CHAPTER IV
RESULTS AND DISCUSSION

4.1 Chemical components of brown and germinated brown rice flour

Chemical compositions of brown rice and germinated brown rice flour are shown in Table 4.1. ‘Chainat 1’ brown rice contained significantly higher protein and crude fiber than KDML 105 brown rice. KDML 105 brown rice had significantly higher content of ash and carbohydrates than ‘Chainat 1’ brown rice. Fat, GABA and vitamin B1 contents in brown rice of both rice cultivars were not different. Protein and fat content of flour in this study was consistent with previous reports which its content was 7%-9% and below 5%, respectively (155-157). Crude fiber content found in this study was lower than the previous report which contained approximately 0.9% (158). In this study, ash content was higher than previous report by Heinemann, Fagundes, Pinto, Penteado, and Lanfer-Marquez (159) who found that ash of brown rice ranging from 1.15% to 1.29%. Carbohydrate was the most component in brown rice at 84.94-86.01% and was higher than some reports (76.5%) (160). GABA content of both brown rice varieties was in agreement with Srijedsadaruk’s study who reported that GABA content in ‘Chainat 1’ and KDML 105 brown rice was 7-12 mg/100 g (161). In this study Vitamin B1 content was higher than other papers (9, 15). The variation of the chemical contents in brown rice from both cultivars and results from other reports could be explained by the different season, location and cultivars such as water management, fertilizer application, harvesting and storage of rice (162).

After germination, protein, crude fiber, GABA and vitamin B1 of both germinated brown rice cultivars were significantly higher than brown rice. In addition, KDML 105 germinated brown rice also had significantly higher fat content. The increase in protein might attributed to increase several enzymes during germination caused production of some non-structural protein nitrogen such as nucleic acids (132). Crude fiber content increased as a result of the formation of primary cell walls and the increasing of fat in germinated brown rice might be due to a dissociation of lipid complexes (163-164).

Increasing of GABA content caused by glutamate decarboxylase enzyme (GAD), the main enzyme that involved in GABA production. GABA is synthesized from glutamic acid by this enzyme, and during soaking process, GAD becomes activated then glutamic acid converts to GABA (52). Increasing of vitamin B1 content in germinated brown rice can be explained as followed. Vitamin B1 or thiamin consists of pyrimidine and thiazole rings linked by a methylene bridge. Alcohol group of the side chain can be esterified with one to three phosphates, yielding thiamin monophosphate (TMP), thiamin pyrophosphate (TPP) and thiamin triphosphate (TTP).Vitamin B1 consists mainly of thiamine pyrophosphate (TPP), which can be transformed into thiamine by gastrointestinal phosphatases before absorption. During germination, ATP is synthesized, results in occurrence of pyrimidine and thiazole. Thiamine phosphate synthase and thiamine phosphate kinase become activated. These enzymes form TPP (165-166). Thus vitamin B1 content in germinated brown rice was increased. The result was in agreement with previous studies of germinated brown rice and similar to the reports in other cereals i.e. soybeans, cowpea and mung bean (15, 72, 164, 167, 168).

Table 4.1 Chemical components of brown and germinated brown rice flour (dry weight basis)

Flour	Protein (g/100g)	Fat (g/100g)	Crude fiber (g/100g)	Ash (g/100g)	Carbo-hydrates (g/100g)	GABA (mg/100g)	Vitamin B1 (mg/100g)
Chainat 1 BR	9.58^{b} (±0.36)	3.03^{b} (±0.02)	0.31^{c} (±0.07)	1.84^{b} (±0.01)	84.94^{b} (±0.45)	12.88^{c} (±0.70)	0.4440^{b} (±0.57)
Chainat 1 GBR	10.33^{a} (±0.13)	3.09^{b} (±0.08)	0.96^{b} (±0.01)	0.84^{c} (±0.03)	84.79^{b} (±0.24)	27.34^{a} (±3.51)	0.6027^{a} (±0.06)
KDML 105 BR	8.37^{c} (±0.08)	3.25^{b} (±0.04)	0.24^{d} (±0.01)	2.04^{a} (±0.02)	86.10^{a} (±0.02)	10.79^{c} (±0.47)	0.4612^{b} (±0.85)
KDML 105 GBR	9.25^{b} (±0.08)	3.60^{a} (±0.22)	1.26^{a} (±0.05)	0.65^{d} (±0.02)	85.24^{b} (±0.46)	19.54^{b} (±0.44)	0.6448^{a} (±0.33)

BR: Brown rice, GBR: Germinated brown rice, GABA: γ-aminobutyric acid

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.2 shows total phenolic content and antioxidant activity of brown rice and germinated brown rice flour. ‘Chainat 1’ brown rice had significantly higher values of all parameters related with antioxidant activity. Total phenolic content of two rice varieties were higher than previous studies (2 mg GAE/100 g). After germination, total phenolic content and ABTS values of both cultivars were significantly higher than brown rice. DPPH values were significantly increased only in ‘Chainat 1’ germinated brown rice. The increasing of the phenolic compounds could be attributed to the biochemical changes of seeds during germination, which might produce some secondary plant metabolites, such as ferulic, p-coumaric acids and flavonoids (169). The increase of phenolic compounds with the germination process could influence the free radical scavenging capacity resulted in the increasing of antioxidant activity due to three groups of phenolic compounds i.e. hydroxycinnamics, flavones and dihydroflavonols (170). However, Fras et al. (171) also observed that the germination could enhance the antioxidant activity that corresponded to an increase in content of vitamins E and C.

Table 4.2 Total phenolic content, DPPH and ABTS value in brown and germinated brown rice flour (dry weight basis)

Flour	Total phenolic content (mg GAE/100 g)	DPPH (mg VCEAC/100 g)	ABTS (mg TEAC/100 g)
Chainat 1 BR	9.45^{b} (±0.10)	3.68^{b} (±0.37)	22.44^{c} (±0.72)
Chainat 1 GBR	11.34^{a} (±0.04)	4.25^{a} (±0.09)	29.14^{a} (±0.00)
KDML 105 BR	8.68^{d} (±0.04)	2.76^{c} (±0.25)	19.45^{d} (±1.04)
KDML 105 GBR	9.25^{c} (±0.04)	3.05^{c} (±0.29)	24.86^{b} (±0.80)

BR: Brown rice, GBR: Germinated brown rice, DPPH: 1,1-Diphenyl-2-picrylhydrazyl, ABTS: 2,2’-Azinobis-3-ethylbenzothiazo-line-6-sulfonic acid, GAE: Gallic acid equivalents, VCEAC: Vitamin C equivalent antioxidant capacity, TEAC: Trolox equivalent antioxidant capacity

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

4.2 Effects of pregelatinization on chemical properties of germinated brown rice flour

4.2.1 Effects of extrusion on chemical properties of germinated brown rice flour

The changes of protein, GABA and vitamin B1 content in germinated brown rice and pregelatinized flour by single screw extruder are shown in Table 4.3. ‘Chainat 1’ pregelatinized flour had higher protein and GABA contents than KDML 105 pregelatinized flour. KDML 105 pregelatinized flour contained higher vitamin B1 content. However, protein and GABA of pregelatinized flour produced from all conditions were not different from germinated brown rice flour. On the other hand, vitamin B1 content was found significantly decreased in pregelatinized flour produced at the temperature of 80 and 100 °C in all water:flour ratio. The highest reduction of vitamin B1 was found in pregelatinized flour produced at 100 °C.

Table 4.4 shows that variety of rice had significant effect on protein, GABA and vitamin B1 contents of pregelatinized flour. Water:flour ratio and temperature had no significant effect on protein and GABA contents. Temperature had significant negative effect on vitamin B1 content. High temperature effected on the decrease of vitamin B1 content. These results could be explained that the protein was trapped with the compact mass of gelatinized starch grains as report by Otegbayo et. al. (142). In addition, Harmuth-Hoene and Seiler (172) reported that amino acids, the main component of protein, was not damaged under the temperature between 125-165 °C. The temperature of this study (60-100 °C) was lower than previous report, thus amino acids might not be destroyed (172), and protein content in pregelatinized flour remained constantly. The reason that water:flour ratio and temperature did not effect on GABA content might be due to GABA can withstand temperature exceed than 135°C (173). This is in agreement with previous report by Ohtsubo et al. (174), who reported that GABA content of pregelatinized flour heated at 150 °C was not decreased, compared to germinated brown rice. Decreasing of vitamin B1 content as a result of increasing the temperatures (80-100 °C) was due to the high sensitivity to heat of vitamin B1 which could be destructed at the temperature of 70 °C (175).

Table 4.3 Protein, GABA and vitamin B1 of germinated brown rice flour and pregelatinized flour by single screw extruder

Flour	Water:rice ratio	Temperature (ºC)	Protein (g/100g)	GABA (mg/100g)	Vitamin B1 (mg/100g)
Chainat 1 GBR			10.33^{a} (±0.02)	27.34^{a} (±0.33)	0.6027^{cd} (±0.01)
Chainat 1 Pregel	1:3	60	10.36^{a} (±0.02)	27.46^{a} (±0.99)	0.6083^{bc} (±0.01)
	1:2	60	10.36^{a} (±0.01)	27.91^{a} (±1.72)	0.6056^{c} (±0.01)
	1:1	60	10.34^{a} (±0.01)	27.80^{a} (±0.40)	0.6022^{cd} (±0.01)
	1:3	80	10.33^{a} (±0.01)	27.06^{a} (±1.72)	0.5762^{e} (±0.01)
	1:2	80	10.35^{a} (±0.01)	27.32^{a} (±1.83)	0.5814^{de} (±0.01)
	1:1	80	10.36^{a} (±0.01)	27.84^{a} (±0.68)	0.5778^{e} (±0.02)
	1:3	100	10.37^{a} (±0.02)	27.23^{a} (±0.59)	0.4838^{h} (±0.02)
	1:2	100	10.38^{a} (±0.01)	27.54^{a} (±0.84)	0.4913^{gh} (±0.02)
	1:1	100	10.36^{a} (±0.02)	27.65^{a} (±0.35)	0.4829^{h} (±0.02)

Table 4.3 (cont)

Flour	Water:flour ratio	Temperature (ºC)	Protein (g/100g)	GABA (mg/100g)	Vitamin B1 (mg/100g)
KDML 105 GBR			9.25^{b}	19.54^{b}	0.6448^{a}
			(±0.24)	(±0.44)	(±0.01)
KDML 105 Pregel	1:3	60	9.28^{b}	19.72^{b}	0.6405^{a}
			(±0.24)	(±0.54)	(±0.01)
	1:2	60	9.26^{b}	19.96^{b}	0.6451^{a}
			(±0.25)	(±0.61)	(±0.01)
	1:1	60	9.28^{b}	19.88^{b}	0.6436^{a}
			(±0.08)	(±0.76)	(±0.01)
	1:3	80	9.30^{b}	19.51^{b}	0.6196^{cde}
			(±0.29)	(±0.38)	(±0.01)
	1:2	80	9.29^{b}	19.73^{b}	0.6282^{ab}
			(±0.15)	(±0.33)	(±0.01)
	1:1	80	9.27^{b}	19.78^{b}	0.6127^{bc}
			(±0.14)	(±0.52)	(±0.01)
	1:3	100	9.27^{b}	19.13^{b}	0.5123^{fg}
			(±0.03)	(±0.22)	(±0.02)
	1:2	100	9.25^{b}	19.94^{b}	0.5124^{fg}
			(±0.10)	(±0.31)	(±0.02)
	1:1	100	9.29^{b}	19.88^{b}	0.5215^{f}
			(±0.26)	(±0.32)	(±0.02)

GBR: Germinated brown rice, GABA: γ-aminobutyric acid

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.4 Model coefficient estimated by multiple linear regression for protein, GABA and vitamin B1 contents of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	Protein	GABA	Vitamin B1
Constant (b_0)	9.816***	23.642***	0.599***
Linear			
x_1	0.540***	3.904***	-0.017***
x_2	ns	ns	ns
x_3	ns	ns	-0.062***
Quadratic			
x_1^2	-	-	
x_2^2	ns	ns	ns
x_3^2	ns	ns	ns
Interaction			
x_1x_2	ns	ns	ns
x_1x_3	ns	ns	ns
x_2x_3	ns	ns	ns
R^2	0.952	0.960	0.951

GABA: γ-aminobutyric acid

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.2.2 Effects of hot air oven drying on chemical properties of germinated brown rice flour

Protein, GABA and vitamin B1 contents of germinated brown rice and pregelatinized flour by hot air oven are shown in Table 4.5. Higher protein and GABA contents were found in 'Chainat 1' pregelatinized flour. Although KDML 105 pregelatinized flour contained higher vitamin B1 content than 'Chainat 1' pregelatinized flour when the flour was heated by hot air oven at 60 and 80 °C but when increased temperature to 100 °C, 'Chainat 1' pregelatinized flour had higher vitamin B1 content than KDML 105 pregelatinized flour. Protein and GABA of pregelatinized flour produced from all conditions were not different from germinated brown rice flour. Vitamin B1 content was decreased significantly in pregelatinized flour produced at the temperature of 80 and 100 °C. The highest reduction of vitamin B1 was found in pregelatinized flour produced at 100 °C. These results were similar to pregelatinized flour produced by single screw extruder but the reduction of vitamin B1 was greater due to the longer processing time.

Table 4.6 shows that variety of rice had significant effect on protein, GABA and vitamin B1 contents of pregelatinized flour in hot air oven dryer. Water:flour ratio and temperature did not affect protein and GABA contents. Temperature had significant negative effect on vitamin B1 content. The higher temperature in hot air oven gave the lower vitamin B1 content. These results could be explained by the same reason as shown in pregelatinized flour produced by single screw extruder.

Table 4.5 Protein, GABA and vitamin B1 of germinated brown rice flour and pregelatinized flour by hot air oven

Flour	Water:flour ratio	Temperature (ºC)	Protein (g/100g)	GABA (mg/100g)	Vitamin B1 (mg/100g)
Chainat 1 GBR			10.33[a] (±0.02)	27.34[a] (±0.33)	0.6067[b] (±0.01)
Chainat 1 Pregel	1:3	60	10.36[a] (±0.02)	27.41[a] (±0.32)	0.5917[bc] (±0.01)
	1:2	60	10.34[a] (±0.01)	27.30[a] (±0.21)	0.5920[bc] (±0.01)
	1:1	60	10.35[a] (±0.01)	27.26[a] (±0.12)	0.5810[c] (±0.01)
	1:3	80	10.33[a] (±0.01)	27.28[a] (±0.20)	0.4313[d] (±0.01)
	1:2	80	10.35[a] (±0.01)	27.46[a] (±0.31)	0.4262[d] (±0.01)
	1:1	80	10.33[a] (±0.02)	27.48[a] (±0.32)	0.4146[d] (±0.01)
	1:3	100	10.34[a] (±0.01)	27.32[a] (±0.20)	0.3298[e] (±0.01)
	1:2	100	10.36[a] (±0.02)	27.35[a] (±0.31)	0.3226[ef] (±0.01)
	1:1	100	10.33[a] (±0.00)	27.37[a] (±0.24)	0.3097[fg] (±0.01)

Table 4.5 (cont)

Flour	Water:flour ratio	Temperature (ºC)	Protein (g/100g)	GABA (mg/100g)	Vitamin B1 (mg/100g)
KDML 105 GBR			9.25^{b} (±0.24)	19.54^{b} (±0.44)	0.6448^{a} (±0.01)
KDML 105 Pregel	1:3	60	9.26^{b} (±0.14)	19.54^{b} (±0.12)	0.6393^{a} (±0.01)
	1:2	60	9.27^{b} (±0.16)	19.57^{b} (±0.24)	0.6377^{a} (±0.01)
	1:1	60	9.27^{b} (±0.03)	19.51^{b} (±0.33)	0.6390^{a} (±0.00)
	1:3	80	9.29^{b} (±0.20)	19.50^{b} (±0.12)	0.5768^{c} (±0.01)
	1:2	80	9.28^{b} (±0.12)	19.58^{b} (±0.32)	0.5888^{bc} (±0.01)
	1:1	80	9.26^{b} (±0.04)	19.51^{b} (±0.20)	0.5928^{bc} (±0.01)
	1:3	100	9.28^{b} (±0.10)	19.59^{b} (±0.12)	0.3020^{g} (±0.01)
	1:2	100	9.27^{b} (±0.17)	19.49^{b} (±0.12)	0.3059^{fg} (±0.03)
	1:1	100	9.34^{b} (±0.13)	19.51^{b} (±0.12)	0.3007^{g} (±0.01)

GBR: Germinated brown rice, GABA: γ-aminobutyric acid

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.6 Model coefficient estimated by multiple linear regression for protein, GABA and vitamin B1 contents of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	Protein	GABA	Vitamin B1
Constant (b_0)	9.807***	23.842***	0.507***
Linear			
x_1	0.530***	3.912***	-0.032***
x_2	ns	ns	ns
x_3	ns	ns	-0.151***
Quadratic			
x_1^2	-	-	-
x_2^2	ns	ns	ns
x_3^2	ns	ns	-0.042**
Interaction			
x_1x_2	ns	ns	ns
x_1x_3	ns	ns	0.017*
x_2x_3	ns	ns	ns
R^2	0.975	0.997	0.917

GABA: γ-aminobutyric acid

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.2.3 Effects of spray drying on chemical properties of germinated brown rice flour

Contents of protein, GABA and vitamin B1 in germinated brown rice and pregelatinized flour by spray dryer are shown in Table 4.7. Higher protein and GABA contents were found in ‘Chainat 1’ pregelatinized flour, whereas, KDML 105 pregelatinized flour contained higher vitamin B1 content than ‘Chainat 1’ pregelatinized flour. Protein and GABA of pregelatinized flour produced from every condition were not different from germinated brown rice flour. In ‘Chainat 1’ pregelatinized flour, vitamin B1 content was not different from germinated brown rice flour but in KDML 105 pregelatinized flour, vitamin B1 content of flour produced at the temperature of 120 °C was found to decrease significantly. The difference of cultivars affected the hydration rate and the forms of existing vitamins as thiamin, mono-, di- and tri-phosphates which are related to the solubility of vitamins and influenced its subsequent loss (137).

Table 4.8 shows that only variety of rice had significant effect on protein, GABA and vitamin B1 content of pregelatinized flour. This may be because the contact time between flour and heat was short (175).

