Effect of Flour Concentration and Retrogradation Treatment on Physical Properties of Instant Sinlek Brown Rice

Supat Chaiyakul, Direk Sukkasem, Patnachapa Natthapanpaisith

Abstract**—**Sinlek rice flour beverage or instant product is a dietary supplement for dysphagia, or difficulty swallowing. It is also consumed by individuals who need to consume supplements to maintain their calorific needs. This product provides protein, fat, iron, and a high concentration of carbohydrate from rice flour. However, the application of native flour is limited due to its high viscosity. Starch modification by controlling starch retrogradation was used in this study. The research studies the effects of rice flour concentration and retrogradation treatment on the physical properties of instant Sinlek brown rice. The native rice flour, gelatinized rice flour, and flour gels retrograded under 4 °C for 3 and 7 days were investigated. From the statistical results, significant differences between native and retrograded flour were observed. The concentration of rice flour was the main factor influencing the swelling power, solubility, and pasting properties. With the increase in rice flour content from 10 to 15%, swelling power, peak viscosity, trough, and final viscosity decreased; but, solubility, pasting temperature, peak time, breakdown, and setback increased. The peak time, pasting temperature, peak viscosity, trough, and final viscosity decreased as the storage period increased from 3 to 7 days. The retrograded rice flour powders had lower pasting temperature, peak viscosity, breakdown, and final viscosity than the gelatinized and native flour powders. Reduction of starch viscosity by gelatinization and controlling starch retrogradation could allow for increased quantities of rice flour in instant rice beverages. Also, the treatment could increase the energy and nutrient densities of rice beverages without affecting the viscosity of this product.

Keywords**—**Instant rice, pasting properties, pregelatinization, retrogradation.

I. Introduction

SINLEK brown rice (Thai rice varieties No.310-19-1-1) is a with relatively low amylose content (18%) has the durable genomic resources of Thai rice. It has high in iron (2.1-2.8 mg/100 g edible portions) and antioxidants which reduce the risk of diabetes. Nutrient analysis of Sinlek rice indicates that it is a good source of phenolic compounds, unsaturated fatty acid, folate, zinc, gamma oryzanol, vitamin E, carbohydrate, dietary fiber, and iron. It also has a low glycemic index. The phytochemical compounds of Sinlek rice have been shown to exert a wide range of biological activities for instance, anti-hyperlipidemia, anti-atherogenesis, anti-platelet aggregation, and antioxidant properties [1], [2] which have been reported to decrease total cholesterol levels, control blood glucose, and reduce the risk of cardiovascular disease in type 2 diabetic patients [3], [4]. The health benefit of Sinlek brown rice and the growing market for rice beverages make the development of this product attractive. The physicochemical properties, sensory characteristics and nutrition values of Sinlek brown rice beverage were adjusted with added sugar, lipid, protein, vitamins, minerals, stabilizer, and flavor. It is suitable for people with lactose intolerance, gluten allergy and dysphagia, or difficulty swallowing. It is still crucial to use rice flour in beverages in order to get similar texture quality in addition to high nutrients. Native Sinlek brown rice flour is highly suitable to use in food systems, but limitations such as high shear resistance and viscosity limit its use in food beverage applications.

Starch modification, which involves the alteration of the physical and chemical characteristics of the native starch to improve its functional characteristics, can be used to tailor starch to specific food applications [5]. On heating in water, crystallites in the granules melt and amylose is solubilized. The granules swell and form gel particles. Gelatinization has been defined as phase transition of starch granules from an ordered state to a disordered state, which takes place during heating in excess water. This transition always involves loss of crystallinity, loss of the anisotropic order (birefringence) and hydration of the starch [6], [7]. The term retrogradation is the process in which a flour or starch suspension is cooled below the melting temperature of starch crystallites, molecular reassociations and storage of gelatinized starch molecules to form an ordered structure [8]-[10]. Starch changes from an amorphous state to a crystalline state, and thus this retrogradation process includes a recrystallization [11]. The retrogradation rate is affected by the inherent starch properties, molecular and crystalline structure, molecular structure [12], concentration [13], presence of non-starch components (e.g., salts, saccharides, lipids, and hydrocolloids) [14], and storage conditions (e.g. temperature, time and water content) [15]. Its occurrence could reduce viscosity and also increase the resistance of starch to digestive enzymes and consequently reduce the glycemic index value [16]-[19]. The relationship between flour concentration and starch retrogradation condition and viscosity properties of rice flour are still not very clear. Therefore, the effects of rice flour concentration and retrogradation treatment on the swelling power, solubility, and pasting properties of tray dried rice powders prepared

