and anthocyanins of this rice variety are 1,592 mg

GEA/100g and 5.5 mg/100g, respectively, and these compounds help to reduce the risk of coronary artery disease and inhibit the growth of human colon cancer cells with IC_{50} value ranging between 12.6 to 76.1 ppm (Saiyot et al., 2017).

Rice noodles mainly consume in Southeast Asian countries. The formation of the rice noodle network structure depends on the starch content and composition and physicochemical properties of the starch (Lu, Li, Cao, Li, & Tatsumi, 2003). Rice noodle (*Khanom Jeen*) production methods are classified into the fermented and unfermented processes. The fermented rice noodle production involves soaking of broken rice grains (stored over 6 months period), wet milling, steaming, kneading, extruding, boiling, and cooling (Keatkrai & Jirapakkul, 2010). During fermentation, the metabolism of some microorganisms occurred leading to taste, acidity, flavor, and texture of fermented rice noodles (Zang et al., 2018). The microorganisms involved include LAB (e.g. *Lactobacillus* and *Pediococcus* spp.), *Enterobacter* spp., yeasts, and filamentous fungi (Nout, 2009). The fermentation process can also reduce protein content in fermented rice flour, increase the gelatinization enthalpy, peak viscosity, and breakdown, and decrease final viscosity, setback, and pasting temperature of rice flour (Park, Sung, Choi, & Park, 2020). Besides, this process leads to improving the shape forming of the noodle. The hardness of fermented noodles increased as fermentation time and heat moisture treatment increased, but adhesiveness decreased (Udomrati, Satmalee, & Surojanametakul, 2015). Since no information exists on the utilization of Mali Nil Surin rice in the noodle industry, thus this research was conducted to investigate the substituted of this rice variety for the production of fermented rice noodles and characterize its properties.

2. Objectives

1) To determine the impact of fermentation on the physicochemical properties, rheological properties, and bioactive compounds of fermented rice flour (Chai Nat and Mali Nil Surin rice)

2) To study the effect of fermented Mali Nil Surin rice flour substitution on the physicochemical properties, rheological properties, and bioactive compounds of rice noodles

3. Materials and Methods

3.1 Materials

Two rice (*Oryza sativa* L.) varieties consisting of Mali Nil Surin rice (SU) obtained from Kamphaeng Phet Province, Thailand and Chai Nat rice (CHI) purchased from a local market (Phitsanulok, Thailand).

3.2 Fermented rice flours preparation

The cleaned Chai Nat rice and Mali Nil Surin rice were soaked in water for 2 hours, transferred to the sack, and drained for 10 minutes. The rice sack was wrapped in a plastic rubber cloth and fermented in a tray dryer at 40°C for 9 hours and continue fermented at room temperature for the rest of the day. After 72 hours, the fermented rice was washed with water, wet-milled (1:0.5, w/v) using a blender, centrifuged at 1,500 rpm for 5-10 minutes, and then dried at 40°C for 10 hours. The dried samples were milled by a pulverizer (DXM-200, DXFLL, China), and passed through the standard sieve of 100 meshes, sealed in polyethylene bags, and stored at 4°C until further use. The fermented Chai Nat rice (FCHI) and fermented Mali Nil Surin rice flours (FSU) had moisture contents of 12.70% and 10.31%, respectively.

3.3 Determination of rice flour properties

3.3.1 Chemical compositions and pH value determination

Moisture, protein, and lipid content of rice and fermented rice flours were determined according to the AACC method (AACC, 2005). The result was expressed as a wet basis for the sample. The pH of rice and fermented rice flours were measured using a pH meter (ST3100-F, OHAUS, USA). Amylose content was analyzed by amperometric titration with potassium iodate solution according to the method of Takeda et al. (1987) and Gibson, Solah, and McCleary (1997). Total starch was determined using a Megazyme total starch assay kit (Megazyme International Ireland Ltd, Wick low, Ireland). Determination of amylose and total starch content was expressed as a dry basis for the sample.

3.3.2 Color measurement

The color of two rice varieties and fermented rice flour was determined by Hunter Lab (Color Reader CR-20, Konica Minolta, Japan). The *L** (lightness), *a** (redness), and *b** (yellowness) values were recorded.

3.3.3 Determination of pasting properties

The pasting properties of rice and fermented rice flours were studied using a Rapid Visco Analyzer, RVA (4500, Perten Instruments, Australia). The sample (3 g, 12% moisture) was added 25 ml of distilled water. The viscosity was recorded using the following temperature profile: speed stirred in an RVA container initially at 960 rpm for 10 sec and finally at 160 rpm for the remaining test. The temperature was holding at 50°C for 1 minute followed by heating to 95°C for 2 minutes and 48 seconds, holding at 95°C for 2 minutes and 7 seconds, then cooling was holding at 50°C for 4 minutes and 28 seconds, and ending the process in 12 minutes and 30 seconds. The following parameters were determined including peak viscosity (PV), trough viscosity (TV), breakdown (BD), final viscosity (FV), setback (SB), and pasting temperature (PaT). Each sample was analyzed in triplicate (AACC Method 61-02, 2000).