Table 4.7 Protein, GABA and vitamin B1 of germinated brown rice flour and pregelatinized flour by spray dryer

Flour	Temperature (ºC)	Protein (g/100g)	GABA (mg/100g)	Vitamin B1 (mg/100g)
Chainat 1 GBR		10.33^{a}	27.34^{a}	0.6027^{c}
		(±0.02)	(±0.33)	(±0.01)
Chainat 1 Pregel	100	10.34^{a}	27.30^{a}	0.5981^{c}
		(±0.02)	(±0.34)	(±0.01)
	120	10.33^{a}	27.33^{a}	0.5900^{c}
		(±0.02)	(±0.26)	(±0.01)
KDML 105 GBR		9.25^{b}	19.54^{b}	0.6448^{a}
		(±0.24)	(±0.44)	(±0.01)
KDML 105 Pregel	100	9.32^{b}	19.48^{b}	0.6364^{ab}
		(±0.09)	(±0.26)	(±0.01)
	120	9.27^{b}	19.46^{b}	0.6266^{b}
		(±0.03)	(±0.23)	(±0.01)

GBR: Germinated brown rice, GABA: γ-aminobutyric acid

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.8 Model coefficient estimated by multiple linear regression for protein, GABA and vitamin B1 contents of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	Protein	GABA	Vitamin B1
Constant (b_0)	9.817***	23.392***	0.613***
Linear			
x_1	0.520***	3.912***	-0.019***
x_2	ns	ns	ns
Interaction			
x_1x_2	ns	ns	ns
R^2	0.992	0.995	0.821

GABA: γ-aminobutyric acid

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.2.4 Effects of spouted bed drying on chemical properties of germinated brown rice flour

Contents of protein, GABA and vitamin B1 in germinated brown rice and pregelatinized flour by spouted bed dryer are shown in Table 4.9. Higher protein and GABA contents were found in ‘Chainat 1’ pregelatinized flour, whereas, KDML 105 pregelatinized flour contained higher vitamin B1 content than ‘Chainat 1’ pregelatinized flour. Protein and GABA of pregelatinized flour produced from every condition were not different from germinated brown rice flour. In ‘Chainat 1’ pregelatinized flour, vitamin B1 content was not different from germinated brown rice flour but in KDML 105 pregelatinized flour, vitamin B1 content of flour produced at the temperature of 120 °C was found significantly decreased.

Table 4.10 shows that only variety of rice had significant effect on protein, GABA and vitamin B1 content of pregelatinized flour. The reason is that spouted bed drying is a similar technique to spray drying. The atomized solution is sprayed with spouted hot air. As the hot spouting air evaporates the water, the dried solids are recovered in an overhead cyclone (176). As a result, similar outcomes were found.

Table 4.9 Protein, GABA and vitamin B1 of germinated brown rice flour and pregelatinized flour by spouted bed dryer

Flour	Temperature (ºC)	Protein (g/100g)	GABA (mg/100g)	Vitamin B1 (mg/100g)
Chainat 1 GBR		10.33^{a}	27.34^{a}	0.6027^{c}
		(±0.02)	(±0.33)	(±0.01)
Chainat 1 Pregel	100	10.35^{a}	27.39^{a}	0.5968^{c}
		(±0.00)	(±0.25)	(±0.01)
	120	10.33^{a}	27.36^{a}	0.5933^{c}
		(±0.01)	(±0.22)	(±0.01)
KDML 105 GBR		9.25^{b}	19.54^{b}	0.6448^{a}
		(±0.24)	(±0.44)	(±0.01)
KDML 105 Pregel	100	9.26^{b}	19.52^{b}	0.6353^{ab}
		(±0.19)	(±0.32)	(±0.01)
	120	9.29^{b}	19.45^{b}	0.6272^{b}
		(±0.26)	(±0.31)	(±0.01)

GBR: Germinated brown rice, GABA: γ-aminobutyric acid

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.10 Model coefficient estimated by multiple linear regression for protein, GABA and vitamin B1 contents of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	Protein	GABA	Vitamin B1
Constant (b_0)	9.807***	23.431***	0.613***
Linear			
x_1	0.533***	3.944***	-0.018***
x_2	ns	ns	ns
Interaction			
x_1x_2	ns	ns	ns
R^2	0.923	0.996	0.868

GABA: γ-aminobutyric acid

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3 Effects of pregelatinization on physical properties of germinated brown rice flour

4.3.1 Effects of pregelatinization on pasting characteristics of germinated brown rice flour

4.3.1.1 Effects of extrusion on pasting characteristics of germinated brown rice flour

Table 4.11 shows pasting profiles of germinated brown rice and pregelatinized flour. ‘Chainat 1’ germinated brown rice flour had higher pasting temperature and viscosity than KDML 105 germinated brown rice flour due to the difference of amylose content. ‘Chainat 1’ rice cultivars are categorized in high amylose rice group (26-27% dry basis) and KDML 105 rice is categorized in low amylose rice group (12-17% dry basis) (34). Higher amylose content gave more rigidity to starch granules by increasing their crystallinity, resulting in slower occurrence of swelling, granule rupture and amylose leaching, therefore higher pasting temperature and viscosity were found (27, 177, 178). After pregelatinization, ‘Chainat 1’ pregelatinized flour had higher pasting temperature and viscosity than KDML 105 pregelatinized flour. At 60 °C, pasting temperature of Chainat 1 pregelatinized flour was not significantly reduced but at 80 °C, pasting temperature was significantly decreased and was lowest at 100 °C. On the contrary, pasting temperature of KDML 105 pregelatinized flour was significantly decreased at the temperature of 60 °C. At 80 and 100 °C, pasting temperature was significantly reduced to lowest in every water:flour ratio, which was lower than Chainat 1 pregelatinized flour. This could be explained by the fact that amylose content in KDML 105 germinated brown rice flour was low, and the starch granules had less rigidity, resulting in low thermal stability. Therefore quicker pasting temperature and lower viscosity were found (179, 180, 181). This is in agreement with Varavinit et al. (182) who found positive correlation between amylose content and pasting temperature and viscosity. All the viscosity parameters (peak, trough, final and setback viscosities) were found significantly lower in pregelatinized flour than in the germinated brown rice flour except breakdown viscosity which was found lower and higher. This could be explained by breakdown viscosity is a different value between peak and trough viscosities which were varied in each pregelatinized flour hence, the value of breakdown viscosity was also varied (183).

Table 4.12 shows that variety of rice and temperature had significant effect on pasting temperature but no significant effect was found by water:flour ratio. In viscosity, variety of rice and temperature had significant effect on peak, breakdown, final and setback viscosities. Water:flour ratio only had significant effect on breakdown viscosities. Temperature had negative significant effect on all viscosity parameters except peak viscosity. Water:flour ratio had significant quadatric effects on peak, breakdown and setback viscosity. Temperature had significant quadatric effects on pasting temperature and trough, breakdown, final and setback viscosity. Significant interaction between water:flour ratio and temperature had positive effect on viscosity of pregelatinized flour. This explained the variation of viscosity in pregelatinized flour produced from different conditions. Increasing temperature caused reduction of pasting temperature and viscosities of pregelatinized flour. This finding is due to the fact that when starch granule was heated with water, swelling, rupture, crystallinity loss and amylose leaching would occur thus flour could absorb water and raise viscosity instantly. Consequently, when the flour was reheated, it caused a decrease in paste viscosity and quicker pasting temperature (25). Apart from the number of incidents above, increasing temperature destroyed hydrogen bonds in the starch molecules therefore, at the highest temperature, pasting temperature and viscosity of pregelatinized flour were the lowest. Moisture is usually an effective factor influencing the pasting temperature and viscosity of flour. In order to cause gelatinization, there must be adequate availability of water. Thus, higher moisture content during pregelatinization gave lower pasting temperature and viscosity to flour (27).

Table 4.11 Pasting profile of germinated brown rice flour and pregelatinized flour by single screw extruder

Flour	Water :flour ratio	Tem-perature (ºC)	PT (ºC)	PV (RVU)	TV (RVU)	BD (RVU)	FV (RVU)	SB (RVU)
Chainat 1 GBR			78.27^{a} (±0.78)	150.17^{a} (±0.65)	141.86^{a} (±0.88)	8.64^{j} (±0.65)	391.00^{a} (±0.72)	249.47^{a} (±0.59)
Chainat 1 Pregel	1:3	60	78.28^{a} (±0.58)	56.86^{e} (±0.70)	35.94^{g} (±0.67)	20.92^{e} (±0.44)	106.14^{c} (±0.46)	69.86^{c} (±0.25)
	1:2	60	78.02^{a} (±0.86)	44.64^{j} (±0.55)	34.89^{h} (±0.67)	10.09^{i} (±0.29)	99.97^{d} (±0.64)	64.42^{d} (±0.51)
	1:1	60	77.38^{a} (±0.40)	29.61^{n} (±0.51)	24.69^{k} (±0.75)	4.92^{l} (±0.29)	64.28^{j} (±0.64)	39.58^{h} (±0.55)
	1:3	80	71.32^{b} (±0.45)	58.56^{d} (±0.61)	47.28^{c} (±0.71)	11.94^{h} (±0.54)	79.80^{g} (±0.39)	33.19^{j} (±0.85)
	1:2	80	69.52^{c} (±0.29)	34.69^{l} (±0.70)	28.06^{j} (±0.75)	6.64^{k} (±0.10)	61.72^{k} (±0.54)	33.33^{j} (±0.63)
	1:1	80	69.23^{c} (±0.12)	53.61^{f} (±0.81)	37.03^{f} (±0.51)	16.58^{f} (±0.51)	74.61^{h} (±0.88)	37.58^{i} (±0.74)
	1:3	100	64.52^{d} (±0.67)	15.42^{p} (±0.73)	13.20^{o} (±0.29)	2.22^{m} (±0.46)	15.19^{p} (±0.39)	2.00^{q} (±0.17)
	1:2	100	62.85^{ef} (±0.56)	21.03^{o} (±0.94)	16.03^{n} (±0.05)	5.00^{l} (±0.98)	23.33^{o} (±0.58)	7.30^{p} (±0.62)
	1:1	100	63.43^{e} (±1.03)	45.58^{j} (±0.17)	31.95^{i} (±0.62)	13.64^{g} (±0.50)	59.14^{l} (±0.46)	27.19^{l} (±0.68)

Table 4.11 (cont)

Flour	Water :flour ratio	Tem-perature (ºC)	PT (ºC)	PV (RVU)	TV (RVU)	BD (RVU)	FV (RVU)	SB (RVU)
KDML 105 GBR			62.02[f] (±0.38)	125.31[b] (±1.00)	98.42[b] (±0.88)	26.89[d] (±0.92)	238.89[b] (±0.67)	140.47[b] (±0.68)
KDML 105 Pregel	1:3	60	53.13[h] (±0.44)	47.08[i] (±0.66)	38.03[e] (±0.62)	9.06[j] (±0.20)	83.42[e] (±0.51)	45.39[f] (±0.34)
	1:2	60	55.28[g] (±0.60)	49.36[h] (±0.05)	39.11[d] (±0.13)	10.25[i] (±0.08)	81.92[f] (±0.79)	42.80[g] (±0.77)
	1:1	60	54.78[g] (±0.63)	20.72[o] (±0.64)	15.53[n] (±0.73)	5.53[l] (±0.64)	40.50[n] (±2.57)	24.30[m] (±0.72)
	1:3	80	50.40[i] (±0.48)	42.55[k] (±0.69)	34.41[h] (±0.58)	8.14[j] (±0.19)	68.05[i] (±0.46)	33.97[j] (±0.68)
	1:2	80	50.20[i] (±0.00)	33.25[m] (±0.42)	22.28[m] (±0.10)	11.30[h] (±0.94)	73.39[h] (±0.34)	51.44[e] (±0.21)
	1:1	80	50.13[i] (±0.03)	51.53[g] (±0.65)	33.97[h] (±0.67)	17.22[f] (±0.49)	65.58[j] (±0.66)	30.61[k] (±0.73)
	1:3	100	50.40[i] (±0.23)	43.42[k] (±0.14)	12.36[o] (±0.17)	35.39[b] (±0.34)	24.44[o] (±0.42)	12.41[o] (±0.63)
	1:2	100	50.37[i] (±0.46)	54.19[f] (±0.54)	23.53[l] (±0.51)	31.00[c] (±0.44)	47.75[m] (±0.14)	24.22[m] (±0.38)
	1:1	100	50.17[i] (±0.06)	92.39[c] (±0.60)	23.30[l] (±0.46)	68.75[a] (±0.58)	41.36[n] (±0.62)	17.72[n] (±0.58)

GBR: Germinated brown rice, PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.12 Model coefficient estimated by multiple linear regression for pasting profiles of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	PT (ºC)	PV (RVU)	TV (RVU)	BD (RVU)	FV (RVU)	SB (RVU)
Constant (b_0)	60.094 ***	41.088 ***	32.731 ***	8.319 ***	73.507 ***	40.758 ***
Linear						
x_1	9.427 ***	-4.139 **	ns	-5.816 ***	3.210 **	1.755 *
x_2	ns	ns	ns	3.248 **	ns	ns
x_3	-4.596 ***	ns	-5.653 ***	7.937 ***	-22.084 ***	-16.292 ***
Quadratic						
x_1^2	-	-	-	-	-	-
x_2^2	ns	6.916 **	ns	5.479 **	ns	-6.102 **
x_3^2	1.418 ***	ns	-8.124 ***	6.091 **	-13.240 ***	-5.255 **
Interaction						
x_1x_2	-0.435 **	ns	ns	-3.238 **	ns	ns
x_1x_3	-2.551 ***	-10.160 ***	ns	-10.447 ***	-6.704 ***	-6.602 ***
x_2x_3	ns	16.593 ***	7.931 ***	8.039 ***	18.206 ***	10.233 ***
R^2	0.995	0.748	0.657	0.847	0.898	0.881

PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.1.2 Effects of hot air oven drying on pasting characteristics of germinated brown rice flour

Table 4.13 shows pasting profile of germinated brown rice and pregelatinized flour. 'Chainat 1' pregelatinized flour had higher pasting temperature and viscosity than KDML 105 pregelatinized flour. In 'Chainat 1' rice, at 60 °C, pasting temperature of pregelatinized flour was not different from the germinated brown rice flour. At 80 and 100 °C, pasting temperature decreased significantly in every water:flour ratio. At 100 °C, different water:flour ratio caused significantly different pasting temperature, and lowest pasting temperature was found at the condition of 1:1 water:flour ratio. In KDML 105, pregelatinized flour from every condition had significantly lower pasting temperature than the germinated brown rice flour. Lowest pasting temperature was found at the same condition of Chainat 1 rice. All viscosities (peak, trough, breakdown, final and setback viscosities) in Chainat 1 pregelatinized flour were significantly lower but in KDML 105 pregelatinized flour, all viscosities were also significantly lower except breakdown viscosity which was found lower and higher. Lowest viscosity of pregelatinized flour of both rice cultivars were found when flour was produced at the condition of 1:1 water:flour ratio at 100 °C.

Table 4.14 shows that variety of rice had significant effect on pasting temperature and viscosity of pregelatinized flour. Water:flour ratio and temperature had significant negative effects on pasting temperature and viscosity of pregelatinized flour. Temperature had more significant linear effects on pasting temperature and viscosity. This implied that increasing of water in the water:flour ratio and temperature caused reduction of pasting temperature and viscosity, and temperature had more influence on the reduction. Water:flour ratio had significant quadatric effects on trough viscosity. Temperature had significant quadatric effects on pasting temperature and peak, trough, final and setback viscosity. Significant interaction between water:flour ratio and temperature had negative effect on viscosity of pregelatinized flour. The decreasing in pasting temperature and viscosity of pregelatinized flour were attributed to the disruption of molecular order within the starch granules during heating in the oven, resulting in the loss of starch granule integrity and destruction of starch crystallinity (28). Higher temperature caused more disruption of starch molecule thus lower pasting temperature and viscosity was found. In addition higher water content supported gelatinization therefore, high water content during pregelatinization gave lower pasting temperature and viscosity flour (184).

Table 4.13 Pasting profile of germinated brown rice flour and pregelatinized flour by hot air oven

Flour	Water :flour ratio	Tem-perature (ºC)	PT (ºC)	PV (RVU)	TV (RVU)	BD (RVU)	FV (RVU)	SB (RVU)
Chainat 1 GBR			78.27^{a} (±0.78)	150.17^{a} (±0.65)	141.86^{a} (±0.88)	8.64^{j} (±0.65)	391.00^{a} (±0.72)	249.47^{a} (±0.59)
Chainat 1 Pregel	1:3	60	78.12^{ab} (±0.16)	125.86^{b} (±0.68)	117.55^{b} (±0.41)	8.30^{gh} (±0.29)	293.08^{b} (±0.76)	175.53^{b} (±0.96)
	1:2	60	77.63^{bc} (±0.26)	119.92^{d} (±0.60)	112.20^{d} (±0.21)	7.72^{h} (±0.41)	287.33^{c} (±0.14)	175.14^{b} (±0.34)
	1:1	60	77.20^{c} (±0.35)	121.30^{c} (±0.58)	114.53^{c} (±0.35)	6.78^{i} (±0.39)	265.47^{d} (±0.35)	150.94^{c} (±0.67)
	1:3	80	75.57^{d} (±0.28)	91.47^{k} (±0.34)	88.58^{g} (±0.30)	2.89^{lm} (±0.24)	230.64^{g} (±0.59)	142.06^{e} (±0.60)
	1:2	80	75.52^{d} (±0.18)	93.61^{j} (±0.21)	90.00^{f} (±0.76)	3.28^{kl} (±0.13)	236.83^{f} (±0.96)	146.83^{d} (±0.79)
	1:1	80	75.20^{d} (±0.35)	84.53^{l} (±0.19)	83.19^{i} (±0.17)	1.34^{n} (±0.14)	211.72^{h} (±0.56)	128.53^{g} (±0.39)
	1:3	100	70.12^{e} (±0.26)	43.83^{p} (±0.50)	40.64^{p} (±0.38)	3.20^{klm} (±0.25)	95.28^{o} (±0.34)	54.64^{p} (±0.62)
	1:2	100	68.72^{f} (±0.28)	38.72^{q} (±0.89)	34.94^{q} (±0.76)	3.78^{k} (±0.42)	86.66^{p} (±0.14)	51.72^{q} (±0.72)
	1:1	100	67.58^{g} (±0.35)	36.72^{r} (±0.54)	31.22^{r} (±0.40)	5.50^{j} (±0.22)	71.64^{q} (±0.48)	40.42^{r} (±0.76)

Table 4.13 (cont)