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from the Sinlek brown rice variety were studied.

II. Materials and Methods

A. Materials and Sample Preparation

Sinlek brown rice (harvested in 2015) was purchased from Rice Gene Disocvery and Rice Science Center Unit (RGD&RSC), Kasetsart University, Kamphaeng Saen Campus, Thailand. It was ground to flour in a grinder and sieved through a sieve (177 µm), packed in plastic bags, vacuum sealed and stored at -18 °C for further use.

B. Preparation of Instant Sinlek Brown Rice

The Sinlek brown rice flour was mixed with distilled water in order to give a 10 and 15% flour concentration. The flour suspended in a capped container was heated in a shaking water bath at 50 to 90 °C for 1 minute, held for 12 minutes then immediately cooled down to 40 °C. For retrogradation treatment, the gelatinized flour was cooled down to 4 °C and stored at this temperature for 3 and 7 days. The flour gel was poured onto a drying tray layered with a Teflon sheet (thickness 3 mm). The sheet was dried in a conventional oven (Model 400, Memmert GmbH + Co., Germany) at 60 °C until the moisture content of the flour was 5-6%. The dried flour was ground into powder and was passed through a sieve (177 µm) packed in plastic bags, vacuum sealed and stored at -18 °C until further use.

C. Swelling and Solubility Properties

Flour swelling power and solubility of the samples were determined according to [20]. 0.5 g flour solid was mixed with 15 ml distilled water and then heated in a shaking water bath at 65 and 85 ºC for 30 minutes. The samples were cooled and centrifuged at 5000 x g for 15 minutes. The supernatant was poured into an aluminum dish and dried overnight at 130 ºC and weighed. The swelling power was the ratio of the weight of the wet sediment to the initial weight of dried flour. Solubility was the ratio of the weight of the dried supernatant to the initial weight of the dried flour.

D. Pasting Properties

Pasting properties of the flour samples were analyzed using a Rapid Visco Analyser RVA-4 (Newport Scientific, Warriewood, Australia) [21]. RVA tests were performed with around 3 g flour solid and approximately 25 ml of distilled water (corrected to 14% moisture content). After the canister was fitted to the device, the operations were run based on the approved profile. Each sample was held at 50 °C for 1 minute, heated to 95 °C at 12 °C per minute, held for 2.5 minutes, cooled down to 50 °C at 12°C per minute, and held at 50 °C for 1.5 minutes. The total elapsed time was 12.5 minutes. The RVA measures pasting temperature and viscosity profile.

E. Experimental Design and Data Analysis

The experimental design was based on a 2x3 factorial design. The independent variables considered in this study were flour concentration (X_1) and retrogradation treatment (X_2). All measurements were performed in triplicate. The data were subjected to analysis of variance (ANOVA) using a general linear model procedure, SPSS for Windows version 18.0 (SPSS Inc., USA). Mean comparison was performed using Duncan's multiple range test. Response surface methodology was used to determine the effects of flour concentration and retrogradation treatment on pasting properties by generating a second-order polynomial equation (1) [22]:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{22} x_2^2 \qquad (1)$$

where Y represents the experimental response, β_0, β_1, β_2, β_{12} and β_{22} are coefficients of intercept, linear, interactive and quadratic effects, respectively and x_1 and x_2 are independent variables.