3.3.4 Evaluation of antioxidant activity and total phenolic content

The extraction of the bioactive compound of rice flours was prepared according to the method described by Sompong, Siebenhandl-Ehn, Linsberger-Martin, and Berghofer (2011) and Falleh, Ksouri, Lucchessi, Abdelly, and Magné (2012) with a slight modification. A sample (5 g) was mixed with 10 mL methanol (80%) in a 50 mL plastic centrifuge tube. Then, the plastic centrifuge tube was placed in an ultrasonic bath (Elmasonic S30H, Elma, Germany) filled with cold water for 30 minutes with a gently shaking every 5 minutes. The extract solution was centrifuged at 6,000 rpm for 10 minutes, evaporated with an evaporator at 40°C, and filtered through filter paper (Whatman no. 4). The evaporated extract was reconstituted in 50% methanol (5 mL) and stored at 0°C for further analysis.

The DPPH assay was performed by the method of Shao, Xu, Sun, Bao, and Beta (2014) with minor modification. A 0.1 mM of DPPH radical solution was prepared in 80% methanol. The diluted extracts or standards (500 µl) were added to 1 ml of DPPH solution. After incubating for 30 minutes in the dark, the absorbance was measured by a spectrophotometer at 517 nm. The result was expressed as mg of Trolox equivalents/100 g of sample (dry weight).

Ferric Reducing Antioxidant Power (FRAP) assay was determined according to Thuengtung, Niwat, Tamura, and Ogawa. (2018). A 50 µl of sample was mixed with 1.5 ml of FRAP reagent containing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ in 40 mM HCl, and 20 mM $FeCl_3$ (10:1:1, v/v/v). The mixture was incubated at 37°C for 30 minutes, and the absorbance of the mixture was measured at 595 nm. The result was expressed as mg of Trolox equivalents/100 g of sample (dry weight).

Total phenolic content (TPC) was determined by the Folin-Ciocalteu colorimetric method with minor modification (Shao et al., 2014). A 300 µl of diluted extracts or standard solutions were added to 1.5 ml of 10-fold diluted Folin-Ciocalteu reagent and neutralized with 1.2 ml saturated sodium carbonate (7.5%, w/v). The absorbance was measured at 765 nm (Genesys20, Themo, USA) after 2 hours of reaction at room temperature in the dark. The result was expressed as mg of gallic acid equivalent/100 g of sample (dry weight).

3.4 Fermented rice noodles (Khanom Jeen) preparation

The fermented rice flours (FCHI and FSU) were adjusted the moisture content to 45%. Rice noodles were produced by replacing FCHI with FSU flours at the level of 0, 10, 20, and 30% of the flour weight. For noodle production, 30% of FCHI flour was pregelatinized by mixing flour with water at the ratio of 1:1(w/v) and heated in the pan. Pregelatinized Flour was then mixed with the remaining flour and warm water and kneaded to achieve smooth and paste-like consistency (Artisan, Kitchen aid, USA). The tapioca starch (25%), and water were added to the paste, and continue kneaded until homogeneous. The paste was then filtered with a filter cloth 2 times and extruded through the die into boiling water (85-90°C) for 20-30 seconds, the noodle immediately cooled with rinsing water, and drained to obtain fresh noodles, and the rice noodles were stored at 4°C for further analysis. The fermented rice noodles were designated as R0, R10, R20, and R30 following the replacement percentage of FSU.

3.5 Determination of rice noodles

3.5.1 pH value determination

The pH value of rice noodles was determined according to Yeoh, Alkarkhi, and Easa (2013). Ten grams of rice noodles were homogenized with 100 mL of deionized water for 5 minutes and allowed to stand for 30 minutes. The suspension was then filtered. The pH of the filtrate was measured using a pH meter (ST3100-F, OHAUS, USA).

3.5.2 Color measurement

The color of rice noodles was determined by Hunter Lab (Color Reader CR-20, Konica Minolta, Japan). The *L** (lightness), *a** (redness), and *b** (yellowness) values were recorded.