Flour	Water :flour ratio	Tem- perature (ºC)	PT (ºC)	PV (RVU)	TV (RVU)	BD (RVU)	FV (RVU)	SB (RVU)
KDML 105 GBR			62.02h (±0.38)	125.31b (±1.00)	98.42e (±0.88)	26.89c (±0.92)	238.89e (±0.67)	140.47f (±0.68)
KDML 105 Pregel	1:3	60	60.92i (±0.12)	116.91e (±0.88)	87.00h (±0.30)	29.92b (±0.73)	196.56j (±0.13)	109.56k (±0.32)
	1:2	60	60.28j (±0.40)	115.37f (±0.36)	82.06j (±0.73)	33.11a (±0.38)	196.25jk (±0.17)	114.19j (±0.56)
	1:1	60	59.62k (±0.12)	111.64h (±0.31)	78.05k (±0.29)	33.58a (±0.60)	195.64k (±0.31)	117.59h (±0.38)
	1:3	80	58.50l (±0.31)	114.17g (±0.02)	90.03f (±0.18)	24.14e (±0.05)	206.64i (±0.27)	116.61i (±0.13)
	1:2	80	57.12m (±0.19)	102.53i (±0.25)	77.14l (±0.19)	25.39d (±0.42)	175.39l (±0.26)	98.25m (±0.17)
	1:1	80	56.26n (±0.36)	91.95k (±0.29)	78.50k (±0.42)	13.44f (±0.34)	175.50l (±0.25)	97.00n (±0.17)
	1:3	100	54.63o (±0.16)	76.50m (±0.30)	69.69m (±0.38)	6.81i (±0.13)	175.78l (±0.24)	106.08l (±0.22)
	1:2	100	53.28p (±0.12)	62.50n (±0.30)	58.78n (±0.51)	3.72k (±0.21)	156.42m (±0.42)	97.64mn (±0.76)
	1:1	100	52.45q (±0.26)	50.84o (±0.52)	48.31o (±0.24)	2.53m (±0.29)	116.53n (±0.46)	68.22o (±0.38)

GBR: Germinated brown rice, PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.14 Model coefficient estimated by multiple linear regression for pasting profiles of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	PT	PV	TV	BD	FV	SB
Constant (b_0)	66.301 ***	96.329 ***	83.626 ***	12.612 ***	208.525 ***	124.901 ***
Linear						
x_1	8.477 ***	-4.790 ***	2.406 ***	-7.214 ***	10.220 ***	7.815 ***
x_2	-0.795 ***	-5.981 ***	-4.974 ***	-1.007 *	-13.456 ***	-8.481 ***
x_3	-3.915 ***	-33.474 ***	-25.651 ***	-7.823 ***	-61.003 ***	-35.353 ***
Quadratic						
x_1^2	-	-	-	-	-	-
x_2^2	ns	ns	1.422 *	ns	ns	ns
x_3^2	-1.314 ***	-11.382 ***	-11.660 ***	ns	-28.066 ***	-16.407 ***
Interaction						
x_1x_2	ns	2.879 ***	2.003 ***	ns	ns	ns
x_1x_3	-0.507 ***	-7.827 ***	-13.928 ***	6.102 ***	-37.715 ***	-23.786 ***
x_2x_3	-0.313 *	-2.868 ***	-2.354 ***	ns	-6.795 **	-4.442 *
R^2	0.996	0.991	0.994	0.938	0.970	0.934

PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.1.3 Effects of spray drying on pasting characteristics of germinated brown rice flour

Table 4.15 shows pasting profile of germinated brown rice and pregelatinized flour. ‘Chainat 1’ pregelatinized flour had higher pasting temperature and viscosity than KDML 105 pregelatinized flour. Pasting temperature and viscosity of pregelatinized flour were significantly lower than those from the germinated brown rice flour. Pasting temperature of pregelatinized flour produced from 100 and 120 °C was not different. In ‘Chainat 1’ pregelatinized flour, all viscosities decreased with increasing of temperature except for breakdown viscosities. In KDML 105 pregelatinized flour, all viscosities except breakdown and setback viscosity decreased with increasing of temperature.

Table 4.16 shows that variety of rice had significant effect on pasting temperature and viscosity of pregelatinized flour. Temperature had no significant effect on pasting temperature but had negative effects on all viscosity parameters of pregelatinized flour except for breakdown viscosity. Significant interaction between variety of rice and temperature had positive effect on trough viscosity and negative effect on breakdown, final and setback viscosity of pregelatinized flour. Even though the temperatures used in spray drying were higher than in single screw extruder and hot air oven, the results shows that temperature had no effect on pasting temperature and only little effect on viscosity. This could be because spray drying is a quick heating process (183). This result was consistent with report by Guraya et al. (185) who demonstrated that spray drying can destroy small numbers of starch granules.

Table 4.15 Pasting profile of germinated brown rice flour and pregelatinized flour by spray dryer

Flour	Temperature (ºC)	PT	PV	TV	BD	FV	SB
Chainat 1 GBR		78.27[a] (±0.78)	150.17[a] (±0.65)	141.86[a] (±0.88)	8.64[j] (±0.65)	391.00[a] (±0.72)	249.47[a] (±0.59)
Chainat 1 Pregel	100	76.52[b] (±0.21)	135.08[b] (±0.65)	106.56[b] (±0.17)	28.53[a] (±0.48)	339.86[b] (±0.63)	233.30[b] (±0.77)
	120	76.37[b] (±0.33)	132.83[c] (±0.76)	105.97[b] (±0.05)	26.86[b] (±0.80)	329.25[c] (±0.58)	223.28[c] (±0.53)
KDML 105 GBR		62.02[c] (±0.38)	125.31[d] (±1.00)	98.42[c] (±0.88)	26.89[b] (±0.92)	238.89[d] (±0.67)	140.47[d] (±0.68)
KDML 105 Pregel	100	60.13[d] (±0.21)	99.67[e] (±0.82)	76.55[d] (±0.44)	23.12[c] (±0.48)	187.67[e] (±0.79)	111.12[e] (±0.75)
	120	60.13[d] (±0.12)	95.94[f] (±0.63)	71.72[e] (±0.50)	24.22[c] (±0.34)	183.19[f] (±0.92)	111.47[e] (±0.82)

GBR: Germinated brown rice, PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.16 Model coefficient estimated by multiple linear regression for pasting profiles of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	PT	PV	TV	BD	FV	SB
Constant (b_0)	68.288 ***	115.882 ***	90.201 ***	25.681 ***	259.992 ***	169.793 ***
Linear						
x_1	8.154 ***	18.076 ***	16.064 ***	2.012 ***	74.561 ***	58.449 ***
x_2	ns	-1.493 ***	-1.353 ***	ns	-3.771 ***	-2.418 ***
Interaction						
x_1x_2	ns	ns	1.061 ***	-0.693 **	-1.535 ***	-2.596 ***
R^2	0.999	0.999	1.000	0.941	1.000	1.000

PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.1.4 Effects of spouted bed drying on pasting characteristics of germinated brown rice flour

Table 4.17 shows pasting profile of germinated brown rice and pregelatinized flour. ‘Chainat 1’ pregelatinized flour had higher pasting temperature and viscosity than KDML 105 pregelatinized flour. Pasting temperature of pregelatinized flour was not different from that of the germinated brown rice flour but viscosity of pregelatinized flour was significantly lower than germinated brown rice flour. In ‘Chainat 1’ pregelatinized flour, all viscosities decreased with increasing of temperature except for breakdown and setback viscosities. KDML 105 pregelatinized flour, breakdown viscosity were not decreased with increasing of temperature.

Table 4.18 shows that variety of rice had significant effect on pasting temperature and viscosity of pregelatinized flour. Temperature had significant negative effect on pasting temperature and all viscosity parameters of pregelatinized flour except for breakdown viscosity. Significant interaction between variety of rice and temperature had positive effect on peak, trough, final and setback viscosity. Similar result as spray drying was found. The reason why temperature had little effect on pasting temperature and viscosity could be due to spouted bed drying had very short drying time, shorter than spray drying thus heat can cause only little damage on starch (97).

Table 4.17 Pasting profile of germinated brown rice flour and pregelatinized flour by spouted bed dryer

Flour	Temperature (ºC)	PT	PV	TV	BD	FV	SB
Chainat 1 GBR		78.27[a] (±0.78)	150.17[a] (±0.65)	141.86[a] (±0.88)	8.64[c] (±0.65)	391.00[a] (±0.72)	249.47[b] (±0.59)
Chainat 1 Pregel	100	77.60[ab] (±0.31)	136.80[b] (±0.10)	121.17[b] (±0.52)	15.64[b] (±0.59)	376.42[b] (±0.38)	255.25[a] (±0.43)
	120	77.37[b] (±0.03)	131.06[c] (±0.05)	115.22[c] (±0.34)	15.84[b] (±0.29)	371.31[c] (±0.27)	256.08[a] (±0.50)
KDML 105 GBR		62.02[c] (±0.38)	125.31[d] (±1.00)	98.42[d] (±0.88)	26.89[a] (±0.92)	238.89[d] (±0.67)	140.47[c] (±0.68)
KDML 105 Pregel	100	61.88[c] (±0.12)	105.36[e] (±0.41)	79.19[e] (±0.17)	26.17[a] (±0.34)	214.25[e] (±0.58)	135.05[d] (±0.74)
	120	61.55[c] (±0.15)	95.50[f] (±0.44)	69.51[f] (±0.17)	25.99[a] (±0.46)	198.36[f] (±0.38)	128.85[e] (±0.50)

GBR: Germinated brown rice, PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.18 Model coefficient estimated by multiple linear regression for pasting profiles of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	PT	PV	TV	BD	FV	SB
Constant (b_0)	69.600 ***	117.180 ***	96.273 ***	20.908 ***	290.083 ***	193.810 ***
Linear						
x_1	7.883 ***	16.750 ***	21.922 ***	5.170 ***	83.779 ***	61.857 ***
x_2	-0.142 *	-3.903 ***	-3.907 ***	ns	-5.249 ***	-1.342 ***
Interaction						
x_1x_2	ns	1.027 ***	0.935 ***	ns	2.694 ***	1.758 ***
R^2	1.000	1.000	1.000	0.994	1.000	1.000

PT: Pasting temperature, PV: Peak viscosity, TV: Trough viscosity, BD: Breakdown viscosity, FV: Final viscosity, SB: Setback viscosity

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2 Effects of pregelatinization on thermal properties of germinated brown rice flour

4.3.2.1 Effects of extrusion on thermal properties of germinated brown rice flour

4.3.2.1.1 Gelatinization Characteristics

From table 4.19, gelatinization onset (T_o), peak (T_p) and conclusion (T_c) temperatures, gelatinization enthalpy (ΔH) and degree of gelatinization of germinated brown rice and pregelatinized flour are reported. T_o, T_p, T_c and ΔH of 'Chainat 1' germinated brown rice flour were higher than those in KDML 105 germinated brown rice flour. T_o, T_p, T_c and ΔH were significantly decreased in pregelatinized flour of both rice cultivars from all conditions. However, at the condition of 1:3 and 1:2 water:flour ratio at 60 ºC, T_o and T_p of pregelatinized

'Chainat 1' flour were not decrease significantly. ΔH decreased when water and temperature increased. Lowest ΔH was found at the condition of 2:1 and 1:1 water:flour ratio at 100 ºC. Degree of gelatinization increased with water and temperature. Highest degree of gelatinization was found at the condition of 2:1 and 1:1 water:flour ratio at 100 ºC.

Similar trend was found between T_o from DSC results and pasting temperature from RVA results of germinated brown rice flour and pregeltinized flour but DSC method had a wider range of temperatures (20-100 ºC). Hence, it can detect temperature more quickly than RVA.

Table 4.20 shows that variety of rice had significant effect on T_o, T_p, T_c and ΔH. Water:flour ratio and temperature had significant negative effects on T_o, T_p, T_c and ΔH and significant positive effects on degree of gelatinization of pregelatinized flour. Temperature had more significant linear effects on all parameters. This implied that increasing of water in the water:flour ratio and temperature caused decreasing of T_o, T_p, T_c and ΔH and increasing of degree of gelatinization. Water:flour ratio had significant positive quadatric effects on ΔH and degree of gelatinization. Temperature had significant positive quadatric effects on all parameters. Significant interaction between water:flour ratio and temperature had positive effect on T_o, T_p, T_c and degree of gelatinization but had negative effect on ΔH of pregelatinized flour.

Decreasing of T_o, T_p, T_c and ΔH when water and temperature increased was due to the fact that higher water and temperature during extrusion increased the rate of gelatinization, resulting in higher degree of gelatinization of pregelatinized flour (110). Blanche and Sun (186) noted that extrusion process caused damaged and depolymerized starch molecules, contributed to the loss of crystal structure of starch molecules during heat shearing in extrusion (187-188). Other studies, pregelatinized flour by extrusion shows no gelatinization peak which could be explained by complete starch gelatinization after the process. In this study the temperature used in extrusion process was rather low. Thus, in the DSC thermograms of this study, gelatinization peak can be observed which may be due to the partial degradation of starch that occurred during extrusion process and some starch granules retained their crystalline structure under these particular extrusion conditions (189).

Table 4.19 Gelatinization properties of germinated brown rice flour and pregelatinized flour by single screw extruder

Flour	Water :flour ratio	Tem-perature (ºC)	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
Chainat 1 GBR			73.89^{b} (±0.25)	77.59^{b} (±0.24)	86.50^{a} (±0.27)	2.23^{a} (±0.17)	-
Chainat 1 Pregel	1:3	60	74.01^{b} (±0.03)	77.46^{b} (±0.02)	84.40^{b} (±1.10)	1.53^{b} (±0.03)	31.28^{ab} (±1.28)
	1:2	60	75.69^{a} (±0.03)	78.93^{a} (±0.02)	84.92^{b} (±0.44)	1.51^{bc} (±0.12)	32.04^{abc} (±5.27)
	1:1	60	46.47^{e} (±0.36)	53.99^{e} (±0.69)	64.56^{g} (±0.54)	1.41^{c} (±0.11)	36.57^{cd} (±4.99)
	1:3	80	45.12^{fg} (±0.17)	52.42^{fg} (±1.42)	64.26^{gh} (±0.81)	1.51^{bc} (±0.03)	32.14^{abcd} (±1.32)
	1:2	80	45.08^{fg} (±0.14)	51.08^{h} (±0.04)	63.93^{g} (±0.28)	1.27^{d} (±0.09)	43.05^{e} (±4.20)
	1:1	80	43.66^{h} (±0.06)	55.07^{g} (±0.44)	69.11^{e} (±0.46)	1.26^{d} (±0.04)	43.29^{e} (±1.60)
	1:3	100	45.67^{f} (±0.38)	54.09^{de} (±0.60)	67.46^{f} (±0.28)	1.48^{bc} (±0.02)	33.71^{abcd} (±0.93)
	1:2	100	45.18^{fg} (±0.09)	51.10^{h} (±0.13)	63.37^{ih} (±0.39)	0.80^{f} (±0.05)	64.03^{f} (±2.31)
	1:1	100	45.00^{fg} (±0.30)	50.82^{h} (±0.33)	70.02^{e} (±0.16)	0.79^{f} (±0.05)	64.41^{f} (±2.46)

Table 4.19 (cont)

Flour	Water :flour ratio	Tem-perature (ºC)	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
KDML 105 GBR			65.24^{c} (±0.21)	70.47^{c} (±0.35)	81.96^{c} (±0.96)	1.53^{b} (±0.33)	-
KDML 105 Pregel	1:3	60	64.36^{d} (±0.50)	70.28^{c} (±1.06)	81.00^{d} (±1.40)	1.07^{e} (±0.02)	30.24^{f} (±1.11)
	1:2	60	42.90^{i} (±0.32)	47.98^{ij} (±0.67)	57.42^{m} (±0.26)	1.02^{e} (±0.02)	33.21^{cdef} (±1.29)
	1:1	60	44.82^{g} (±0.32)	50.98^{h} (±1.00)	60.70^{l} (±0.21)	0.97^{e} (±0.00)	36.66^{c} (±0.37)
	1:3	80	44.75^{g} (±0.51)	52.63^{f} (±0.61)	60.51^{l} (±0.37)	1.01^{e} (±0.03)	33.94^{cdef} (±1.80)
	1:2	80	42.00^{j} (±0.98)	47.64^{j} (±0.79)	60.22^{l} (±0.28)	0.84^{f} (±0.00)	45.00^{b} (±0.38)
	1:1	80	41.96^{j} (±0.08)	51.34^{h} (±0.16)	61.24^{kl} (±0.26)	0.83^{f} (±0.01)	45.94^{b} (±0.40)
	1:3	100	42.79^{i} (±0.10)	51.56^{gh} (±0.53)	61.96^{jk} (±0.34)	0.99^{e} (±0.07)	35.33^{cde} (±4.60)
	1:2	100	42.04^{j} (±0.72)	48.72^{i} (±0.41)	61.16^{k} (±0.04)	0.57^{g} (±0.00)	62.93^{a} (±0.37)
	1:1	100	41.58^{j} (±0.10)	50.91^{h} (±0.17)	62.53^{ij} (±0.42)	0.56^{g} (±0.01)	63.73^{a} (±0.53)

GBR: Germinated brown rice, T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.20 Model coefficient estimated by multiple linear regression for gelatinization properties of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
Constant (b_0)	44.075***	50.548***	61.787***	1.044***	44.633***
Linear					
x_1	3.261***	2.940***	3.627***	0.206***	ns
x_2	-4.434***	-3.778***	-2.619**	-0.147***	7.829***
x_3	-7.165***	-6.036***	-3.876***	-0.194***	10.344***
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	0.115***	-6.110***
x_3^2	7.112***	5.541***	5.079***	-0.062*	3.120*
Interaction					
x_1x_2	ns	ns	ns	ns	ns
x_1x_3	-2.886**	-3.025**	-1.629*	-0.037*	ns
x_2x_3	5.650***	4.856***	5.410***	-0.113***	5.925***
R^2	0.772	0.717	0.694	0.922	0.886

T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2.1.2 Retrogradation Characteristics

After gelatinization, flours were kept at 4 ºC for 14 days to analyze retrogradation property (Table 4.21). T_{or}, T_{pr}, T_{cr} and ΔH_r represented T_o, T_p, T_c and ΔH of retrograded flours. T_{or} and T_{cr} of 'Chainat 1' and KDML 105 germinated brown rice flours were not different but T_{pr} of Chainat 1 germinated brown rice flour was significantly higher than KDML 105 germinated brown rice flour. ΔH_r of Chainat 1 germinated brown rice flour was higher than KDML 105 germinated brown rice flour. In 'Chainat 1' germinated brown rice flour, T_{or} and T_{pr} of pregelatinized flours were significantly lower than germinated brown rice flour but no significant diferrence was found in T_{cr}. ΔH_r of pregelatinized flour produced from every water:flour ratio at 60 ºC and 1:3 water:flour ratio at 80 ºC were not different from germinated brown rice flour but in other conditions, ΔH_r were significantly lower. % retrogradation of pregelatinized flour was significantly higher than germinated brown rice flour. In KDML 105 germinated brown rice flour, T_{or} of pregelatinized flours produced at 80 and 100 ºC were significantly lower than germinated brown rice flour but no significant diferrence was found in T_{pr} and T_{cr}. ΔH_r of pregelatinized flour produced from 1:2 and 1:1 water:flour at 100 ºC were significantly lower than that from germinated brown rice flour. % retrogradation of pregelatinized flour was significantly higher than germinated brown rice flour. Highest percentage of retrogradation was found at the condition of 2:1 and 1:1 water:flour ratio at 100 ºC.