A Pearson's correlation matrix on product properties was carried out using SPSS in order to determine correlation coefficients between parameters.

III. Results and Discussion

A. Swelling and Solubility Properties

The rice flour sample from every condition had high swelling power when compared with native Sinlek rice flour (1.52-2.78%). Native flour cannot dissolve in water when the temperature is lower than the gelatinization temperature, because flour has hydrogen bonds in between the hydroxyl group of each starch granules. When the temperature is higher than the gelatinization temperature, the hydrogen bonds will break, so water molecules can bond with a free hydroxyl group. Starch granules will swell, and then flour can be soluble, become clearer and has higher viscosity [10], [11]. Therefore, the flour suspension was heated at 90 °C for 12 minutes, which is higher than the gelatinization temperature (87-89 ºC), hence it could disperse in water and instantly raise viscosity at 65 °C (Table I).

TABLE I
Swelling Power and Solubility of Instant Sinlek Brown Rice

Flours	Swelling power (%)		Solubility(g/g)	
	65 °C	85 °C	65 °C	85 °C
Gelatinized 10%	10.30 ± 0.37^a	11.23 ± 0.25^a	5.59 ± 0.05^c	11.73 ± 0.27^b
15 %	10.29 ± 0.58^a	10.79 ± 0.31^a	8.55 ± 0.33^a	14.26 ± 0.18^a
Retrograted at 4 °C 10%, 3day	10.75 ± 0.42^a	10.85 ± 0.14^a	4.44 ± 0.02^d	11.51 ± 0.13^b
10%, 7day	11.85 ± 0.73^a	11.25 ± 0.20^a	4.32 ± 0.09^d	8.98 ± 0.15^c
15%, 3day	9.19 ± 0.38^b	9.19 ± 0.22^b	7.47 ± 0.03^b	12.75 ± 0.12^b
15%, 7day	9.12 ± 0.13^b	9.12 ± 0.26^b	7.56 ± 0.20^b	11.54 ± 0.14^b

Means in the same column with different letters are significantly different ($p \leq 0.05$).

The results showed that the swelling powers of gelatinized rice flours chilled at 4 °C for different times were not significantly different. However, retrogradation treatment significantly decreased the swelling power of 15% instant rice flour samples. Lan et al. reported that the decrease in swelling power of treated flour could be attributed to increased crystallite perfection and to additional interaction between amylose-amylose chains and/or amylose-amylopectin chains

[24]. In the present work, swelling power of all samples was not different with the different temperatures tested (65 °C or 85 °C). The 10% gelatinized flour stored at 4 °C for 3 and 7 days had significantly higher swelling power than the 15% gelatinized flour that was stored under the same conditions. This may be due to the ratio of amylose to water, amylose solubilized during gelatinization and amylose recrystallization within the gelatinized granules which takes place on cooling and during storage. The amylose inhibits swelling. One proposed mechanism could be that cereal starch granules do not show complete swelling until amylose has been leached out of the granule [25]-[27]. The solubility of instant rice flours significantly increased with increasing flour concentration. Retrogradation treatment reduced the solubility of all samples. This is in agreement with results of [23]. They reported that the decrease in starch solubility with treatment can be attributed to an internal rearrangement of starch granules that provides higher interaction between starch functional groups, the formation of more ordered amylopectin clusters, and the formation of amylose-lipid complexes within starch granules [23], [28]. However, solubility was not significantly different when stored at 4 °C for 3 and 7 days. The results conclude that the swelling power and solubility of gelatinized flour at 65 °C was not significantly different between controlled paste storage times. The solubility of all samples increased with increasing temperature. Slight granule solubility was found for 10% gelatinized flour after heating to 65 °C, while most granules can be soluble after heating to 70 °C and fully soluble at temperatures above 85 °C.