3.5.3 Dynamic viscoelastic and viscosity measurement

Rheological properties of rice noodle paste (before extrusion) at the level of 0, 10, 20, and 30% of FSU replacement were measured in dynamic (oscillation) shear mode using a strain-controlled Rheometer (MCR92, Anton Paar, Austria). A preliminary test was made by performing an amplitude sweep (0.01-10% strain) at a frequency of 0.01-10 Hz, which showed a linear viscoelastic region of the extruded rice noodles paste around the strain value of 0.1%. Before measurement, the sample was left at 25°C for 1 minute between a parallel plate geometry (1.0 mm gap; 50-mm diameter) to recover from a structural breakdown on loading and then subjected to frequency sweep test (0.1-10 Hz) at a constant strain of 0.1%. Dynamic frequency test value including storage modulus (G′), loss modulus (G″) and loss tangent (tan δ) was analyzed. The viscosity of paste samples was measured as a function of shear rate 0.01-100 s^{-1} under the constant shear condition at 25°C.

3.5.4 Textural properties of rice noodles

The hardness and adhesiveness of rice noodles were measured with a Texture analyzer (TA-HD plus, Stable microsystem, UK). Five rice noodles (5 cm in length) were tested using the light knife blade (A/LKB-F). The specific parameters were as follows: 2.0 mm/sec pre-test speed, 2.0 mm/sec test speed, 15.0 mm/sec post-test speed and 5 g triggering force. The texture parameters including hardness (g force) and adhesiveness (g.cm) were analyzed by the instrument software.

3.5.5 Evaluation of antioxidant activity and total phenolic content

The antioxidant activity of rice noodles including DPPH assay, Ferric Reducing Antioxidant Power (FRAP) assay, and total phenolic content were performed according to the method described above.

3.6 Statistical Analysis

Results were represented as the mean of triplicates with standard deviations. The results were analyzed for one-way ANOVA followed by Duncan's multiple range test for significant differences ($p<0.05$) using the IBM SPSS statistics 22 software (SPSS Inc., Chicago, USA).

4. Results and Discussion

4.1 Composition of rice and fermented rice flours

Chemical composition, amylose content, and total starch of rice and fermented rice flour are shown in Tables 1. The results indicated that the moisture content of fermented rice flours was 10.31 - 12.70 %, which was in the range of 10-15% for commercial rice flour standards (Riker & Fujibayashi, 2017). After fermentation, a significant decrease in crude protein content of both rice varieties was observed. The decrease of crude protein is caused by microorganisms naturally present in rice and microorganisms resulting from the fermentation process, which leads to the release of proteolytic enzymes that play a role in hydrolyzing the protein in rice (Matthews et al., 2004; Lu et al., 2003). The lipid content was significantly decreased after fermentation in CHI and FCHI samples but not significant in SU and FSU samples.

Amylose and total starch content were measured to investigate the changes during fermentation. Amylose and total starch content of raw rice and fermented rice flour significantly increased after fermentation ($p<0.05$). These results indicated that fermentation affects the amylose and total starch of rice granule. The structure of starch especially amylopectin degraded by lactic acid, produced by microorganisms during fermentation, leading to an increasing in the ratio of amylose (Lu, Li, Min, Wang, & Tatsumi, 2005;

Lu, Yuan, Sasaki, Li & Kohyama, 2007). Li, Corke, and Beta (2007) found that acid hydrolysis of high amylose corn starch mainly in the amorphous region of amylopectin caused an increase in amylose content.

Table 1 Chemical composition, amylose content, and total starch of rice and fermented rice flours

Sample	Moisture (%)	Protein (%)	Lipid (%)	Amylose content (%)	Total starch (%)
CHI	12.45±0.05^{b}	6.75±0.07^{c}	0.13±0.03^{b}	23.30±0.21^{b}	85.88±0.92^{b}
SU	10.49±0.09^{c}	8.32±0.04^{a}	3.64±0.00^{a}	7.13±0.07^{d}	72.11±0.40^{d}
FCHI	12.70±0.12^{a}	4.36±0.34^{d}	0.05±0.00^{c}	25.36±0.54^{a}	88.82±0.22^{a}
FSU	10.31±0.07^{d}	7.88±0.28^{b}	3.65±0.04^{a}	9.46±0.21^{c}	76.75±0.04^{c}

The means with different small letters in the same column were significantly different (p<0.05)

4.2 The pH value and color of rice and fermented rice flours

The pH of raw rice (CHI and SU) significantly decreased after fermentation (p<0.05). Results indicated that fermentation caused an increase in lactic acid. This result concurred with Park et al. (2020) who found that increasing the amount of organic acid rapidly produced during fermentation resulted in a decrease in pH value. The acid produced ranged from 0.26 mg/g after 12 hours of fermentation to 9.06 mg/g after 72 hours of fermentation. The pH value of fermented rice flours obtained in this study was close to the Thai Industrial Standards Institute, which is in the range of 3.0- 4.5 for fermented rice flour (TISI 499, 2004). The pH value of FSU was lower than FCHI (3.97 and 4.24). It might be caused by the ability of lactic acid produced from native microorganisms presented in different rice varieties. The raw rice and fermented rice flours showed significant (p<0.05) differences in color values (Tables 2). A significantly increased lightness (*L**) of FCHI and FSU flour was observed compared to CHI and SU flour. Redness (*a**) of FSU flour was significantly higher than that of unfermented flour (SU). Yellowness (*b**) of CHI and SU was higher than FCHI and FSU flour.