Table 4.22 shows that variety of rice had significant effect on T_{or}, T_{cr}, ΔH_r and % retrogradation. Water:flour ratio and temperature had significant negative effects on ΔH_r and significant positive effects on % retrogradation of pregelatinized flour. Temperature had more significant linear effects. This implied that increasing of water in the water:flour ratio and temperature caused decreasing of ΔH_r and increasing of % retrogradation. Water:flour ratio had significant quadatric effects on ΔH_r and % retrogradation but temperature only had significant quadatric effects on % retrogradation. Significant interaction between water:flour ratio and temperature had negative effect on ΔH_r but positive effect was found on % retrogradation.

The decreasing of T_{or}, T_{pr}, T_{cr}, ΔH_r and increasing of % retrogradation of pregelatinized flour could be explained by retrogradation of pregelatinized flour, while recrystallization of amylose was in less stable forms and more heterogeneous in stability than those existing in the native starch granules before gelatinization, and in the conditions that high gelatinization occurred (high water content and temperature), most starch molecules were damaged. Consequently amylose can be easily leached out and reordered. Thus, lower ΔH_r and higher percentage of retrogradation were found (190-191).

Table 4.21 Retrogradation properties of germinated brown rice flour and pregelatinized flour by single screw extruder

Flour	Water :flour ratio	Tem-perature (ºC)	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retro-gradation
Chainat 1 GBR			46.06^{ab} (±0.74)	55.90^{b} (±1.06)	64.66^{bcdefg} (±0.26)	1.13^{a} (±0.21)	50.79^{e} (±8.30)
Chainat 1 Pregel	1:3	60	42.70^{cd} (±1.55)	54.21^{c} (±0.88)	65.36^{abcde} (±0.38)	1.13^{a} (±0.03)	73.80^{bc} (±3.16)
	1:2	60	43.17^{cd} (±0.31)	53.85^{cd} (±0.23)	66.55^{ab} (±1.09)	1.09^{a} (±0.04)	72.66^{bcd} (±6.71)
	1:1	60	42.47^{d} (±0.10)	53.56^{a} (±0.69)	65.52^{abcd} (±1.19)	1.06^{ab} (±0.02)	75.42^{b} (±6.65)
	1:3	80	42.69^{cd} (±0.29)	53.43^{ab} (±0.46)	67.46^{a} (±1.46)	1.06^{ab} (±0.05)	70.07^{bcd} (±3.34)
	1:2	80	42.66^{d} (±0.65)	53.80^{cd} (±0.80)	65.54^{abcd} (±0.06)	0.90^{c} (±0.00)	71.51^{bcd} (±5.27)
	1:1	80	42.57^{d} (±0.33)	53.07^{cd} (±0.85)	66.22^{abc} (±0.53)	0.89^{c} (±0.00)	70.51^{bcd} (±2.31)
	1:3	100	42.35^{d} (±0.13)	53.27^{ab} (±1.03)	66.12^{abc} (±1.73)	0.99^{b} (±0.00)	67.42^{bcd} (±1.30)
	1:2	100	42.47^{d} (±0.10)	53.60^{cd} (±0.58)	65.17^{abcdef} (±2.42)	0.72^{d} (±0.04)	90.79^{a} (±9.36)
	1:1	100	42.60^{d} (±1.28)	53.61^{cd} (±1.57)	66.54^{ab} (±0.72)	0.70^{d} (±0.04)	89.19^{a} (±8.29)

Table 4.21 (cont)

Flour	Water :flour ratio	Tem- perature (ºC)	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retro- gradation
KDML 105 GBR			46.15[a] (±0.32)	54.31[c] (±0.68)	63.16[defg] (±2.28)	0.73[d] (±0.01)	47.44[e] (±0.44)
KDML 105 Pregel	1:3	60	44.65[abc] (±1.14)	53.15[cd] (±0.65)	62.41[g] (±0.10)	0.71[d] (±0.05)	66.78[bcd] (±3.68)
	1:2	60	43.78[cd] (±1.05)	52.85[cd] (±0.58)	62.97[efg] (±0.12)	0.65[de] (±0.06)	63.58[d] (±4.42)
	1:1	60	44.35[abcd] (±1.32)	53.12[cd] (±1.05)	62.43[g] (±1.06)	0.65[de] (±0.03)	67.00[bcd] (±3.51)
	1:3	80	43.89[cd] (±0.65)	53.56[cd] (±0.80)	62.78[fg] (±1.08)	0.66[de] (±0.00)	65.25[cd] (±1.96)
	1:2	80	43.45[d] (±0.46)	52.03[d] (±1.86)	63.47[defg] (±1.12)	0.63[de] (±0.00)	74.59[b] (±0.29)
	1:1	80	43.69[cd] (±0.49)	53.70[cd] (±0.79)	63.77[cdefg] (±2.38)	0.60[e] (±0.00)	72.30[bcd] (±0.40)
	1:3	100	43.94[cd] (±2.21)	53.24[cd] (±1.18)	62.40[g] (±0.77)	0.64[de] (±0.01)	64.52[d] (±4.62)
	1:2	100	44.11[cd] (±1.44)	53.53[cd] (±0.60)	63.00[g] (±0.64)	0.49[f] (±0.01)	86.14[a] (±1.63)
	1:1	100	44.28[bcd] (±0.89)	53.04[cd] (±0.40)	62.64[g] (±1.27)	0.46[f] (±0.01)	83.20[a] (±0.40)

GBR: Germinated brown rice, T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.22 Model coefficient estimated by multiple linear regression for retrogradation properties of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retrogradation
Constant (b_0)	43.111***	53.170***	64.858***	0.757***	73.654***
Linear					
x_1	0.693***	ns	1.588***	0.171***	2.111*
x_2	ns	ns	ns	-0.069***	4.147***
x_3	ns	ns	ns	-0.107***	5.169***
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	0.048***	-4.423*
x_3^2	ns	ns	ns	ns	4.337*
Interaction					
x_1x_2	ns	ns	ns	-0.019**	ns
x_1x_3	ns	ns	ns	-0.036***	ns
x_2x_3	ns	ns	ns	-0.042***	4.826***
R^2	0.291	-0.043	0.617	0.968	0.599

T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2.2 Effects of hot air oven drying on thermal properties of germinated brown rice flour

4.3.2.2.1 Gelatinization Characteristics

Table 4.23 shows gelatinization onset (T_o), peak (T_p), conclusion (T_c) temperatures, gelatinization enthalpy (ΔH) and degree of gelatinization of pregelatinized flour by hot air oven. In Chainat 1 pregelatinized flour, T_o was decreased significantly when temperature of 100 ºC was used. There was no significant difference between T_p of germinated brown rice flour and pregelatinized flour except that at the condition of 1:1 water:flour ratio at 80 ºC, the temperature was higher. T_c of pregelatinized flour had both higher and lower value than T_c of germinated brown rice. ΔH of pregelatinized flour was not significant different from germinated brown rice except that at the condition of 1:1 water:flour ratio at 100 ºC, pregelatinized flour had significantly lower ΔH. Degree of gelatinization of pregelatinized flour produced from every condition was not different from one another. In KDML 105 rice flour, T_o of pregelatinized flour was significantly lower than that of germinated brown rice flour. T_p and T_c were found no significant difference. ΔH of pregelatinized flour produced from 100 ºC was significantly lower than germinated brown rice. Similar to 'Chainat 1' pregelatinized flour, degree of gelatinization of pregelatinized flour produced from every condition had no significant difference. T_o from DSC gave similar trend of result to pasting temperature from RVA.

Table 4.24 shows that variety of rice had significant effect on T_o, T_p, T_c and ΔH. Water:flour ratio only had significant effects on T_p. Temperature had significant negative effects on T_o, and ΔH but significant positive effects on T_p and degree of gelatinization of pregelatinized flour. Temperature had significant negative quadatric effects on T_o. Significant interaction between water:flour ratio and temperature had positive effect on T_c. The reason that increasing temperature caused lower T_o, ΔH and higher degree of gelatinization of flour was described by Malumba et al. (192) who reported that onset temperature and gelatinization enthalpies decreased with increase of temperatures, indicating that gelatinization occurred which was confirmed by the increasing of degree of gelatinization results (193).

Table 4.23 Gelatinization properties of germinated brown rice flour and pregelatinized flour by hot air oven

Flour	Water :flour ratio	Temperature (ºC)	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
Chainat 1 GBR			73.89^{b} (±0.25)	77.59^{b} (±0.24)	86.50^{bc} (±0.27)	2.23^{a} (±0.17)	-
Chainat 1 Pregel	1:3	60	73.84^{b} (±0.18)	77.67^{b} (±0.14)	88.74^{ab} (±0.26)	2.18^{ab} (±0.06)	2.04^{cd} (±2.47)
	1:2	60	73.45^{bc} (±0.23)	77.18^{b} (±0.15)	86.74^{bc} (±0.82)	2.18^{ab} (±0.00)	2.16^{cd} (±0.22)
	1:1	60	73.75^{b} (±0.22)	77.56^{b} (±0.14)	86.26^{c} (±0.66)	2.17^{ab} (±0.08)	2.38^{cd} (±3.41)
	1:3	80	73.32^{bcd} (±0.30)	76.97^{b} (±0.38)	86.46^{bc} (±2.14)	2.13^{ab} (±0.08)	4.25^{cd} (±3.66)
	1:2	80	73.31^{bcd} (±0.22)	77.50^{b} (±0.24)	87.13^{abc} (±0.64)	2.11^{ab} (±0.10)	5.38^{bcd} (±4.39)
	1:1	80	76.88^{a} (±0.11)	81.36^{a} (±0.22)	88.36^{abc} (±0.37)	2.08^{ab} (±0.15)	6.54^{abcd} (±6.64)
	1:3	100	72.64^{de} (±0.18)	76.95^{b} (±0.29)	88.67^{ab} (±0.57)	2.11^{ab} (±0.10)	5.39^{bcd} (±4.74)
	1:2	100	72.80^{cde} (±0.14)	77.33^{b} (±0.16)	89.26^{a} (±0.19)	2.09^{ab} (±0.07)	6.15^{abcd} (±2.99)
	1:1	100	72.16^{e} (±0.26)	77.03^{b} (±0.76)	89.13^{a} (±0.12)	2.06^{b} (±0.05)	7.23^{abcd} (±2.10)

Table 4.23 (cont)

Flour	Water :flour ratio	Tem-perature (ºC)	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
KDML 105 GBR			65.24^{f} (±0.21)	70.47^{c} (±0.35)	81.96^{d} (±0.96)	1.53^{c} (±0.03)	-
KDML 105 Pregel	1:3	60	64.35^{g} (±0.55)	69.96^{cd} (±0.16)	79.77^{de} (±2.52)	1.44^{cd} (±0.01)	5.96^{abcd} (±0.53)
	1:2	60	64.25^{gh} (±0.38)	69.86^{cd} (±0.14)	79.44^{e} (±0.69)	1.42^{cd} (±0.10)	7.23^{abcd} (±6.92)
	1:1	60	63.61^{ghi} (±0.54)	69.76^{cd} (±0.58)	78.72^{e} (±0.75)	1.41^{cd} (±0.12)	8.06^{abc} (±7.79)
	1:3	80	64.18^{gh} (±0.28)	69.76^{cd} (±0.24)	79.59^{e} (±3.76)	1.40^{cd} (±0.04)	8.21^{abc} (±2.64)
	1:2	80	63.51^{hi} (±0.24)	69.58^{d} (±0.22)	79.82^{de} (±0.70)	1.40^{cd} (±0.08)	8.62^{abc} (±5.07)
	1:1	80	63.50^{hi} (±0.04)	69.60^{d} (±0.04)	79.67^{de} (±0.48)	1.38^{cd} (±0.05)	9.49^{abc} (±3.03)
	1:3	100	63.53^{hi} (±1.15)	69.60^{d} (±1.15)	79.48^{e} (±0.45)	1.34^{d} (±0.04)	12.80^{ab} (±2.66)
	1:2	100	63.30^{i} (±0.97)	70.20^{cd} (±0.13)	80.35^{de} (±1.07)	1.33^{d} (±0.08)	13.26^{a} (±5.11)
	1:1	100	63.16^{i} (±0.21)	70.17^{cd} (±0.03)	80.76^{de} (±0.30)	1.32^{d} (±0.02)	13.58^{a} (±1.18)

GBR: Germinated brown rice, T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.24 Model coefficient estimated by multiple linear regression for gelatinization properties of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
Constant (b_0)	68.912***	73.956***	83.499***	1.752***	7.063***
Linear					
x_1	4.931***	3.949***	4.064***	0.370***	-2.539***
x_2	ns	0.381*	ns	ns	ns
x_3	-0.471**	ns	0.664**	-0.046***	2.550***
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	ns	ns
x_3^2	-0.714**	ns	ns	ns	ns
Interaction					
x_1x_2	0.400**	0.345*	ns	ns	ns
x_1x_3	ns	ns	ns	ns	ns
x_2x_3	ns	ns	0.660*	ns	ns
R^2	0.971	0.949	0.914	0.966	0.390

T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2.2.2 Retrogradation Characteristics

Retrogradation properties of pregelatinized flour by hot air oven were shown in Table 4.25 In 'Chainat 1' pregelatinized flour, T_{or} and T_{pr} of pregelatinized flour were significantly lower than germinated brown rice flour but no significant difference was found in T_{cr}, ΔH_r and % retrogradation. In KDML 105 pregelatinized flour, only T_{or} of pregelatinized flour were significantly lower than germinated brown rice flour. T_{pr} and T_{cr}, ΔH_r and % retrogradation of pregelatinized flour were not different from germinated brown rice flour.

Table 4.26 shows that variety of rice had significant effect on T_{or}, T_{pr}, T_{cr} and ΔH_r. Water:flour ratio had no significant effects on all parameters. Temperature had significant negative effects on T_{or} and T_{pr}. This implied that when the temperature increased T_{or} and T_{pr} were decreased. Lower T_{or} and T_{pr} of pregelatinized flour referred to the less stable form of reordering of starch molecules due to disruption of the starch structure in pregelatinization process which in this case similar results were found in gelatinization properties (189). These results were in agreement with the study of Vandeputte et al. (194) who reported that the destruction of starch was negatively correlated with the melting temperature in retrogradation of flour (195).

Table 4.25 Retrogradation properties of germinated brown rice flour and pregelatinized flour by hot air oven

Flour	Water :flour ratio	Tem-perature (ºC)	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retro-gradation
Chainat 1 GBR			46.06^{ab} (±0.74)	55.90^{a} (±1.06)	64.66^{cdef} (±0.26)	1.13^{a} (±0.21)	50.79 (±8.30)
Chainat 1 Pregel	1:3	60	44.62^{abcde} (±0.36)	55.09^{ab} (±0.25)	64.72^{cde} (±0.31)	1.13^{a} (±0.05)	51.76 (±3.26)
	1:2	60	44.33^{cdefg} (±1.28)	54.63^{bc} (±0.35)	64.26^{cdefg} (±1.45)	1.11^{a} (±0.08)	51.09 (±3.88)
	1:1	60	43.87^{cdefg} (±1.95)	54.56^{bc} (±0.50)	65.18^{cd} (±0.77)	1.11^{a} (±0.01)	51.15 (±2.44)
	1:3	80	43.59^{cdefg} (±0.66)	54.21^{bcd} (±0.24)	66.14^{c} (±1.20)	1.10^{a} (±0.23)	51.64 (±12.54)
	1:2	80	43.46^{defg} (±0.52)	54.51^{bc} (±0.15)	65.57^{cd} (±0.81)	1.08^{a} (±0.01)	51.29 (±2.65)
	1:1	80	43.12^{efg} (±1.06)	53.77^{cde} (±0.48)	64.01^{cdefg} (±0.49)	1.08^{a} (±0.08)	51.75 (±2.37)
	1:3	100	42.8^{fg} (±0.72)	53.76^{cde} (±0.35)	64.52^{cdefg} (±0.99)	1.09^{a} (±0.01)	51.71 (±2.81)
	1:2	100	42.65^{g} (±0.72)	53.72^{cde} (±0.52)	64.80^{cde} (±0.66)	1.06^{a} (±0.06)	51.00 (±1.73)
	1:1	100	42.61^{g} (±0.24)	53.69^{cde} (±0.56)	65.20^{ab} (±0.23)	1.05^{a} (±0.05)	51.10 (±3.47)

Table 4.25 (cont)

Flour	Water :flour ratio	Tem-perature (ºC)	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retro-gradation
KDML 105 GBR			46.15^{a} (±0.32)	54.31^{bcd} (±0.68)	63.16^{defg} (±2.28)	0.73^{b} (±0.01)	47.44 (±0.44)
KDML 105 Pregel	1:3	60	45.25^{abc} (±1.01)	54.36^{bcd} (±1.27)	62.51^{efg} (±2.49)	0.72^{b} (±0.01)	50.02 (±0.42)
	1:2	60	44.9^{abcd} (±1.14)	53.24^{de} (±0.23)	62.54^{efg} (±1.58)	0.71^{b} (±0.09)	50.48 (±7.51)
	1:1	60	44.64^{abcde} (±0.29)	53.56^{cde} (±0.27)	62.56^{g} (±1.54)	0.71^{b} (±0.02)	50.81 (±5.47)
	1:3	80	44.48^{bcdef} (±0.61)	53.61^{cde} (±0.23)	62.21^{fg} (±0.79)	0.71^{b} (±0.05)	50.76 (±2.71)
	1:2	80	44.14^{cdefg} (±0.80)	52.90^{e} (±0.93)	62.24^{fg} (±0.56)	0.71^{b} (±0.02)	51.01 (±3.80)
	1:1	80	43.77^{cdefg} (±0.49)	53.28^{de} (±0.54)	62.17^{fg} (±0.65)	0.71^{b} (±0.03)	51.13 (±2.00)
	1:3	100	44.10^{cdefg} (±0.24)	53.28^{de} (±0.42)	62.11^{g} (±0.60)	0.71^{b} (±0.00)	53.34 (±1.96)
	1:2	100	43.93^{cdefg} (±0.94)	53.58^{cde} (±0.73)	62.19^{fg} (±2.67)	0.71^{b} (±0.01)	53.50 (±3.93)
	1:1	100	43.68^{cdefg} (±1.35)	53.53^{cde} (±0.57)	62.12^{g} (±0.87)	0.71^{b} (±0.04)	53.42 (±2.72)

GBR: Germinated brown rice, T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.26 Model coefficient estimated by multiple linear regression for retrogradation properties of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retrogradation
Constant (b_0)	43.776***	53.627***	63.710***	0.895***	51.160***
Linear					
x_1	-0.433***	0.366***	1.320***	0.189***	ns
x_2	ns	ns	ns	ns	ns
x_3	-0.651***	-0.323**	ns	ns	ns
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	ns	ns
x_3^2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
x_1x_3	ns	-0.195*	ns	ns	ns
x_2x_3	ns	ns	ns	ns	ns
R^2	0.403	0.442	0.526	0.899	-0.111

T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2.3 Effects of spray drying on thermal properties of germinated brown rice flour

4.3.2.3.1 Gelatinization Characteristics

Table 4.27 shows gelatinization onset (T_o), peak (T_p), conclusion (T_c) temperatures, gelatinization enthalpy (ΔH) and degree of gelatinization of pregelatinized flour by spray dryer. 'Chainat 1' pregelatinized flour had significantly higher T_o, T_p, T_c, ΔH and degree of gelatinization than KDML 105 pregelatinized flour. T_o, T_p, T_c, ΔH of pregelatinized flour from both rice cultivars were not different from germinated brown rice flour. In addition, T_o, T_p, T_c, ΔH and degree of gelatinization of pregelatinized flour produced from 100 and 120 ºC were not different. When compared to pasting temperature from RVA result, pasting temperature of spray dried flour was decreased significantly from germinated brown rice flour but there was no reduction of T_o in spray dried flour. This could be due to in DSC measurement. T_o indicates the melting of starch crystallites which can happen at different temperature from the pasting temperature that increasing viscosity occurred (196).