B. Pasting Properties

Pasting viscosities of the gelatinized and retrograded rice flour under different conditions are shown in Fig. 1. Native rice flour had a peak viscosity 1930±31.11 cP, trough 1545.50±12.02 cP, breakdown 392.50±19.09 cP, final viscosity 3392.02±28.28 cP, and setback 1846.50±16.26 cP, which were higher than gelatinized-retorgraded rice flour (Fig. 1). The result showed that 10% flour concentration in all treatments had significantly lower pasting temperatures than native rice flour. This is due to the gelatinized rice flour swelling more readily than native flour, resulting in a lower pasting temperature that is due to the ability of starch to entrap water. However, the pasting temperatures of 15% gelatinized flour stored at 4 °C for 3 and 7 days were significantly higher than for native rice flour. This can be attributed to the fact that 15% rice flour samples are more resistant to shearing and cooking than native rice flour and 10% rice flour samples; in other words, 15% rice flour samples have higher granular rigidity than do native rice flour and 10% rice flour samples, which is in agreement with the results of the effect of flour concentration on starch swelling. It appears that the swelling power of 10% rice flour and native rice flour was higher than 15% rice flour, indicating high water absorption during pasting. Pasting parameters of starch slurry during heating have been proposed to be related to properties of swelling power/solubility [29], or properties of the swollen granules and soluble materials of starch [30]. Retrogradation treatment at 4 °C tends to increase the region of crystallinity, as a result of reorientation of the starch granules [23]. The strengthening of intragranular bonded forces allows the starch to absorb more heat before structural disruption and paste formation takes place [31]. The peak time, peak viscosity, and final viscosity of gelatinized flour chilled at 4 °C decreased significantly from 3 to 7 days. These results were similar for the waxy maize starch gels and sweet potato starches [15], [32]. In fact, the same trends were observed. The increased level of recrystallization by extending storage time might give the adverse effect of hindering the swelling of starch powders. There was a significant interaction between flour concentration and retrogradation treatment on pasting properties.

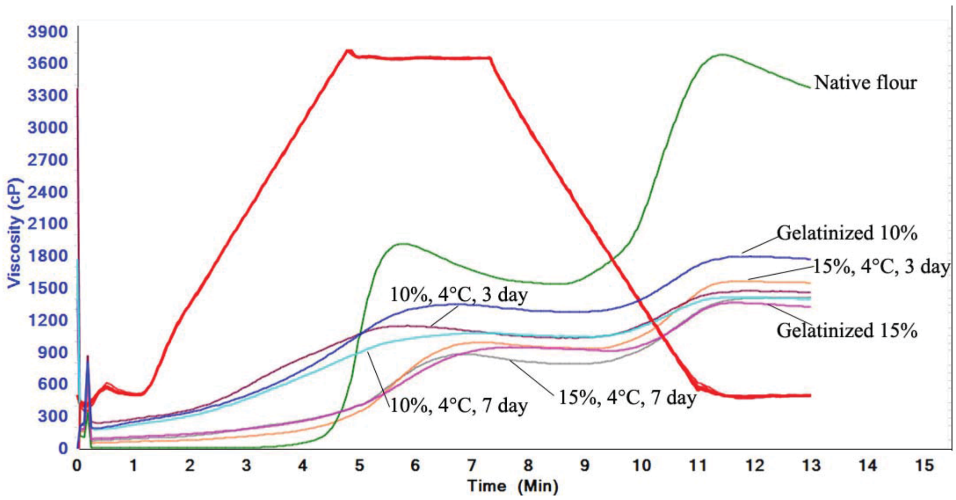
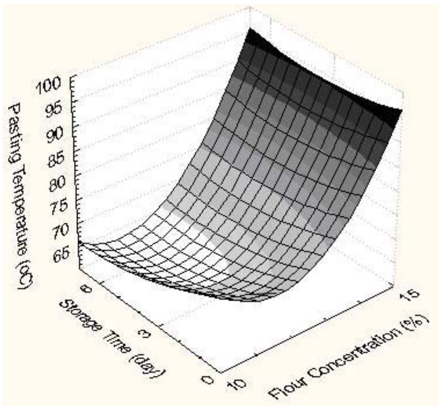