Table 2 The pH value and color of rice and fermented rice flours

Sample	pH value	Color		
		L*	***a****	***b****
CHI	5.94±0.01^{b}	97.70±0.29^{b}	0.00±0.00^{c}	5.03±0.09^{a}
SU	6.32±0.01^{a}	58.90±0.09^{d}	5.30±0.00^{b}	3.50±0.00^{b}
FCHI	4.24±0.01^{c}	101.28±0.28^{a}	-0.13±0.05^{d}	2.49±0.03^{d}
FSU	3.97±0.01^{d}	72.19±0.23^{c}	5.94±0.05^{a}	2.93±0.05^{c}

Means with different letters in the same column are significantly different (p<0.05)

4.3 The pasting properties of rice and fermented rice flours

As presented in Tables 3, for all samples, the viscosity increased over the heating, then decreased during the heating state at 95°C, and finally re-increased during cooling. The PV of SU flour was higher than CHI flour (p<0.05) showing that the SU sample had high viscosity with high swollen starch granule. Both fermented rice flours had high PV values compared to unfermented rice flour, which was attributed to enzymatic hydrolysis of protein on the surface of starch leading to purification of starch granules (Matthews et al., 2004). The growth of microorganisms or acid produced by lactic acid bacteria could hydrolyze the amorphous regions of starch granules thereby leaving an increased proportion of crystalline structure in the starch granules. This greater proportion of crystalline region absorbed more heat, and consequently increased the viscosity (Lu et al., 2005).

Breakdown (BD) indicates the ability of starch granules to withstand heating at high shear stress and high temperature. The breakdown value of CHI flour was lower than SU flour. The low amylopectin content of CHI rice contains double helices arranged between molecules via hydrogen bonds forming a crystalline structure that lowers breakdown values. The BD values of both flours after fermentation were higher than raw rice flours due to the proportion of crystalline increased.

Setback (SB) indicates reassociation or retrogradation of starch. SB values of SU were lower than CHI, indicating low retrogradation of SU sample that was caused by the rearrangement of low leached amylose molecules (Boonmeejoy, Wichaphon, & Jiamyangyuen, 2019). The FCHI flours after fermentation had a higher setback value compared to raw rice flours due to an increase in amylose content after the structure of amylopectin was hydrolyzed. SU flour after fermentation had lower SB values. Shearing and heating caused the starch structure of the low amylose rice flour to be easily disrupted (Jeong, Kim, Yoon, & Lee, 2017).

Table 3 Pasting profiles of rice and fermented rice flours

Samples	PV (cP)	TV (cP)	BD (cP)	FV (cP)	SB (cP)	PaT (°C)
CHI	934.80±8.79^{d}	792.00±6.08^{c}	143.00±3.54^{d}	1,664.40±12.52^{c}	729.60±11.99^{b}	91.35±0.85^{a}
SU	1,456±16.53^{c}	778.00±5.20^{d}	672.60±16.21^{b}	1,800±15.94^{b}	343.80±15.32^{c}	90.18±0.43^{b}
FCHI	2,144±11.42^{b}	1,467.67±11.37^{a}	648.00±8.97^{c}	3,150.40±6.99^{a}	1,020.20±22.83^{a}	89.89±0.04^{b}
FSU	2,292±12.25^{a}	917.00±1.00^{b}	1,368.20±7.69^{a}	1,353.00±8.46^{d}	-939.00±5.43^{d}	78.42±0.41^{c}

Means with different letters in the same column are significantly different (p<0.05)

4.4 The pH value, color, and texture properties of rice noodles

The substitution of FSU flour affected the pH of rice noodles. Increasing levels of FSU flour substituted from 0 to 30% decreased the pH of rice noodles from 6.12 to 4.98 due to the high acidity of FSU flour (Tables 4). An increasing level of FSU flour substitution significantly decreased lightness and increased redness and yellowness of rice noodles (p<0.05) owing to the purple-dark color of Mali Nil Surin rice.

Textural parameters (hardness and adhesiveness) of rice noodles are shown in Tables 4. Significantly decreased (P<0.05) in the hardness and adhesiveness of rice noodles was observed as levels of FSU flour substitution increased. The result was consistent with the setback and pasting temperature value. The reduction of amylose content by FSU flour replacement affects the arrangement of the starch structure after cooling.