Table 4.28 shows that variety of rice had significant effect on T_o, T_p, T_c, ΔH and degree of gelatinization. Temperature had significant negative effects on T_p. The reason that temperature had no significant effect on T_o, T_c, ΔH and degree of gelatinization could be explained by minimal gelatinization occurred during the process that could cause only small destruction of starches.

Table 4.27 Gelatinization properties of germinated brown rice flour and pregelatinized flour by spray dryer

Flour	Temperature (ºC)	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
Chainat 1 GBR		73.89^a (±0.25)	77.59^a (±0.24)	86.50^a (±0.27)	2.23^a (±0.17)	-
Chainat 1 Pregel	100	74.05^a (±0.23)	78.03^a (±0.04)	85.63^a (±1.33)	2.16^a (±0.06)	2.80 (±2.94)
	120	73.89^a (±0.25)	77.67^a (±0.47)	85.78^a (±0.86)	2.14^a (±0.06)	3.56 (±2.82)
KDML 105 GBR		65.24^b (±0.21)	70.47^{bc} (±0.35)	81.96^b (±0.96)	1.53^b (±0.03)	-
KDML 105 Pregel	100	65.15^b (±0.17)	70.70^b (±0.18)	82.25^b (±0.22)	1.51^b (±0.03)	1.63 (±2.26)
	120	65.06^b (±0.16)	70.17^c (±0.13)	86.50^b (±0.27)	1.50^b (±0.01)	2.35 (±0.63)

GBR: Germinated brown rice, T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at p<0.05.

Table 4.28 Model coefficient estimated by multiple linear regression for gelatinization properties of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
Constant (b_0)	69.537***	74.141***	84.068***	1.828***	2.587**
Linear					
x_1	4.435***	3.708***	1.637***	0.327***	ns
x_2	ns	-0.222*	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	0.998	0.995	0.805	0.980	-0.213

T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2.3.2 Retrogradation Characteristics

Retrogradation properties of pregelatinized flour were shown in Table 4.29 There were no significant differences in T_{or}, T_{pr}, T_{cr} and percentage of retrogradation of ‘Chainat 1’ and KDML 105 pregelatinized flour. ΔH_r of ‘Chainat 1’ pregelatinized flour was significantly higher than KDML 105 pregelatinized flour. T_{or}, T_{pr}, T_{cr}, ΔH_r and percentage of retrogradation of pregelatinized flour from both rice cultivars were not different from germinated brown rice flour. Moreover, T_{or}, T_{pr}, T_{cr}, ΔH_r and percentage of retrogradation of pregelatinized flour produced from 100 and 120 ºC were not different.

Table 4.30 shows that variety of rice had significant effect on T_{cr} and ΔH_r and percentage of retrogradation of pregelatinized flour. Temperature had no significant effects on all parameters. This could be due to the short duration of the contact time between heat and flour which could cause small destruction of starches in pregelatinized flour resulted in the rigid rearrangement of amylose similar to the germinated brown rice flour (197).

Table 4.29 Retrogradation properties of germinated brown rice flour and pregelatinized flour by spray dryer

Flour	Temperature (ºC)	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retrogradation
Chainat 1 GBR		46.06 (±0.74)	55.90^{a} (±1.06)	64.66 (±0.26)	1.13^{a} (±0.21)	50.79 (±8.30)
Chainat 1 Pregel	100	45.26 (±0.67)	55.10^{ab} (±0.41)	64.68 (±0.78)	1.13^{a} (±0.19)	52.33 (±8.25)
	120	45.34 (±0.09)	55.53^{ab} (±1.06)	65.17 (±0.87)	1.13^{a} (±0.24)	52.88 (±12.41)
KDML 105 GBR		46.15 (±0.32)	54.31^{ab} (±0.68)	63.16 (±2.28)	0.73^{b} (±0.01)	47.44 (±0.43)
KDML 105 Pregel	100	45.48 (±0.55)	53.84^{b} (±0.64)	63.29 (±1.29)	0.73^{b} (±0.05)	48.28 (±4.44)
	120	45.36 (±1.13)	54.26^{ab} (±1.41)	63.32 (±1.44)	0.73^{b} (±0.00)	48.63 (±0.44)

GBR: Germinated brown rice, T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.30 Model coefficient estimated by multiple linear regression for retrogradation properties of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retrogradation
Constant (b_0)	45.360***	54.682***	64.116***	0.930***	50.532***
Linear					
x_1	ns	ns	0.809*	0.203**	ns
x_2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	-0.350	0.202	0.239	0.611	-0.241

GBR: Germinated brown rice, T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy
ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2.4 Effects of spouted bed drying on thermal properties of germinated brown rice flour

4.3.2.4.1 Gelatinization Characteristics

Table 4.31 shows gelatinization onset (T_o), peak (T_p), conclusion (T_c) temperatures, gelatinization enthalpy (ΔH) and degree of gelatinization of pregelatinized flour by spout bed dryer. ‘Chainat 1’ pregelatinized flour had significantly higher T_o, T_p, T_c, ΔH and degree of gelatinization than KDML 105 pregelatinized flour. T_o, T_p, T_c, ΔH of ‘Chainat 1’ pregelatinized flour were not different from germinated brown rice flour and no significant difference in T_o, T_p, T_c, ΔH and degree of gelatinization of pregelatinized flour produced from 100 and 120 ºC. T_o and T_p of KDML 105 pregelatinized flour were significantly lower than germinated brown rice flour but there were no significant difference was found in T_c and ΔH. No significant difference was found between T_o, T_p, T_c, ΔH and degree of gelatinization of pregelatinized flour produced from 100 and 120 ºC. Different results of ‘Chainat 1’ and KDML 105 pregelatinized flour could be explained by the difference in amylose content as mentioned in pasting characteristic that KDML 105 pregelatinized flour was a low amylose type of flour. It had less rigidity of starch granules. Pregelatinization could cause more damage of starch granules which made the flour susceptible for the melting of the starch granules. Therefore, T_o and T_p of KDML 105 pregelatinized flour were found to be significantly lower (198).

Table 4.32 shows that variety of rice had significant effect on T_o, T_p, T_c, ΔH. Temperature had no significant effects on all parameters. This finding was the result of short duration of heat in the process as seen in low degree of gelatinization similar to pregelatinized flour produced by spray dryer.

Table 4.31 Gelatinization properties of germinated brown rice flour and pregelatinized flour by spouted bed dryer

Flour	Temperature (ºC)	T_o (ºC)	T_p (ºC)	Tc (ºC)	ΔH (J/g)	Degree of gelatinization
Chainat 1 GBR		73.89^{a} (±0.25)	77.59^{a} (±0.24)	86.50^{a} (±0.27)	2.23^{a} (±0.17)	-
Chainat 1 Pregel	100	73.62^{a} (±0.28)	77.18^{a} (±0.15)	86.09^{a} (±0.10)	2.16^{a} (±0.07)	2.71 (±3.07)
	120	73.38^{a} (±0.42)	77.06^{a} (±0.09)	85.97^{a} (±0.38)	2.15^{a} (±0.11)	3.52 (±4.82)
KDML 105 GBR		65.24^{b} (±0.21)	70.47^{b} (±0.35)	81.96^{b} (±0.96)	1.53^{b} (±0.03)	-
KDML 105 Pregel	100	64.20^{c} (±0.55)	69.05^{c} (±0.72)	81.26^{b} (±1.53)	1.50^{b} (±0.03)	2.11 (±1.85)
	120	63.91^{c} (±0.96)	68.54^{c} (±1.16)	81.29^{b} (±0.85)	1.50^{b} (±0.01)	2.29 (±0.64)

GBR: Germinated brown rice, T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.32 Model coefficient estimated by multiple linear regression for gelatinization properties of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	T_o (ºC)	T_p (ºC)	T_c (ºC)	ΔH (J/g)	Degree of gelatinization
Constant (b_0)	68.777***	72.959***	83.652***	1.827***	2.657*
Linear					
x_1	4.720***	4.164***	2.378***	0.330***	ns
x_2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	0.985	0.976	0.881	0.965	-0.311

T_o: Gelatinization onset temperature, T_p: Gelatinization peak temperature, T_c: Gelatinization conclusion temperature, ΔH: Gelatinization enthalpy

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.2.4.2 Retrogradation Characteristics

Retrogradation properties of pregelatinized flour were shown in Table 4.33 There were no significant difference in T_{or}, T_{pr}, T_{cr} and percentage of retrogradation of ‘Chainat 1’ and KDML 105 pregelatinized flour. ΔH_r of Chainat 1’ pregelatinized flour was significantly higher than KDML 105 pregelatinized flour. T_{or}, T_{pr}, T_{cr}, ΔH_r and percentage of retrogradation of pregelatinized flour from both rice cultivars were not different from germinated brown rice flour. There were no significant difference in T_{or}, T_{pr}, T_{cr}, ΔH_r and % retrogradation of pregelatinized flour from two temperatures.

Table 4.34 shows that variety of rice had significant effect on T_{or}, T_{cr} and ΔH_r of pregelatinized flour. Temperature had significant negative effects on T_{or} but no significant effects were found on other parameters. The reason that temperature had effect only on T_{or} could be due to the minimum contact time between heat and flour in the process hence slight destruction of starch granules occurred in pregelatinized flour (197).

Table 4.33 Retrogradation properties of germinated brown rice flour and pregelatinized flour by spouted bed dryer

Flour	Temperature (ºC)	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retrogradation
Chainat 1 GBR		46.06[a] (±0.74)	55.90 (±1.06)	64.66[bc] (±0.26)	1.13[a] (±0.21)	50.79 (±8.30)
Chainat 1 Pregel	100	46.36[a] (±0.09)	55.34 (±0.41)	66.86[ab] (±0.76)	1.13[a] (±0.10)	52.27 (±3.92)
	120	45.81[ab] (±0.58)	55.35 (±2.39)	67.25[a] (±0.51)	1.13[a] (±0.15)	52.82 (±7.56)
KDML 105 GBR		46.15[a] (±0.32)	54.31 (±0.68)	63.16[c] (±2.28)	0.73[b] (±0.01)	47.44 (±0.43)
KDML 105 Pregel	100	45.67[ab] (±0.34)	55.28 (±0.83)	62.47[c] (±2.14)	0.73[b] (±0.02)	48.62 (±1.79)
	120	45.02[b] (±0.36)	55.14 (±0.40)	62.22[c] (±0.87)	0.73[b] (±0.03)	48.64 (±2.15)

GBR: Germinated brown rice, T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.34 Model coefficient estimated by multiple linear regression for retrogradation properties of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	T_{or} (ºC)	T_{pr} (ºC)	T_{cr} (ºC)	ΔH_r (J/g)	% Retrogradation
Constant (b_0)	45.714***	55.276***	64.701***	0.930***	50.587***
Linear					
x_1	0.373*	ns	2.354***	0.202***	ns
x_2	-0.299*	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	0.588	-0.366	0.785	0.824	-0.067

T_{or}: Retrogradation onset temperature, T_{pr}: Retrogradation peak temperature, T_{cr}: Retrogradation conclusion temperature, ΔH_r: Retrogradation enthalpy

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.3 Effects of pregelatinization on rheological properties of germinated brown rice flour

4.3.3.1 Effects of extrusion on rheological properties of germinated brown rice flour

Fig. 4.1 shows rheological properties of germinated brown rice. Storage modulus (G′) is a measure of the energy that stores in the material or recoverable per cycle of deformation. Loss modulus (G′′) is a measure of the energy that lost as viscous dissipation per cycle of deformation. Tanδ is the ratio of G′′/ G′ (76). In this study all pastes exhibited a typical gel behavior where G′ is higher than G′′ throughout the measured temperature range (76). At an earlier stage of heating before the temperatures of 76.12 and 66.45 °C ($T_{oG'}$), the increase in G′ and G′′ of Chainat 1 and KDML 105 germinated brown rice flour respectively, was relatively slow. This indicated that amylose molecules were dissolved from the swollen starch particles and the suspension was transformed into a “sol” (154). After the temperature reached 76.12 and 66.45 °C, G′ and G′′ increased rapidly along the increase of temperature to the maximum G′ (1644 and 1176 Pa) at 80.95 and 76.12 °C ($T_{G'max}$) and the maximum G′′ were 366 and 204 Pa. Tan $\delta_{G'max}$ was 0.15 and 0.12 respectively. The increase in G′ and G′′ during this period was corresponded to the transition of sol to gel, which attributed to the continuous swelling starch granules that finally become a close-packed network, which was constructed from the solubilized amylose and reinforced by strong interaction among the swollen starch particles, resulting in an increase of gel volume (27, 199-200). This was in agreement with previous study by Ring (201), who pointed out that the gelatinized starch granules could strengthen the gel network built by amylose. Further increase in temperature after $T_{G'max,}$ G′ and G′′ of germinated brown rice flour in both cultivars decreased rapidly, indicating that network destruction occurred. The gel network was destroyed during prolonged heating (202). The destruction was probably because the melting of the crystalline region remaining in the swollen starch granule, causing deformation and loosening in the network or resulted from the disentanglement of the amylopectin molecules in the swollen starch granule, which softened the network (203). Another reason for the destruction could be due to the loss of interaction between starch granules and the network (204).

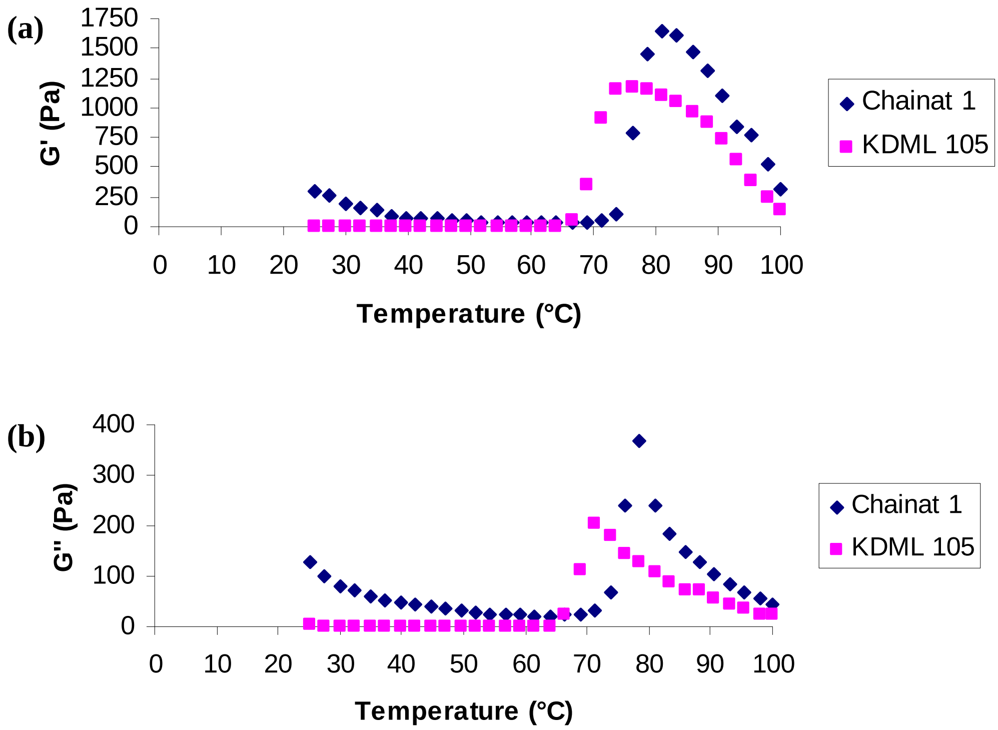

Figure 4.1 Changes in (a) storage modulus (G′) and (b) loss modulus (G′′) of 10% germinated brown rice flour suspensions during heating from 20 to 100 °C

Table 4.35 shows $T_{oG'}$, $T_{G'max}$, G'_{max}, G''_{max} and tan $\delta_{G'max}$ of germinated brown rice and pregelatinized flour. When compared between two rice cultivars, ‘Chainat 1’ germinated brown rice flour which is a high amylose rice had significantly higher $T_{oG'}$, $T_{G'max}$, G'_{max}, G''_{max} and tan $\delta_{G'max}$ than KDML 105 germinated brown rice flour which is a low amylose rice. This was probably because high amylose starch granules had stronger structure, evident from harder particles resulting in lower degree of swelling and retarded gelatinization. Thus the diffusion of amylose sol may be affected and the formation of a gel network may be inhibited (205-207). On the contrary, low amylose starch granules could swell more readily during heating thus the granules were less rigid (177). Furthermore, the amylose leached from high amylose starch granules could build stronger gel networks. The remaining amylose in the particles delayed the breakdown of crystalline regions and the disentanglement of amylopectin branches could also be reduced. Thus G'_{max}, G''_{max}, tan $\delta_{G'max}$, $T_{oG'}$ and $T_{G'max}$ of 'Chainat 1' germinated brown rice flour were higher (204). When compared between germinated brown rice and pregelatinized flour (Table 4.35), it was found that, for 'Chainat 1' pregelatinized flour, $T_{oG'}$ was significantly lower than germinated brown rice flour when the flour was produced at the conditions of 1:1 water:flour ratio at 60 °C and every water:flour ratio at 80 and 100 °C. In KDML 105, $T_{oG'}$ of pregelatinized flour produced from all conditions were lower than germinated brown rice flour. $T_{G'max}$ of pregelatinized flour from both rice cultivars were both higher and lower than germinated brown rice flour. Pregelatinized flour of both rice cultivars produced from every condition had significantly lower G'_{max} and G''_{max}. Lowest G'_{max} and G''_{max} were found in 1:1 water:flour ratio at 100 °C pregelatinized condition for both rice cultivars. Tan $\delta_{G'max}$ of pregelatinized flour from both rice cultivars were found to be higher and lower than germinated brown rice flour. Higher G'_{max} values indicate greater strength of a paste or gel while higher G''_{max} values indicate higher viscosities. The reason why $T_{oG'}$, G'_{max} and G''_{max} of pregelatinized flour were smaller than the germinated brown rice flour was because extrusion process caused disintegration of starch granules, destructuration and depolymerization of starch chains, accelerated the gelatinization and melting (208-209). Differences in $T_{G'max}$ and tan $\delta_{G'max}$ could be due to the difference of starch granular structure in each pregelatinized flour produced from different conditions. (210-211).