Fig. 1 Pasting viscosity of gelatinized and retrograded rice flour gels

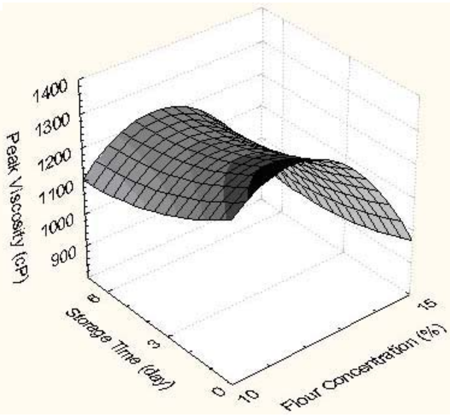
Multiple linear regression equations were generated relating pasting properties to coded levels of the variables. Models were developed as in Table II. All main effects, linear and quadratic, and interaction of effects were calculated for each model. From the values of regression coefficient, we observed that the flour concentration and paste storage time had a significantly positive or negative effect on pasting properties. The flour concentration had a negative correlation with the peak viscosity, trough, and final viscosity but positive correlation with pasting temperature, peak time, breakdown and setback viscosity. By contrast, retrogradation treatment had a negative correlation with pasting temperature, peak time, peak viscosity, trough, and final viscosity. The large differences in pasting properties were considered sufficient to allow a valid analysis of the correlation coefficient using a multiple linear regression equation. Flour concentration had a greater influence than storage time on pasting temperature, peak viscosity, trough, and setback viscosity.

TABLE II
THE LINER REGRESSION MODELS FOR PASTING PROPERTIES USING INDEPENDENT VARIABLES FLOUR CONCENTRATION (X_1) AND RETROGRADATION TREATMENT (X_2) OF INSTANT SINLEK BROWN RICE

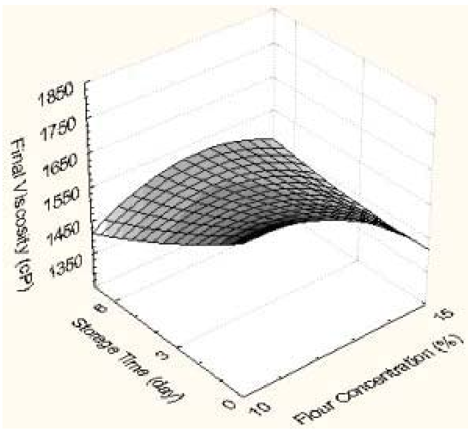
Dependent Variable	Predictive Model	R^2
Pasting temperature	$81.663 + 12.396x_1 - 2.787x_2 + 2.55x_1x_2 + 1.913x_2^2$	0.99
Peak time	$6.915 + 0.26x_1 - 0.258x_2 + 0.192x_1x_2 - 0.357x_2^2$	0.88
Peak viscosity	$1040.5 - 129.25x_1 - 60.875x_2 + 37.625x_1x_2 + 27.875x_2^2$	0.81
Trough	$915 - 173.667x_1 - 53.250x_2 + 70.75x_1x_2$	0.95
Breakdown	$125.5 + 44.417x_1 - 33.125x_1x_2$	0.75
Final viscosity	$1490.5 - 61.5x_1 - 58.75x_2 + 89.75x_1x_2 + 5.5x_2^2$	0.75
Setback from trough	$575.5 + 112.167x_1 + 19.0x_1x_2$	0.81
Setback from peak	$450 + 67.75x_1 + 52.125x_1x_2$	0.89



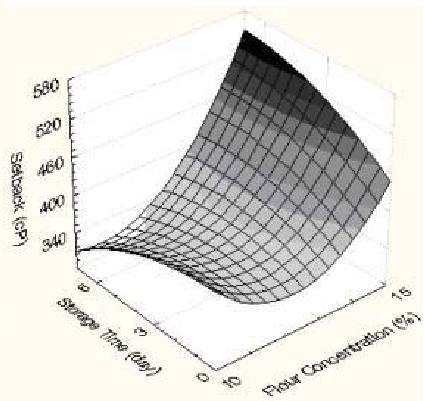
(a)