Table 4 The pH value, color and texture properties of rice noodles

Determination/sample	R0	R10	R20	R30
pH value	6.12±0.00^{a}	5.58±0.01^{b}	5.05±0.00^{c}	4.98±0.00^{d}
*L**	70.61 ± 0.32 ^{a}	42.25 ± 0.15^{b}	31.61 ± 0.23^{c}	25.61 ± 0.23^{d}
*a**	-2.15 ± 0.05^{d}	5.90 ± 0.00^{c}	7.88 ± 0.06^{b}	8.90 ± 0.07 ^{a}
*b**	0.91 ± 0.03^{d}	0.96 ± 0.07^{c}	1.68 ± 0.06^{b}	2.15 ± 0.05 ^{a}
Hardness (g force)	839.44 ± 99.40^{a}	611.71 ± 81.18^{b}	377.47 ± 106.40^{c}	138.59 ± 17.22^{d}
Adhesiveness (g.cm)	32.95±3.19^{a}	26.36±2.53^{b}	16.84±3.42^{c}	9.80±2.17^{d}

Means with different letters in the same row are significantly different (p<0.05)

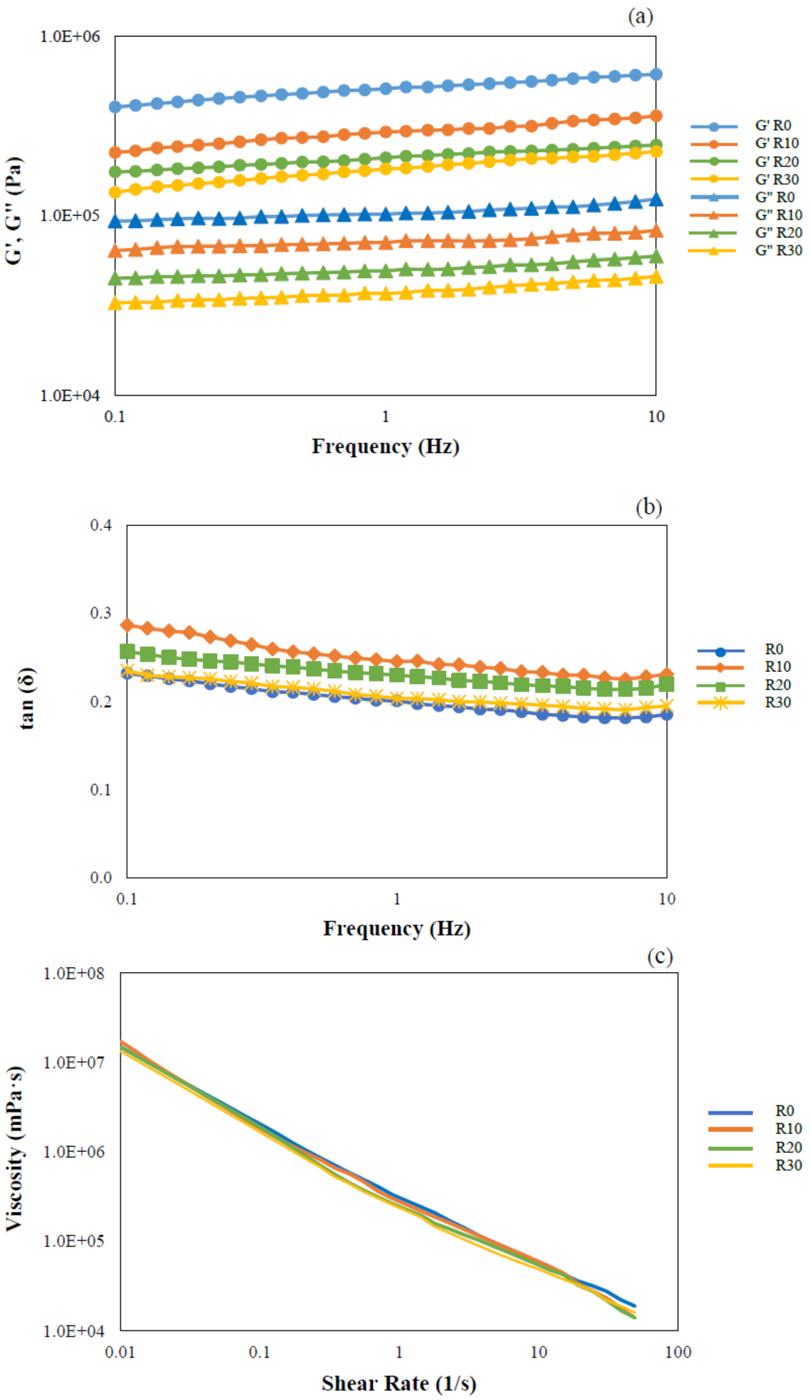

Figure 1 Viscoelastic (a, b) and viscosity (c) properties of rice noodle pastes with different levels of fermented Mali Nil Surin rice flour substitute