From table 4.36, variety of rice had significant effect on $T_{oG'}$, $T_{G'max}$, G''_{max} and tan $\delta_{G'max}$. Water:flour ratio had significant negative effect on $T_{oG'}$, G'_{max}, G''_{max}. Temperature had significant negative effect on all parameters except tan $\delta_{G'max}$. Water:flour ratio had significant positive quadatric effects on tan $\delta_{G'max}$. Temperature had significant positive quadatric effect on $T_{oG'}$, $T_{G'max}$ and G'_{max} but had no significant quadatric effect on G''_{max}. Significant negative quadatric effect of temperature was found in tan $\delta_{G'max}$. In addition, water:flour ratio and temperature had significant interaction, positive effect was found in $T_{oG'}$, $T_{G'max}$ and G'_{max} and negative effect was found in G''_{max} and tan $\delta_{G'max}$.

From the results, higher water content and temperature in pregelatinization gave pregelatinized flour with lower $T_{oG'}$, G'_{max} and G''_{max}. According to RVA and DSC results, high moisture and high temperature resulted in pregelatinized flour with high gelatinization. Higher water content supported gelatinization and higher temperature caused disruption of the internal hydrogen bonds, which hold starch granules. As a result, the swelling of the granules took place and the modulii of the pastes increased. Thus pregelatinized flour at higher temperature had less $T_{oG'}$, G'_{max} and G''_{max} (226). The variation of $T_{G'max}$ and tan $\delta_{G'max}$ might result from the interaction of water content and temperature. The present observations corroborate with earlier studies (212-213).

Table 4.35 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by single screw extruder during heating cycle

Flour	Water :flour ratio	Tem- perature (ºC)	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Chainat 1 GBR			76.12^{a} (±0.00)	80.96^{cd} (±0.00)	1643.67^{a} (±0.58)	365.60^{a} (±4.00)	0.15^{g} (±0.00)
Chainat 1 Pregel	1:3	60	76.13^{a} (±0.00)	80.95^{d} (±0.00)	698.67^{c} (±2.42)	92.01^{h} (±1.52)	0.09^{k} (±0.00)
	1:2	60	76.12^{a} (±0.00)	85.80^{b} (±0.00)	369.00^{h} (±1.40)	49.93^{l} (±0.67)	0.10^{k} (±0.00)
	1:1	60	47.10^{c} (±0.00)	80.97^{c} (±0.01)	342.33^{i} (±2.39)	129.39^{d} (±1.06)	0.20^{e} (±0.00)
	1:3	80	47.10^{c} (±0.00)	80.96^{cd} (±0.00)	483.90^{e} (±2.52)	89.09^{h} (±0.68)	0.14^{h} (±0.00)
	1:2	80	47.10^{c} (±0.00)	90.64^{a} (±0.00)	401.23^{g} (±4.28)	68.12^{k} (±0.71)	0.14^{gh} (±0.01)
	1:1	80	47.10^{c} (±0.00)	76.12^{f} (±0.00)	221.43^{p} (±2.22)	81.27^{i} (±1.74)	0.19^{e} (±0.00)
	1:3	100	47.09^{c} (±0.00)	80.96^{cd} (±0.00)	239.33^{m} (±1.15)	76.78^{j} (±1.75)	0.20^{e} (±0.00)
	1:2	100	47.10^{c} (±0.00)	90.64^{a} (±0.00)	238.41^{mn} (±1.23)	75.79^{j} (±0.68)	0.11^{j} (±0.00)
	1:1	100	47.10^{c} (±0.00)	85.80^{b} (±0.00)	212.10^{q} (±2.42)	31.52^{n} (±0.45)	0.13^{i} (±0.00)

Table 4.35 (cont)

Flour	Water :flour ratio	Tem- perature (ºC)	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
KDML 105 GBR			66.45^{b} (±0.00)	76.12^{f} (±0.00)	1178.00^{b} (±2.00)	204.63^{b} (±1.93)	0.12^{i} (±0.00)
KDML 105 Pregel	1:3	60	42.26^{de} (±0.00)	80.95^{d} (±0.00)	525.57^{d} (±3.82)	185.79^{c} (±3.58)	0.20^{e} (±0.00)
	1:2	60	42.26^{de} (±0.01)	80.96^{cd} (±0.01)	525.03^{d} (±3.18)	185.78^{c} (±3.59)	0.20^{e} (±0.00)
	1:1	60	42.25^{e} (±0.00)	78.54^{e} (±0.00)	434.43^{f} (±3.20)	113.23^{f} (±2.85)	0.20^{e} (±0.00)
	1:3	80	42.27^{d} (±0.02)	78.54^{e} (±0.00)	301.93^{j} (±1.90)	117.92^{e} (±1.36)	0.28^{d} (±0.00)
	1:2	80	42.26^{de} (±0.00)	49.52^{g} (±0.00)	260.37^{k} (±1.87)	99.43^{g} (±0.16)	0.28^{d} (±0.00)
	1:1	80	42.26^{de} (±0.01)	49.52^{g} (±0.01)	251.70^{l} (±1.40)	75.83^{j} (±3.25)	0.32^{b} (±0.01)
	1:3	100	42.26^{de} (±0.00)	47.10^{h} (±0.00)	234.60^{n} (±2.10)	99.43^{g} (±0.16)	0.42^{a} (±0.00)
	1:2	100	42.26^{e} (±0.00)	47.10^{h} (±0.00)	229.51^{o} (±2.28)	70.34^{k} (±0.40)	0.31^{c} (±0.00)
	1:1	100	42.26^{de} (±0.00)	76.12^{f} (±0.00)	224.87^{p} (±0.99)	38.97^{m} (±0.99)	0.16^{f} (±0.00)

GBR: Germinated brown rice, $T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.36 Model coefficient estimated by multiple linear regression for rheological properties during heating cycle of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Constant (b_0)	46.295***	70.483***	313.218***	86.806***	0.212***
Linear					
x_1	5.645***	9.137***	ns	-16.269***	-0.059***
x_2	-2.420**	ns	-66.247***	-15.902***	ns
x_3	-4.838***	-5.037**	-126.352***	-30.274***	0.028***
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	ns	0.020*
x_3^2	4.833**	5.440*	36.059*	ns	-0.032**
Interaction					
x_1x_2	-2.417**	ns	-41.244***	13.286***	0.025***
x_1x_3	-4.838***	6.650***	ns	15.733***	-0.021***
x_2x_3	3.630**	4.533*	51.313***	-8.820*	-0.055***
R^2	0.759	0.632	0.861	0.781	0.870

$T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

From table 4.37, after flour samples were heated, the flour pastes were cooled from 100 to 5 °C. Both G′ and G′′ increased continuously with a decrease in temperature. This result was attributed to the retrogradation of amylose and the initiation of hydrogen bonds development. A decrease in temperature slowed down the interaction of starch granules and the gel system tended to be steady with more rigidity and intensity (214). At 5 °C, ‘Chainat 1’ germinated brown rice flour exhibited the higher $G'_{5°C}$ and $G''_{5°C}$ values than KDML 105 germinated brown rice flour but tan $\delta_{G'5°C}$ of two rice cultivars were not significantly different. ‘Chainat 1’ pregelatinized flour had lower $G'_{5°C}$, $G''_{5°C}$ and tan $\delta_{G'5°C}$ compared to germinated brown rice flour. In KDML 105 pregelatinized flour, $G'_{5°C}$ and $G''_{5°C}$ decreased significantly but tan $\delta_{G'5°C}$ was not significantly different from germinated brown rice flour. This could be due to the difference of $G'_{5°C}$ and $G''_{5°C}$ that influenced the tan $\delta_{G'5°C}$ value. $G'_{5°C}$ and $G''_{5°C}$ of pregelatinized flour from both rice cultivars tend to decrease with increasing of water content in the ratio and temperature. Lowest values were found in pregelatinized flour produced at the condition of 1:1 water:flour ratio at 100 °C.

From table 4.38, variety of rices had significant effect on $G''_{5\,°C}$ and tan $\delta_{G'5\,°C}$. Water:flour ratio and temperature had significant negative effects on $G'_{5\,°C}$ and $G''_{5\,°C}$. In addition, temperature had more significant effect. Water:flour ratio had significant positive quadatric effects on $G'_{5\,°C}$ and $G''_{5\,°C}$ and had negative quadatric effects on tan $\delta_{G'5\,°C}$. Temperature also had significant positive quadatric effects on $G'_{5\,°C}$ and $G''_{5\,°C}$. Significant interaction between water:flour ratio and temperature was found. It had significant negative effect on $G''_{5\,°C}$ and tan $\delta_{G'5\,°C}$ of pregelatinized flour.

Increasing water and temperature in pregelatinization decreased $G'_{5\,°C}$ and $G''_{5\,°C}$ value significantly, suggesting that the gel structures were less rigid, which was in agreement with the result of rheological properties during heating. Tan $\delta_{G'5\,°C}$ of germinated brown rice flour and pregelatinized flour varied significantly ($p < 0.05$). The variation was ascribed to the difference in $G'_{5\,°C}$ and $G''_{5\,°C}$ value (151).

Table 4.37 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by single screw extruder during cooling cycle

Flour	Water:flour ratio	Temperature (ºC)	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
Chainat 1 GBR			1447.90[a] (±8.20)	247.77[a] (±5.69)	0.17[d] (±0.00)
Chainat 1 Pregel	1:3	60	843.77[b] (±3.66)	87.37[ih] (±1.18)	0.10[i] (±0.00)
	1:2	60	674.86[e] (±1.92)	86.53[i] (±1.20)	0.13[g] (±0.00)
	1:1	60	674.03[e] (±2.05)	83.57[j] (±0.56)	0.12[h] (±0.00)
	1:3	80	639.62[g] (±3.90)	76.96[k] (±0.56)	0.12[h] (±0.00)
	1:2	80	442.64[k] (±0.92)	61.37[m] (±2.01)	0.14[f] (±0.01)
	1:1	80	434.85[l] (±0.25)	57.45[n] (±1.04)	0.13[g] (±0.00)
	1:3	100	496.17[h] (±2.25)	63.32[m] (±1.57)	0.13[g] (±0.00)
	1:2	100	425.33[m] (±3.64)	54.73[n] (±0.57)	0.13[g] (±0.01)
	1:1	100	402.97[o] (±0.99)	51.15[o] (±1.00)	0.13[g] (±0.00)

Table 4.37 (cont)

Flour	Water:flour ratio	Temperature (ºC)	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
KDML 105 GBR			826.50[c] (±3.60)	138.80[c] (±1.31)	0.17[d] (±0.00)
KDML 105 Pregel	1:3	60	759.18[d] (±4.18)	145.67[b] (±1.19)	0.19[c] (±0.00)
	1:2	60	651.99[f] (±1.98)	131.15[d] (±0.91)	0.20[a] (±0.00)
	1:1	60	653.25[f] (±1.59)	127.90[e] (±1.81)	0.20[ab] (±0.00)
	1:3	80	679.73[e] (±0.64)	107.71[f] (±1.73)	0.16[e] (±0.00)
	1:2	80	473.37[i] (±2.28)	89.74[h] (±1.09)	0.19[c] (±0.00)
	1:1	80	465.53[j] (±2.25)	76.49[kl] (±0.48)	0.16[e] (±0.01)
	1:3	100	477.34[i] (±6.37)	92.79[g] (±1.41)	0.19[bc] (±0.00)
	1:2	100	417.10[n] (±1.38)	73.57[l] (±1.75)	0.17[d] (±0.00)
	1:1	100	374.33[p] (±5.51)	62.41[m] (±1.22)	0.17[d] (±0.00)

GBR: Germinated brown rice, $G'_{5\,°C}$: Storage modulus at 5 °C, $G''_{5\,°C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\,°C}$: Loss tangent at 5 °C

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.38 Model coefficient estimated by multiple linear regression for rheological properties during cooling cycle of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	$G'_{5\ °C}$ (Pa)	$G''_{5\ °C}$ (Pa)	Tan $\delta_{G'5\ °C}$
Constant (b_0)	482.057***	76.143***	0.157***
Linear			
x_1	ns	-15.833***	-0.029***
x_2	-74.236***	-9.571***	ns
x_3	-138.654***	-22.018***	ns
Quadratic			
x_1^2	-	-	-
x_2^2	60.851***	3.216**	-0.010***
x_3^2	48.235***	10.058***	ns
Interaction			
x_1x_2	ns	3.658***	0.004***
x_1x_3	ns	7.307***	0.007***
x_2x_3	ns	-2.623***	-0.006**
R^2	0.946	0.984	0.915

$G'_{5\ °C}$: Storage modulus at 5 °C, $G''_{5\ °C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\ °C}$: Loss tangent at 5 °C

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.3.2 Effects of hot air oven drying on rheological properties of germinated brown rice flour

Table 4.39 shows rheological properties of germinated brown rice and pregelatinized flour by hot air oven. ‘Chainat 1’ pregelatinized flour had significantly higher $T_{oG'}$, $T_{G'max}$, G'_{max} and G''_{max} than KDML 105 pregelatinized flour. In ‘Chainat 1’ pregelatinized flour, there was no significant difference between $T_{oG'}$ of germinated brown rice flour and pregelatinized flour. $T_{G'max}$ was found significantly lower in pregelatinized flour produced from the condition of 1:1 water:flour ratio at 60 and 1:3 and 1:1 water:flour ratio at 100 °C. G'_{max} and G''_{max} of pregelatinized flour were significantly lower than germinated brown rice flour. In KDML 105 pregelatinized flour, $T_{oG'}$ of germinated brown rice flour and pregelatinized flour were not different but $T_{G'max}$ was found significantly lower only in pregelatinized flour produced from condition of 1:1 water:flour ratio at 60 °C. G'_{max} and G''_{max} of pregelatinized flour was signigficantly lower.

From table 4.40, variety of rice had significant effect on $T_{oG'}$, $T_{G'max}$, G'_{max} and G''_{max}. Water:flour ratio had significant negative effect on $T_{G'max}$, G'_{max}, G''_{max}. Temperature had significant positive effect on $T_{G'max}$ and negative effect on G'_{max} and G''_{max}. Water:flour ratio had significant positive quadatric effects on tan $\delta_{G'max}$. Temperature had significant positive quadatric effect on G'_{max} and G''_{max}. Significant interaction between water:flour ratio and temperature was found. Positive effect was found in $T_{G'max}$. Negative effect was found in G'_{max}.

The reason that water:flour and temperature had no significant effect on $T_{oG'}$ could be explained by in hot air oven process no other mechanical stress was involved. There was only thermal stress hence the destruction of flour might be minimal, pregelatinized flour could stand the heat similar to germinated brown rice flour (215). Increasing temperature and water content decreased G'_{max} and G''_{max}. These values resulted from the strength of gel networks built by amylose leached from starch granules and amylose remaining in the particles (216). Decrease of these values could be due to the fact that during pregelatinization, pregelatinized flour already lost some amylose leaded to less amylose left in the starch granules to form gel. Therefore weaker gel was exhibited (216).

Table 4.39 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by hot air oven during heating cycle.

Flour	Water :flour ratio	Tem-perature (ºC)	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Chainat 1 GBR			76.12[a] (±0.00)	80.97[a] (±0.00)	1643.67[a] (±0.58)	365.60[a] (±4.00)	0.15[b] (±0.00)
Chainat 1 Pregel	1:3	60	76.12[a] (±0.00)	80.96[ab] (±0.00)	1365.90[b] (±4.26)	227.70[b] (±1.60)	0.11[f] (±0.00)
	1:2	60	76.12[a] (±0.00)	80.96[ab] (±0.00)	1344.33[c] (±3.78)	116.57[ij] (±4.15)	0.06[j] (±0.00)
	1:1	60	76.12[a] (±0.00)	80.95[b] (±0.00)	1253.30[d] (±3.45)	206.57[c] (±2.11)	0.10[h] (±0.00)
	1:3	80	76.12[a] (±0.00)	80.96[ab] (±0.00)	1245.17[e] (±0.81)	194.57[d] (±3.80)	0.11[f] (±0.00)
	1:2	80	76.12[a] (±0.02)	80.96[ab] (±0.02)	1085.47[h] (±3.11)	157.42[f] (±2.81)	0.10[h] (±0.01)
	1:1	80	76.12[a] (±0.00)	80.96[ab] (±0.02)	1036.00[i] (±2.11)	185.65[e] (±1.69)	0.18[a] (±0.00)
	1:3	100	76.11[a] (±0.01)	80.95[b] (±0.01)	1194.73[f] (±4.20)	192.73[d] (±1.36)	0.13[c] (±0.00)
	1:2	100	76.12[a] (±0.02)	80.95[ab] (±0.01)	966.03[j] (±0.65)	127.08[gh] (±2.47)	0.10[h] (±0.01)
	1:1	100	76.11[a] (±0.02)	80.95[b] (±0.00)	897.86[k] (±1.62)	111.08[j] (±1.46)	0.11[fg] (±0.00)

Table 4.39 (cont)

Flour	Water :flour ratio	Tem- perature (ºC)	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
KDML 105 GBR			66.45^{b} (±0.00)	76.12^{cd} (±0.00)	1178.00^{g} (±2.00)	204.63^{c} (±1.93)	0.12^{e} (±0.00)
KDML 105 Pregel	1:3	60	66.45^{b} (±0.00)	76.12^{cd} (±0.00)	863.36^{l} (±2.74)	151.75^{f} (±1.53)	0.12^{de} (±0.00)
	1:2	60	66.45^{b} (±0.00)	76.12^{cd} (±0.00)	853.30^{m} (±2.34)	132.20^{g} (±1.70)	0.10^{gh} (±0.00)
	1:1	60	66.45^{b} (±0.00)	73.70^{e} (±0.00)	767.47^{n} (±4.01)	132.07^{g} (±2.54)	0.13^{c} (±0.00)
	1:3	80	66.45^{b} (±0.00)	76.11^{d} (±0.00)	761.65^{o} (±2.04)	127.31^{gh} (±1.02)	0.11^{f} (±0.00)
	1:2	80	66.45^{b} (±0.00)	76.12^{cd} (±0.01)	706.44^{q} (±1.84)	118.10^{i} (±2.74)	0.12^{e} (±0.00)
	1:1	80	66.45^{b} (±0.00)	76.11^{d} (±0.00)	693.63^{r} (±0.97)	75.39^{l} (±2.14)	0.09^{i} (±0.01)
	1:3	100	66.45^{b} (±0.00)	76.12^{cd} (±0.00)	722.27^{p} (±2.05)	113.70^{ij} (±11.01)	0.11^{ef} (±0.00)
	1:2	100	66.45^{b} (±0.00)	76.13^{cd} (±0.00)	704.21^{q} (±2.07)	103.44^{k} (±1.59)	0.10^{h} (±0.00)
	1:1	100	66.45^{b} (±0.00)	76.13^{c} (±0.00)	674.40^{s} (±3.59)	125.48^{h} (±3.68)	0.13^{d} (±0.00)

GBR: Germinated brown rice, $T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.40 Model coefficient estimated by multiple linear regression for rheological properties during heating cycle of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Constant (b_0)	71.824***	78.672***	912.719***	124.494***	0.104***
Linear					
x_1	4.835***	2.552***	202.336***	24.439***	ns
x_2	ns	-0.202**	-69.202***	-14.293**	ns
x_3	ns	0.201**	-107.346***	-16.112***	ns
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	ns	0.022**
x_3^2	ns	ns	45.870***	1.959***	ns
Interaction					
x_1x_2	ns	0.199**	-33.906***	ns	ns
x_1x_3	ns	-0.205**	-43.471***	ns	0.008*
x_2x_3	ns	0.305***	-17.032*	ns	ns
R^2	1.000	0.979	0.983	0.634	0.229

$T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

$G'_{5\,°C}$, $G''_{5\,°C}$ and tan $\delta_{G'5\,°C}$ of pregelatinized flour from both rice cultivars were significantly lower than germinated brown rice flour (Table 4.41). ‘Chainat 1’ pregelatinized flour had higher $G'_{5\,°C}$ and $G''_{5\,°C}$ than KDML 105 pregelatinized flour. Tan $\delta_{G'5\,°C}$ of pregelatinized flour from both rice cultivars was similar. The lowest value of $G'_{5\,°C}$ and $G''_{5\,°C}$ was found when the condition of 1:1 water:flour ratio at 100 ºC was used in both rice cultivars.