(b)



(c)



(d)

Fig. 2 Response surface plot for (a) pasting temperature (b) peak viscosity (c) final viscosity and (d) setback as a function of flour concentration and storage time

TABLE III
PEARSON CORRELATION COEFFICIENTS BETWEEN VARIOUS SWELLING POWER, SOLUBILITY AND PASTING PROPERTIES OF INSTANT SINLEK BROWN RICE

	SP65	SP85	SU65	SU85	PST	PT	PV	TR	BD	FV	SB1
SP85	0.685*										
SU65	-0.580*	-0.855**									
SU85	-0.423	-0.650*	0.738**								
PST	-0.674*	-0.888**	0.924**	0.776**							
PT	-0.636*	-0.620*	0.623*	0.706*	0.677*						
PV	0.321	0.819**	-0.685*	-0.689*	-0.667*	-0.435					
TR	0.378	0.852**	-0.730**	-0.681*	-0.759**	-0.417	0.961*				
BD	-0.370	-0.581*	0.542	0.375	0.681*	0.197	-0.456	-0.685*			
FV	-0.115	0.414	-0.318	-0.393	-0.230	-0.129	0.843**	0.755**	-0.209		
SB1	-0.706*	-0.833**	0.755**	0.596*	0.898*	0.490	-0.515	-0.674*	0.809**	-0.025	
SB2	-0.785**	-0.584*	0.736**	0.618*	0.849**	0.587*	-0.442	-0.516	0.494	0.110	0.910**

SP65-swelling power (65°C), SP85-swelling power (85°C),SU65-solubility (65°C), SU85-solubility (85°C), PST-pasting temperature, PT-peak time, PV-peak viscosity, TR-trought viscosity, BD-breakdown, FV-final viscosity, SB1-setback form trough, SB2-setback from peak
* $P < 0.05$
** $P < 0.01$

Predictive models (Table II) were used to graphically represent responses as shown in Figs. 2 (a)-(d). An increase in flour concentration from 10 to 15% tends to increase pasting temperature, peak time, breakdown and setback but decrease peak viscosity, trough and final viscosity of sample. The results from this experiment showed that the peak viscosity, final viscosity and setback decreased as the storage period increased from 3 to 7 days. This is agreement with the finding of [27]. They reported that the viscosity was related to starch retrogradation. Amylose retrogradation and amylopectin retrogradation contributed to the decreased adhesiveness of cooked milled rice during storage. The Pearson correlation coefficients between swelling, solubility, pasting temperature and past viscosity are shown in Table III. The swelling power of instant Sinlek brown rice showed a negative correlation with solubility, pasting temperature, peak time and setback. On the other hand, the swelling power showed a positive correlation with pasting viscosity. These results indicate that swelling of the granules into gel particles results in an increase in viscosity.

IV. CONCLUSION

The flour concentration and retrogradation treatment affect swelling power, solubility and pasting properties of instant Sinlek brown rice. The swelling power of instant rice was negatively correlated with flour concentration. Solubility had a positive correlation with flour concentration. There was interaction between flour concentration and retrogradation treatment on pasting properties. Rice flour can be used as a 15% increase in formula without affecting the viscosity of the product. When flour is modified by gelatinization and storage at 4 °C for 7 days, gelatinized starch molecules reassociate to an ordered structure, and this is referred to as retrogradation. This may provide a way to improve the viscosity and nutritional value of prepared instant rice. Paste storage time and temperature control (4 °C) could be used in starch retrogradation to produce instant Sinlek brown rice, which can improved the sensory quality of rice beverages or imitation milk products made from rice.

ACKNOWLEDGMENT

This work was supported by the Faculty of Public Health, Mahidol University, Thailand. We would also like to thank Dr. Carol Hutchison for her help editing this manuscript.

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