The effects of FSU replacement on the rheological properties of fermented rice noodles paste were investigated in terms of dynamic viscoelasticity and viscosity. As presented in Figure 1 (a), the storage (G′) and loss (G″) moduli tended to increase with increasing frequency for all the paste samples. The paste samples had higher values of G′ than those of G″ over the tested frequency, indicating that elastic properties were predominant (Oh & Lee, 2020). However, when the rice noodles were replaced with FSU, both moduli decreased as the levels of FSU increased. It may be caused by the low amylose of FSU. The paste samples showed a weak gel-like characteristic (Park, Oh, Park, Ryu, & Lee, 2019). Besides, a decrease in both moduli of rice noodle pastes might occur from amylose content in raw rice and fermented rice flours. Jeong et al. (2017) studied the effect of zein on the mixing properties of rice doughs with different amylose content and found that mixtures of high amylose rice with zein showed higher storage moduli than those from low amylose rice. The result indicated that amylose positively affected the formation of the strong structure. Loss tangent (tan δ) of all samples was lower than 1 represented the predominance of an elastic component.

All paste samples had similar viscosity patterns, the viscosity decreased with increasing shear rate showing rheological behavior of Non-Newtonian type and exhibiting shear-thinning (Pseudoplastic) characteristics (Figure 1, (c)). The final viscosity was lower than viscosity during the initial shearing, indicating that some network structure is being shear-degraded (Inglett, Peterson, Carriere, & Maneepun, 2005).

4.5 The total phenolic content and antioxidant activity of rice, fermented rice flours, and rice noodles

The total phenolic content (TPC) of rice, fermented rice flours, and rice noodles are presented in Tables 5. The SU and FSU flour contained high amounts of total phenolic content compared to CHI and FCHI flour. Reduction in TPC after fermentation was observed in SU flour. A decreased in TPC caused by processing steps included soaking, fermenting, and drying. Besides, anthocyanins that are the major phenolic compounds found in rice can dissolve easily in water even they are stable at a low pH (Barczak, 2005). The TPC of rice noodles tended to increase as the levels of FSU substitution increased.

The antioxidant capacity included DPPH radical scavenging and FRAP assay are displayed in Tables 5. DPPH radical scavenging of FCHI was lower than CHI (8.47 to 10.98 mg Trolox equivalent/100 g, respectively). In contrast, the DPPH value of FSU was higher than SU (37.12 and 31.52 mg Trolox equivalent/100 g, respectively). The increase in DPPH value after fermentation may be caused by the stability of anthocyanins, as antioxidants, at low pH. For rice noodles, the DPPH value significantly increased with an increasing amount of FSU substitution from 0 to 30 %. For the FRAP assay, the result showed that the FRAP value of both rice varieties decreased after the fermentation process, indicating that some bioactive compounds were lost during fermentation. Replacement of FSU in the rice noodles tended to increase FRAP value from 29.19 to 49.33 mg Trolox equivalent per 100 g dry weight of the sample.

Table 5 Total phenolic content and antioxidant activity of rice, fermented rice flours and rice noodles

Sample	**Total phenolic content (mg Gallic acid equivalent/100g DW)**	**DPPH scavenging activity (mg Trolox equivalent/100g DW)**	**FRAP assay (mg Trolox equivalent/100g DW)**
CHI	30.60±0.07[c]	10.98±0.30[e]	49.02±1.42[c]
SU	853.81±29.15[a]	31.52±0.06[b]	1,405.44±113.62[a]
FCHI	52.41±2.19[c]	8.47±0.45[f]	18.76±0.54[c]
FSU	472.64±13.51[b]	37.12±0.38[a]	601.55±20.63[b]
R0	31.04±0.83[c]	6.52±0.28[g]	13.92±0.30[c]
R10	34.00±0.91[c]	12.04±0.17[d]	29.19±1.34[c]
R20	49.54±0.58[c]	12.63±0.10[c]	45.38±1.77[c]
R30	49.15±0.88[c]	13.03±0.03[c]	49.33±1.82[c]

Means with different letters in the same column are significantly different ($p<0.05$)

5. Conclusion

Production of fermented rice flour and fermented rice noodles from Mali Nil Surin rice variety was studied. The fermentation process affected the properties of flour and rice noodles. The protein content of flour decreased, while amylose and total starch increased. The fermented rice flours had high peak viscosity, trough, breakdown, final viscosity, and setback compared with unfermented rice flours. Storage modulus (G′) of rice noodle paste decreased when increasing level of FSU flour substitution and G′ of all paste samples were higher than G″ (loss modulus). Replacement of FCHI with FSU reduced the hardness and adhesiveness of rice noodles. FSU flour substitution increased antioxidants activity and phenolic compounds of rice noodles. However, the proportion of replacing FSU flour or some food additive addition to improving texture in fermented rice noodles should be further investigated.