From table 4.42, variety of rice had significant effect on $G'_{5\,°C}$, $G''_{5\,°C}$ and tan $\delta_{G'5\,°C}$. Water:flour ratio and temperature had significant negative effects on $G'_{5\,°C}$, $G''_{5\,°C}$ and tan $\delta_{G'5\,°C}$. Temperature had more significant effect on $G'_{5\,°C}$ and $G''_{5\,°C}$. Water:flour ratio had significant positive quadatric effects on $G''_{5\,°C}$

and tan $\delta_{G'5\ °C}$. Temperature also had significant positive quadatric effects on tan $\delta_{G'5\ °C}$. Significant interaction between water:flour ratio and temperature was found. Significant positive effect was found in $G'_{5\ °C}$. Significant negative effect was found in tan $\delta_{G'5\ °C}$. These results were similar to G'_{max} and G''_{max}. Increasing temperature and water content decreased G'_5 and G''_5 as a result of starch degradation and some amylose loss resulted in weak gel created by reassociation of the left amylose and amylopectin (217).

Table 4.41 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by hot air oven during cooling cycle

Flour	Water:flour ratio	Temperature (ºC)	$G'_{5\ °C}$ (Pa)	$G''_{5\ °C}$ (Pa)	Tan $\delta_{G'5\ °C}$
Chainat 1 GBR			1447.90[a] (±8.20)	247.77[a] (±5.69)	0.17[a] (±0.00)
Chainat 1 Pregel	1:3	60	1230.13[b] (±1.80)	184.22[b] (±1.22)	0.15[e] (±0.00)
	1:2	60	1226.38[b] (±4.00)	176.15[c] (±1.78)	0.14[f] (±0.00)
	1:1	60	1201.47[d] (±1.86)	154.63[e] (±2.28)	0.13[h] (±0.00)
	1:3	80	1207.17[c] (±1.36)	166.01[d] (±1.78)	0.14[f] (±0.00)
	1:2	80	1043.64[f] (±1.29)	133.33[gh] (±1.89)	0.13[h] (±0.01)
	1:1	80	1026.22[g] (±1.03)	130.85[h] (±2.04)	0.13[h] (±0.00)
	1:3	100	1142.28[e] (±0.70)	134.77[g] (±1.58)	0.12[i] (±0.00)
	1:2	100	962.33[h] (±2.08)	95.39[i] (±1.06)	0.10[j] (±0.01)
	1:1	100	729.77[j] (±3.12)	95.74[i] (±2.94)	0.13[gh] (±0.00)

Table 4.41 (cont)

Flour	Water:flour ratio	Temperature (ºC)	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
KDML 105 GBR			826.50[i] (±3.60)	138.80[f] (±1.31)	0.17[a] (±0.00)
KDML 105 Pregel	1:3	60	505.97[k] (±0.45)	84.23[j] (±2.56)	0.17[ab] (±0.00)
	1:2	60	466.07[l] (±2.72)	64.57[lm] (±1.92)	0.14[fg] (±0.00)
	1:1	60	450.74[m] (±1.28)	62.32[mn] (±0.35)	0.14[f] (±0.00)
	1:3	80	443.67[n] (±2.53)	72.40[k] (±1.24)	0.16[bc] (±0.00)
	1:2	80	426.87[p] (±2.73)	66.13[l] (±1.05)	0.16[d] (±0.00)
	1:1	80	411.12[q] (±1.05)	60.47[no] (±0.41)	0.15[e] (±0.01)
	1:3	100	434.57[o] (±2.08)	70.51[k] (±0.32)	0.16[cd] (±0.00)
	1:2	100	413.85[q] (±1.33)	58.11[o] (±1.00)	0.14[f] (±0.00)
	1:1	100	403.29[r] (±1.02)	53.22[p] (±0.79)	0.13[h] (±0.00)

GBR: Germinated brown rice, $G'_{5\,°C}$: Storage modulus at 5 °C, $G''_{5\,°C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\,°C}$: Loss tangent at 5 °C

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.42 Model coefficient estimated by multiple linear regression for rheological properties during cooling cycle of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
Constant (b_0)	753.776***	100.309***	0.139***
Linear			
x_1	322.958***	37.729***	-0.009***
x_2	-61.765***	-12.910***	-0.007***
x_3	-82.833***	-18.199***	-0.007***
Quadratic			
x_1^2	-	-	-
x_2^2	ns	6.836***	0.009***
x_3^2	ns	ns	-0.008**
Interaction			
x_1x_2	-41.924***	-4.388***	0.004**
x_1x_3	-54.378***	-13.318***	-0.004**
x_2x_3	-44.987***	ns	0.004*
R^2	0.985	0.986	0.802

$G'_{5\,°C}$: Storage modulus at 5 °C, $G''_{5\,°C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\,°C}$: Loss tangent at 5 °C

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.3.3 Effects of spray drying on rheological properties of germinated brown rice flour

Rheological properties of germinated brown rice and pregelatinized flour produced from spray dryer are shown in table 4.43. ‘Chainat 1’ pregelatinized flour had significantly higher $T_{oG'}$, $T_{G'max}$, G'_{max}, G''_{max} and tan $\delta_{G'max}$ than KDML 105 pregelatinized flour. In ‘Chainat 1’ pregelatinized flour, no significant difference was found between $T_{oG'}$ of germinated brown rice flour and pregelatinized flour. Moreover, pregelatinized flour produced from different temperatures also had no significant difference of $T_{oG'}$. $T_{G'max}$ of pregelatinized flour produced from two temperatures were not significantly different but they were higher than germinated brown rice flour. G'_{max}, G''_{max} and tan $\delta_{G'max}$ of pregelatinized flour were signigficantly lower. In KDML 105, there was no significant difference between $T_{oG'}$ and $T_{G'max}$ of germinated brown rice flour and pregelatinized flour produced from two temperatures. G'_{max}, G''_{max} and tan $\delta_{G'max}$ of pregelatinized flour were significantly lower than germinated brown rice flour. Increasing temperature during pregelatinization gave lower G'_{max} and G''_{max} of pregelatinized flour in both rice cultivars. These results were consistent with RVA results.

From table 4.44, variety of rice had significant effect on $T_{oG'}$, $T_{G'max}$, G'_{max}, G''_{max} and tan $\delta_{G'max}$. Temperature had significant negative effect on G'_{max}, G''_{max} and tan $\delta_{G'max}$. The reason that temperature had no significant effect on $T_{oG'}$ and $T_{G'max}$ may be due to starch was slightly damaged in spray drying, pregelatinized flour can tolerate the heat as same as before pregelatinization (185). Decrease of G'_{max} and G''_{max} is according to the slightly degradation of starch hence weak gelation was found (218). Consequently, tan $\delta_{G'max}$ of pregelatinized flour was decreased.

Table 4.43 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by spray dryer during heating cycle

Flour	Temperature (ºC)	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Chainat 1 GBR		76.12^a (±0.00)	80.96^b (±0.00)	1643.67^a (±0.57)	365.60^a (±4.00)	0.15^a (±0.00)
Chainat 1 Pregel	100	76.12^a (±0.00)	83.38^a (±0.00)	1592.67^b (±2.20)	304.44^b (±3.34)	0.11^c (±0.00)
	120	76.11^a (±0.02)	83.38^a (±0.01)	1588.03^c (±0.35)	296.35^c (±2.65)	0.10^d (±0.00)
KDML 105 GBR		66.45^b (±0.00)	76.12^c (±0.00)	1178.00^d (±2.00)	204.63^d (±1.93)	0.12^b (±0.00)
KDML 105 Pregel	100	66.45^b (±0.00)	76.12^c (±0.00)	1128.43^e (±1.76)	182.78^e (±0.74)	0.12^b (±0.00)
	120	66.44^b (±0.00)	76.11^c (±0.00)	1121.32^f (±0.11)	176.23^f (±1.75)	0.10^d (±0.00)

GBR: Germinated brown rice, $T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.44 Model coefficient estimated by multiple linear regression for rheological properties during heating cycle of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Constant (b_0)	71.282***	79.746***	1357.613***	239.52***	0.108***
Linear					
x_1	4.837***	3.631***	232.737***	60.443***	-0.003**
x_2	ns	ns	-2.937***	-3.660**	-0.007***
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	1.000	1.000	1.000	0.999	0.880

$T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

Rheological properties during cooling cycle of germinated brown rice and pregelatinized flour produced from spray dryer are shown in table 4.45. ‘Chainat 1’ pregelatinized flour had significantly higher $G'_{5\ °C}$ and $G''_{5\ °C}$ than KDML 105 pregelatinized flour. Pregelatinized flour of both rice cultivars had significantly lower $G'_{5\ °C}$, $G''_{5\ °C}$ and tan $\delta_{G'5\ °C}$. However, there was no significant difference between these parameters found in pregelatinized flour produced from two temperatures.

From table 4.46, variety of rice had significant effect on $G'_{5\ °C}$, $G''_{5\ °C}$ and tan $\delta_{G'5\ °C}$. Temperature had no significant effect on $G'_{5\ °C}$ and $G''_{5\ °C}$ but had significant negative effect on tan $\delta_{G'5\ °C}$. The reason that temperature had no significant effect on $G'_{5\ °C}$ and $G''_{5\ °C}$ but had small significant effect on tan $\delta_{G'5\ °C}$ could be due to slightly damage of starch in pregelatinized flour (185).

Table 4.45 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by spray dryer during cooling cycle

Flour	Temperature (ºC)	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
Chainat 1 GBR		1447.90^{a} (±8.20)	247.77^{a} (±5.69)	0.17^{a} (±0.00)
Chainat 1 Pregel	100	1283.01^{b} (±1.84)	193.32^{b} (±0.81)	0.15^{b} (±0.00)
	120	1281.47^{b} (±2.20)	191.96^{b} (±0.84)	0.15^{b} (±0.00)
KDML 105 GBR		826.50^{c} (±3.60)	138.80^{c} (±1.31)	0.17^{a} (±0.00)
KDML 105 Pregel	100	683.07^{d} (±3.51)	95.858^{d} (±2.00)	0.14^{b} (±0.00)
	120	684.00^{d} (±2.00)	96.50^{d} (±1.45)	0.14^{b} (±0.00)

GBR: Germinated brown rice, $G'_{5\,°C}$: Storage modulus at 5 °C, $G''_{5\,°C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\,°C}$: Loss tangent at 5 °C

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.46 Model coefficient estimated by multiple linear regression for rheological properties during cooling cycle of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
Constant (b_0)	982.885***	144.408***	0.145***
Linear			
x_1	299.352***	48.234***	0.005***
x_2	ns	ns	0.000***
Interaction			
x_1x_2	ns	ns	0.000***
R^2	1.000	0.999	1.000

$G'_{5\,°C}$: Storage modulus at 5 °C, $G''_{5\,°C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\,°C}$: Loss tangent at 5 °C

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.3.4 Effects of spouted bed drying on rheological properties of germinated brown rice flour

Rheological properties of germinated brown rice and pregelatinized flour produced from spouted bed dryer are shown in table 4.47. ‘Chainat 1’ pregelatinized flour had significantly higher $T_{oG'}$, $T_{G'max}$, G'_{max}, G''_{max} and tan $\delta_{G'max}$ than KDML 105 pregelatinized flour. In ‘Chainat 1’ pregelatinized flour, no significant difference was found between $T_{oG'}$ of germinated brown rice flour and pregelatinized flour. Moreover, pregelatinized flour produced from different temperature also had no significant difference of $T_{oG'}$. $T_{G'max}$ of pregelatinized flour produced from two temperatures was not significantly different but they were higher than germinated brown rice flour. Increasing of $T_{G'max}$ could probably result from inter- and intramolecular hydrogen bonds of amylose chain during the process. The pregelatinized starch granules changed the structure to stronger (215). G'_{max}, G''_{max} and tan $\delta_{G'max}$ of pregelatinized flour were signigficantly lower. Increasing temperature caused decreasing of G'_{max} and tan $\delta_{G'max}$. In KDML 105, there was no significant difference between $T_{oG'}$ and $T_{G'max}$ of germinated brown rice flour and pregelatinized flour produced from two temperatures. G'_{max}, G''_{max} and tan $\delta_{G'max}$ of pregelatinized flour were significantly lower than germinated brown rice flour. Increasing temperature during pregelatinization gave lower G'_{max} and tan $\delta_{G'max}$ of pregelatinized flour.

From table 4.48, variety of rice had significant effect on $T_{oG'}$, $T_{G'max}$, G'_{max}, G''_{max} and tan $\delta_{G'max}$. Temperature had significant negative effect on G'_{max}, G''_{max} and tan $\delta_{G'max}$. According to spouted bed drying is similar to spray drying, similar results were found. The results could be explained by small destruction of starch during pregelatinization (185, 218).

Table 4.47 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by spouted bed dryer during heating cycle

Flour	Temperature (ºC)	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Chainat 1 GBR		76.12[a] (±0.00)	80.96[b] (±0.00)	1643.67[a] (±0.57)	365.60[a] (±4.00)	0.15[a] (±0.00)
Chainat 1 Pregel	100	76.12[a] (±0.00)	83.38[a] (±0.00)	1587.20[b] (±2.03)	305.70[b] (±0.67)	0.11[c] (±0.00)
	120	76.11[a] (±0.00)	83.37[a] (±0.00)	1591.30[c] (±0.10)	302.19[b] (±1.15)	0.10[d] (±0.00)
KDML 105 GBR		66.45[b] (±0.00)	76.12[c] (±0.00)	1178.00[d] (±2.00)	204.63[c] (±1.93)	0.12[b] (±0.00)
KDML 105 Pregel	100	66.44[b] (±0.00)	76.11[c] (±0.00)	1140.00[e] (±2.64)	185.27[d] (±2.45)	0.12[b] (±0.00)
	120	66.45[b] (±0.00)	76.12[c] (±0.010)	1130.53[f] (±1.86)	180.82[d] (±3.62)	0.10[d] (±0.00)

GBR: Germinated brown rice, $T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.48 Model coefficient estimated by multiple linear regression for rheological properties during heating cycle of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	$T_{oG'}$ (ºC)	$T_{G'max}$ (ºC)	G'_{max} (Pa)	G''_{max} (Pa)	Tan $\delta_{G'max}$
Constant (b_0)	71.283***	79.745***	1362.258***	243.496***	0.108***
Linear					
x_1	4.838***	3.630***	226.992***	60.453***	-0.002***
x_2	ns	ns	-1.342*	-1.989*	-0.007***
Interaction					
x_1x_2	ns	ns	3.392***	ns	0.002***
R^2	1.000	1.000	1.000	0.999	1.000

$T_{oG'}$: Onset temperature of storage modulus, $T_{G'max}$: temperature of maximum storage modulus, G'_{max}: maximum storage modulus, G''_{max}: maximum loss modulus, Tan $\delta_{G'max}$: maximum loss tangent

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

Rheological properties during cooling cycle of germinated brown rice and pregelatinized flour produced from spouted bed dryer are shown in table 4.49. ‘Chainat 1’ pregelatinized flour had significantly higher $G'_{5\,°C}$ and $G''_{5\,°C}$ than KDML 105 pregelatinized flour. Pregelatinized flour of both rice cultivars had significantly lower $G'_{5\,°C}$, $G''_{5\,°C}$ and tan $\delta_{G'5\,°C}$. However, there was no significant difference of these parameters found in pregelatinized flour produced from two temperatures.

From table 4.50, variety of rice had significant effect on $G'_{5\,°C}$, $G''_{5\,°C}$ and tan $\delta_{G'5\,°C}$. Temperature had no significant effect on $G'_{5\,°C}$ and $G''_{5\,°C}$ but had significant negative effect on tan $\delta_{G'5\,°C}$. This could be due to the short duration of pregelatinization. As a result, temperature could only cause slight damage of starch in pregelatinized flour (185).