6. Acknowledgements

The author would like to thank the office of the Ministry of Higher Education, Science, Research and Innovation for providing financial support for this project that was coordinated by Naresuan University (R2563A072).

7. References

AACC, 2000, Determination of the Pasting of Rice with the Rapid Visco Analyzer, In AACC, International Approved Methods of Analysis, 11th ed. AACC International, Saint Paul, MN: US.

Abdel-Aal, E.-S. M., Young, J. C., & Rabalski, I. (2006). Anthocyanin composition in black, blue, pink, purple and red cereal grains. *Journal of Agricultural and Food Chemistry*, *54*(13), 4696-4704.

AOAC. 2005. *Official Methods of Analysis of the Association of Official Analytical Chemists.* 18th Ed., Washington DC: USA.

Barczak, A. B. (2005). Acylated anthocyanins as stable, natural food colorants–a review. *Polish Journal of Food and Nutrition Sciences*, *14*(2), 107-116.

Boonmeejoy, J., Wichaphon, J., & Jiamyangyuen, S. (2019). Classification of rice cultivars by using chemical, physicochemical, thermal, hydration properties and cooking quality. *Food and Applied Bioscience Journal*, *7*(2), 42-62.

Chakuton, K., Puangpronpitag, D., & Nakornriab, M. (2012). Physicochemical content and antioxidant activity of colored and non-colored Thai rice cultivars. *Asian Journal of Plant Sciences*, *11*(6), 285-293.

Deng, G. F., Xu, X. R., Zhang, Y., Li, D., Gan, R. Y., & Li, H. B. (2013). Phenolic compounds and bioactivities of pigmented rice. *Critical Reviews in Food Science and Nutrition*, *53*(3), 296-306. doi: 10.1080/10408398.2010.529624.

Falleh, H., Ksouri, R., Lucchessi, M. E., Abdelly, C., & Magné, C. (2012). Ultrasound-assisted extraction: effect of extraction time and solvent power on the levels of polyphenols and antioxidant Activity of *Mesembryanthemum edule* L. Aizoaceae Shoots. *Tropical Journal of Pharmaceutical Research*, *11*(2). doi: 10.4314/tjpr.v11i2.10.

Frank, T., Reichardt, B., Shu, Q., & Engel, K.-H. (2012). Metabolite profiling of colored rice (*Oryza sativa* L.) grains. *Journal of Cereal Science*, *55*(2), 112-119. doi: 10.1016/j.jcs.2011.09.009.

Gibson, T. S., Solah, V. A., & McCleary, B. V. (1997). A Procedure to measure amylose in cereal starches and flours with concanavalin A. *Journal of Cereal Science*, *25*, 111-119.

Inglett, G. E., Peterson, S. C., Carriere, C. J., & Maneepun, S. (2005). Rheological, textural, and sensory properties of Asian noodles containing an oat cereal hydrocolloid. *Food Chemistry*, *90*(1-2), 1-8. doi: 10.1016/j.foodchem.2003.08.023.

Jeong, S., Kim, M., Yoon, M. R., & Lee, S. (2017). Preparation and characterization of gluten-free sheeted doughs and noodles with zein and rice flour containing different amylose contents. *Journal of Cereal Science*, *75*, 138-142. doi: 10.1016/j.jcs.2017.03.022.

Keatkrai, J., & Jirapakkul, W. (2010). Volatile profile of *khanom jeen*, Thai fermented rice noodles and the changes during the fermentation process. *ScienceAsia*, *36*(1), 46-51. doi: 10.2306/scienceasia1513-1874.2010.36.046.

Laleh, G. H., Frydoonfar, H., Heidary, R., Jameei, R., & Zara, S. (2006). The effect of light, temperature, pH and species on stability of anthocyanin pigments in four *Berberis* species. *Pakistan Journal of Nutrition*, *5*(1), 90-92.

Laokuldilok, T., Shoemaker, C. F., Jongkaewwattana, S., & Tulyathan, V. (2011). Antioxidants and antioxidant activity of several pigmented rice brans. *Journal of Agricultural and Food Chemistry*, *59*(1), 193-199. doi: 10.1021/jf103649q.

Li, W., Corke, H., & Beta, T. (2007). Kinetics of hydrolysis and changes in amylose content during preparation of microcrystalline starch from high-amylose maize starches. *Carbohydrate Polymers*, *69*(2), 398-405. doi: 10.1016/j.carbpol.2006.12.022.

Lu, Z.-H., Li, L.-T., Min, W.-H., Wang, F., & Tatsumi, E. (2005). The effects of natural fermentation on the physical properties of rice flour and the rheological characteristics of rice noodles. *International Journal of Food Science and Technology*, *40*(9), 985-992.

Lu, Z. H., Li, L. T., Cao, W., Li, Z. G., & Tatsumi, E. (2003). Influence of natural fermentation on physico-chemical characteristics of rice noodles. *International Journal of Food Science and Technology*, *38*, 505-510.

Lu, Z. H., Yuan, M. L., Sasaki, T., Li, L. T., & Kohyama, K. (2007). Rheological Properties of Fermented Rice Flour Gel. *Cereal Chem*, *84*(6), 620-625.

Matthews, A., Grimaldi, A., Walker, M., Bartowsky, E., Grbin, P., & Jiranek, V. (2004). Lactic acid bacteria as a potential source of enzymes for use in vinification. *Applied and Environmental Microbiology*, *70*(10), 5715-5731. doi: 10.1128/AEM.70.10.5715-5731.2004.

Nout, M. J. (2009). Rich nutrition from the poorest-cereal fermentations in Africa and Asia. *Food Microbiol*, *26*(7), 685-692. doi: 10.1016/j.fm.2009.07.002.

Oh, I., & Lee, S. (2020). Rheological, microstructural and tomographical studies on the rehydration improvement of hot air-dried noodles with oleogel. *Journal of Food Engineering*, *268*. doi: 10.1016/j.jfoodeng.2019.109750

Park, J., Sung, J. M., Choi, Y.-S., & Park, J.-D. (2020). Effect of natural fermentation on milled rice grains: Physicochemical and functional properties of rice flour. *Food Hydrocolloids*, *108*, 1-10. doi: 10.1016/j.foodhyd.2020.106005.

Park, Y., Oh, I. K., Park, S. W., Ryu, K., & Lee, S. (2019). Elucidation of rheological, microstructural, water mobility, and noodle-making properties of rice flour affected by turanose. *Food Chem*, *276*, 9-14. doi: 10.1016/j.foodchem.2018.09.168.

Riker, C., & Fujibayashi, K. (2017). *Rice Flour Standards and Labelling Guidelines Established*. Japan: USDA Foreign Agricultural Service.

Saiyot, A. *e. a.* (2017). Mali Nil Surin (Mali Dam 2), a non-glutinous rice variety. *Thai Rice Research Journal*, *8*(2), 8-25.

Shao, Y., Xu, F., Sun, X., Bao, J., & Beta, T. (2014). Identification and quantification of phenolic acids and anthocyanins as antioxidants in bran, embryo and endosperm of white, red and black rice kernels (*Oryza sativa* L.). *Journal of Cereal Science*, *59*(2), 211-218. doi: 10.1016/j.jcs.2014.01.004.

Shipp, J., & Abdel-Aal, E.-S. M. (2010). Food applications and physiological effects of anthocyanins as functional food ingredients. *The Open Food Science Journal*, *4*, 7-22.

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 Chemistry*, *124*(1), 132-140. doi: 10.1016/j.foodchem.2010.05.115.

Takeda, Y., & Hizukuri, S. (1987). Structures of rice amylopectins with low and high affinities for iodine. *Carbohydrate Research*, *168*, 79-88.

Thuengtung, S., Niwat, C., Tamura, M., & Ogawa, Y. (2018). In vitro examination of starch digestibility and changes in antioxidant activities of selected cooked pigmented rice. *Food Bioscience*, *23*, 129-136. doi: 10.1016/j.fbio.2017.12.014.

Thai Industrial Standards Institute. 2004. *Rice Noodles Flour*. TISI. 499/2004.

Udomrati, S., Satmalee, P., & Surojanametakul, V. (2015). Application of Fermented and Hydrothermal Treated Rice Flour to Increase Resistant Starch in Rice Vermicelli (*Kanom-jeen*). *Thai Science and Technology Journal 23*(3), 507-516.

Yeoh, S.-Y., Alkarkhi, A. F. M., & Easa, A. M. (2014). Effect of cross-linking agents on physicochemical, textural properties and microstructure of canned soy protein isolate-yellow alkaline noodles prepared by retort processing. *Journal of Food Processing and Preservation*, *38*(3), 1187-1197. doi: 10.1111/jfpp.12079.

Yoshida, H., Tomiyama, Y., & Mizushina, Y. (2010). Lipid components, fatty acids and triacylglycerol molecular species of black and red rices. *Food Chemistry*, *123*(2), 210-215. doi: 10.1016/ j.foodchem.2010.04.010.

Zang, J., Xu, Y., Xia, W., Yu, D., Gao, P., Jiang, Q., & Yang, F. (2018). Dynamics and diversity of microbial community succession during fermentation of Suan yu, a Chinese traditional fermented fish, determined by high throughput sequencing. *Food Research International*, *111*, 565-573. doi: 10.1016/j.foodres.2018.05.076.