Table 4.49 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by spouted bed dryer during cooling cycle

Flour	Temperature (ºC)	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
Chainat 1 GBR		1447.90^{a} (±8.20)	247.77^{a} (±5.69)	0.17^{a} (±0.00)
Chainat 1 Pregel	100	1280.67^{b} (±2.08)	196.36^{b} (±0.99)	0.15^{b} (±0.00)
	120	1281.80^{b} (±2.31)	192.79^{b} (±1.04)	0.15^{b} (±0.00)
KDML 105 GBR		826.50^{c} (±3.60)	138.80^{c} (±1.31)	0.17^{a} (±0.00)
KDML 105 Pregel	100	684.47^{d} (±4.72)	94.948^{d} (±2.00)	0.14^{b} (±0.00)
	120	685.43^{d} (±3.85)	96.80^{d} (±0.72)	0.14^{b} (±0.00)

GBR: Germinated brown rice, $G'_{5\,°C}$: Storage modulus at 5 °C, $G''_{5\,°C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\,°C}$: Loss tangent at 5 °C

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.50 Model coefficient estimated by multiple linear regression for rheological properties during cooling cycle of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	$G'_{5\,°C}$ (Pa)	$G''_{5\,°C}$ (Pa)	Tan $\delta_{G'5\,°C}$
Constant (b_0)	983.091***	145.222***	0.145***
Linear			
x_1	298.143***	49.353***	0.005***
x_2	ns	ns	0.000***
Interaction			
x_1x_2	ns	-1.357	0.000***
R^2	1.000	0.999	1.000

$G'_{5\,°C}$: Storage modulus at 5 °C, $G''_{5\,°C}$: Loss modulus at 5 °C, Tan $\delta_{G'5\,°C}$: Loss tangent at 5 °C

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.4 Effects of pregelatinization on swelling power of germinated brown rice flour

4.3.4.1 Effects of extrusion on swelling power of germinated brown rice flour

Table 4.51 shows swelling power of germinated brown rice and pregelatinized at the temperature of 50 to 90 °C. Swelling power of ‘Chainat 1’ germinated brown rice flour was smilar to KDML 105 germinated brown rice flour. Only at the temperature of 70 °C did KDML 105 germinated brown rice flour have significantly higher swelling power. When compared between pregelatinized flour of two rice cultivars, KDML 105 pregelatinized flour in most cases had higher swelling power than ‘Chainat 1’ pregelatinized flour. Pregelatinized flour from every condition had significantly higher swelling power than germinated brown rice flour. The highest swelling power was found in the pregelatinized flour produced from condition of 1:1 water:flour ratio at 100 °C.

Table 4.52 shows that variety of rice had significant effect on swelling power of pregelatinized flour. Water:flour ratio and temperature had significant positive effects on swelling power. Additionally, temperature had more significant linear effects. This implied that increasing of water in the water:flour ratio and temperature caused increasing of swelling power. Water:flour ratio had significant negative quadatric effects only on swelling power at 90 °C. Temperature had significant negative quadatric effects on swelling power at all temperatures. No significant interaction between water:flour ratio and temperature was found.

From the results, increasing temperature and water caused increasing of swelling power. This was because high temperature could destroy hydrogen bonds in the starch molecule, making the starch easier to bind with water and resulting in swelling and due to the fact that high water content assisted gelatinization, which caused swelling of flour (110).

Table 4.51 Swelling power of germinated brown rice flour and pregelatinized flour by single screw extruder

Flour	Water :flour ratio	Temperature (ºC)	Swelling power at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1 GBR			1.49^{k} (±0.49)	1.52^{j} (±0.02)	1.73^{m} (±0.02)	2.14^{k} (±0.08)	2.48^{k} (±0.08)
Chainat 1 Pregel	1:3	60	2.53^{i} (±0.02)	2.84^{h} (±0.04)	3.15^{k} (±0.05)	3.28^{i} (±0.06)	3.79^{i} (±0.10)
	1:2	60	2.63^{i} (±0.04)	2.93^{h} (±0.05)	3.27^{k} (±0.04)	3.81^{h} (±0.02)	3.99^{i} (±0.11)
	1:1	60	3.08^{h} (±0.02)	3.21^{gh} (±0.03)	3.54^{j} (±0.04)	3.97^{h} (±0.04)	4.07^{i} (±0.04)
	1:3	80	4.50^{g} (±0.04)	4.64^{f} (±0.04)	4.82^{h} (±0.04)	5.23^{f} (±0.10)	5.61^{fg} (±0.07)
	1:2	80	5.71^{f} (±0.02)	5.89^{e} (±0.03)	6.18^{f} (±0.04)	6.49^{e} (±0.02)	6.87^{e} (±0.09)
	1:1	80	6.40^{e} (±0.02)	6.68^{d} (±0.12)	6.94^{e} (±0.06)	7.22^{d} (±0.06)	7.41^{d} (±0.04)
	1:3	100	7.09^{d} (±0.02)	7.20^{c} (±0.02)	7.44^{d} (±0.06)	7.79^{c} (±0.02)	8.06^{c} (±0.06)
	1:2	100	7.14^{d} (±0.02)	7.30^{c} (±0.04)	7.50^{d} (±0.08)	7.82^{c} (±0.03)	8.18^{c} (±0.05)
	1:1	100	7.31^{cd} (±0.03)	7.53^{c} (±0.08)	7.76^{c} (±0.09)	8.09^{bc} (±0.07)	8.34^{c} (±0.05)

Table 4.51 (cont)

Flour	Water :flour ratio	Tem- perature (ºC)	Swelling power at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
KDML 105			1.59^{jk}	1.62^{ij}	1.99^{l}	2.44^{jk}	2.74^{k}
GBR			(±0.04)	(±0.20)	(±0.04)	(±0.46)	(±0.22)
KDML 105	1:3	60	1.84^{j}	1.96^{i}	2.21^{l}	2.66^{j}	3.32^{j}
Pregel			(±0.15)	(±0.17)	(±0.11)	(±0.46)	(±0.33)
	1:2	60	3.23^{h}	3.36^{g}	4.20^{i}	4.57^{g}	5.21^{h}
			(±0.34)	(±0.56)	(±0.12)	(±0.38)	(±0.18)
	1:1	60	3.23^{h}	3.37^{g}	4.40^{i}	4.61^{g}	5.47^{gh}
			(±0.12)	(±0.26)	(±0.28)	(±0.59)	(±0.53)
	1:3	80	4.68^{g}	4.86^{f}	5.21^{g}	5.55^{f}	5.79^{f}
			(±0.13)	(±0.15)	(±0.49)	(±0.20)	(±0.13)
	1:2	80	5.73^{f}	5.89^{e}	6.15^{f}	6.45^{e}	6.84^{e}
			(±0.04)	(±0.03)	(±0.05)	(±0.04)	(±0.06)
	1:1	80	6.55^{e}	6.73^{d}	6.91^{e}	7.15^{d}	7.40^{d}
			(±0.24)	(±0.08)	(±0.10)	(±0.08)	(±0.04)
	1:3	100	7.42^{c}	7.52^{c}	7.78^{c}	7.97^{c}	8.11^{c}
			(±0.48)	(±0.31)	(±0.10)	(±0.02)	(±0.12)
	1:2	100	7.94^{b}	8.06^{b}	8.28^{b}	8.47^{b}	8.68^{b}
			(±0.02)	(±0.25)	(±0.26)	(±0.65)	(±0.26)
	1:1	100	8.30^{a}	8.53^{a}	8.88^{a}	9.06^{a}	9.20^{a}
			(±0.01)	(±0.54)	(±0.08)	(±0.05)	(±0.22)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.52 Model coefficient estimated by multiple linear regression for swelling power of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	Swelling power				
	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	5.700***	5.881***	6.151***	6.496***	6.817***
Linear					
x_1	-0.141**	-0.116*	-0.190**	-0.155**	-0.205***
x_2	0.568***	0.586***	0.652***	0.635***	0.601***
x_3	2.389***	2.373***	2.240***	2.193***	2.058***
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	ns	-0.245*
x_3^2	-0.452***	-0.464***	-0.333**	-0.343**	-0.286**
Interaction					
x_1x_2	-0.123*	-0.129*	-0.178**	-0.138*	-0.207**
x_1x_3	-0.172**	-0.199**	ns	ns	ns
x_2x_3	ns	ns	ns	ns	ns
R^2	0.975	0.968	0.964	0.961	0.962

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.4.2 Effects of hot air oven drying on swelling power of germinated brown rice flour

Table 4.53 shows swelling power of germinated brown rice and pregelatinized flour. ‘Chainat 1 pregelatinized flour had no significant difference of swelling power compared with KDML 105 pregelatinized flour. In ‘Chainat 1’ pregelatinized flour, at 60 °C of pregelatinization, swelling power of pregelatinized flour was not different from germinated brown rice flour. Swelling power of pregelatinized flour increased significantly when pregelatinized flour was produced at 80 and 100 °C. However, there were no significant difference between swelling power of pregelatinized flour produced from these two temperatures and in each water:flour ratio. Similar results were found in KDML 105 pregelatinized flour. In this rice cultivar, in the condition of 1:1 water:flour ratio at 60 °C, swelling power of pregelatinized flour was significantly increased. Highest value was found in the pregelatinized flour produced at 100 °C in both rice cultivars.

Table 4.54 shows that variety of rice had significant effect on swelling power of pregelatinized flour. Water:flour ratio and temperature had significant positive effects on swelling power. Additionally, temperature had more significant linear effects. No significant quadatric effect and interaction effect of water:flour ratio and temperature were found. Increasing water and temperature caused more swelling power due to the loss of hydrogen bonds in starch molecules resulting from gelatinization. Therefore starch can bind with water and gave rise to swelling power (27).

Table 4.53 Swelling power of germinated brown rice flour and pregelatinized flour by hot air oven

Flour	Water :flour ratio	Tem-perature (ºC)	Swelling power at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1 GBR			1.49^{i} (±0.04)	1.52^{k} (±0.02)	1.73^{n} (±0.02)	2.14^{j} (±0.08)	2.48^{i} (±0.08)
Chainat 1 Pregel	1:3	60	1.55^{i} (±0.02)	1.68^{jk} (±0.04)	1.89^{mn} (±0.02)	2.32^{j} (±0.08)	2.66^{hi} (±0.05)
	1:2	60	1.74^{ghi} (±0.02)	1.85^{ijk} (±0.02)	2.01^{lmn} (±0.10)	2.46^{ji} (±0.07)	2.78^{ghi} (±0.05)
	1:1	60	1.87^{fghi} (±0.03)	1.96^{hij} (±0.04)	2.18^{jklm} (±0.04)	2.64^{hij} (±0.10)	2.91^{fghi} (±0.06)
	1:3	80	2.03^{efgh} (±0.03)	2.10^{ghi} (±0.10)	2.27^{ijkl} (±0.07)	2.88^{ghi} (±0.09)	3.11^{efgh} (±0.08)
	1:2	80	2.18^{def} (±0.02)	2.40^{fg} (±0.08)	2.50^{ghi} (±0.07)	3.17^{efg} (±0.09)	3.37^{def} (±0.05)
	1:1	80	2.36^{bcde} (±0.02)	2.60^{def} (±0.06)	2.76^{efg} (±0.09)	3.34^{cdefg} (±0.12)	3.58^{cdef} (±0.04)
	1:3	100	2.55^{bcd} (±0.02)	2.87^{bcd} (±0.04)	2.93^{def} (±0.08)	3.54^{abcdef} (±0.11)	3.76^{cd} (±0.08)
	1:2	100	2.63^{bcd} (±0.02)	3.04^{abc} (±0.02)	3.14^{bcd} (±0.13)	3.71^{abcd} (±0.08)	3.88^{bc} (±0.05)
	1:1	100	2.78^{ab} (±0.04)	3.20^{ab} (±0.03)	3.33^{ab} (±0.10)	3.86^{abc} (±0.05)	4.00^{abc} (±0.06)

Table 4.53 (cont)

Flour	Water :flour ratio	Tem- perature (ºC)	Swelling power at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
KDML 105 GBR			1.59^{i} (±0.04)	1.62^{jk} (±0.20)	1.99^{lmn} (±0.04)	2.44^{ij} (±0.46)	2.74^{ghi} (±0.22)
KDML 105 Pregel	1:3	60	1.68^{hi} (±0.15)	1.73^{jk} (±0.06)	2.11^{klm} (±0.35)	2.57^{hij} (±0.51)	2.84^{ghi} (±0.23)
	1:2	60	1.84^{fghi} (±0.07)	1.98^{hij} (±0.08)	2.33^{ijk} (±0.09)	2.93^{ghi} (±0.21)	3.18^{efg} (±0.16)
	1:1	60	2.07^{efgh} (±0.72)	2.16^{ghi} (±0.37)	2.46^{hij} (±0.11)	3.07^{fgh} (±0.61)	3.36^{def} (±0.46)
	1:3	80	2.16^{defg} (±0.13)	2.27^{fgh} (±0.24)	2.67^{fgh} (±0.21)	3.29^{defg} (±0.44)	3.57^{cde} (±0.26)
	1:2	80	2.32^{cde} (±0.40)	2.46^{efg} (±0.32)	2.82^{ef} (±0.24)	3.46^{bcdef} (±0.42)	3.68^{cd} (±0.22)
	1:1	80	2.54^{bcd} (±0.26)	2.77^{cde} (±0.19)	2.95^{def} (±0.06)	3.55^{abcdef} (±0.35)	3.86^{bcd} (±0.14)
	1:3	100	2.67^{abc} (±0.12)	2.89^{bcd} (±0.04)	3.02^{cde} (±0.22)	3.67^{abcde} (±0.18)	4.07^{abc} (±0.66)
	1:2	100	2.74^{abc} (±0.15)	3.04^{abc} (±0.22)	3.28^{abc} (±0.11)	3.87^{ab} (±0.09)	4.28^{ab} (±0.49)
	1:1	100	3.02^{a} (±0.45)	3.26^{a} (±0.56)	3.46^{a} (±0.38)	4.01^{a} (±0.17)	4.44^{a} (±0.49)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.54 Model coefficient estimated by multiple linear regression for swelling power of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	Swelling power				
	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	2.243***	2.436***	2.672***	3.308***	3.536***
Linear					
x_1	-0.074*	ns	-0.115***	-0.139***	-0.180***
x_2	0.166***	0.201***	0.187***	0.183***	0.179***
x_3	0.469***	0.579***	0.515***	0.556***	0.559***
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	ns	ns
x_3^2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
x_1x_3	ns	ns	ns	ns	ns
x_2x_3	ns	ns	ns	ns	ns
R^2	0.782	0.880	0.897	0.804	0.804

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.4.3 Effects of spray drying on swelling power of germinated brown rice flour

Table 4.55 shows swelling power of germinated brown rice and pregelatinized flour by spray dryer. ‘Chainat 1 pregelatinized flour had no significant difference of swelling power compared with KDML 105 pregelatinized flour. In ‘Chainat 1’ pregelatinized flour, swelling power had no significant difference from germinated brown rice flour. Whereas swelling power of KDML 105 pregelatinized flour were significantly different from germinated brown rice flour at 50 and 60 °C of measurement. This may correlate to amylose content of flour (219) due to the fact that the amylose is known to inhibit granule swelling. Thus KDML 105 rice which was categorized in low amylose type of rice is easier to swell when contact with heat than

Chainat 1 rice which is a high amylose rice. Therefore, KDML 105 pregelatinized flour had higher swelling power than Chainat 1 pregelatinized flour (86).

Table 4.56 shows that variety of rice had significant effect on swelling power of pregelatinized flour. Temperature had no significant effect on swelling power. This was a result of short drying time in the process. High temperature could not destroy starch granules, resulting in the remaining of rigid starch granules (97).

Table 4.55 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by spray dryer

Flour	Temperature (ºC)	Swelling power at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1 GBR		1.49^{b} (±0.04)	1.52^{c} (±0.02)	1.73^{b} (±0.02)	2.14^{b} (±0.08)	2.48^{c} (±0.08)
Chainat 1 Pregel	100	1.59^{b} (±0.02)	1.70^{bc} (±0.02)	1.91^{ab} (±0.04)	2.36^{ab} (±0.06)	2.58^{bc} (±0.08)
	120	1.62^{b} (±0.02)	1.72^{b} (±0.02)	1.94^{ab} (±0.04)	2.38^{ab} (±0.03)	2.60^{bc} (±0.04)
KDML 105 GBR		1.59^{b} (±0.04)	1.62^{bc} (±0.20)	1.99^{ab} (±0.04)	2.44^{ab} (±0.46)	2.74^{ab} (±0.22)
KDML 105 Pregel	100	1.84^{a} (±0.19)	1.97^{a} (±0.12)	2.13^{a} (±0.22)	2.66^{a} (±0.24)	2.91^{a} (±0.08)
	120	1.83^{a} (±0.01)	1.93^{a} (±0.06)	2.14^{a} (±0.38)	2.68^{a} (±0.24)	2.93^{a} (±0.04)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.56 Model coefficient estimated by multiple linear regression for swelling power of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	Swelling power				
	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	1.720***	1.832***	2.029***	2.520***	2.755***
Linear					
x_1	-0.115**	-0.120***	ns	-0.148*	-0.165***
x_2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	0.576	0.756	-0.029	0.339	0.882

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.4.4 Effects of spouted bed drying on swelling power of germinated brown rice flour

Table 4.57 shows swelling power of germinated brown rice and pregelatinized flour by spouted bed dryer. ‘Chainat 1 pregelatinized flour had no significant difference of swelling power compared with KDML 105 pregelatinized flour. Pregelatinized flour of both rice cultivars had no significant difference of swelling power from germinated brown rice flour. Moreover, pregelatinized flour produced from different temperatures also had no significant difference from each other.

Table 4.58 shows that variety of rice had significant effect on swelling power of pregelatinized flour. Temperature had no significant effect on swelling power. This result was similar to pregelatinized flour from spray drying as a result of similar technique of the equipment (97).

Table 4.57 Dynamic rheological properties of germinated brown rice flour and pregelatinized flour by spouted bed dryer

Flour	Temperature (ºC)	Swelling power at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1 GBR		1.49 (±0.04)	1.52 (±0.02)	1.73 (±0.02)	2.14 (±0.08)	2.48 (±0.08)
Chainat 1 Pregel	100	1.55 (±0.02)	1.67 (±0.24)	1.80 (±0.03)	2.20 (±0.07)	2.49 (±0.02)
	120	1.56 (±0.03)	1.68 (±0.02)	1.80 (±0.06)	2.23 (±0.04)	2.50 (±0.06)
KDML 105 GBR		1.59 (±0.04)	1.62 (±0.20)	1.99 (±0.04)	2.44 (±0.46)	2.74 (±0.22)
KDML 105 Pregel	100	1.64 (±0.10)	1.78 (±0.18)	2.06 (±0.42)	2.50 (±0.41)	2.86 (±0.32)
	120	1.67 (±0.25)	1.76 (±0.05)	2.07 (±0.58)	2.54 (±0.30)	2.86 (±0.12)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.58 Model coefficient estimated by multiple linear regression for swelling power of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	Swelling power at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	1.606***	1.721***	1.932***	2.367***	2.679***
Linear					
x_1	ns	ns	ns	ns	-0.184**
x_2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	-0.133	0.022	-0.143	0.103	0.481

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.5 Effects of pregelatinization on solubility of germinated brown rice flour

4.3.5.1 Effects of extrusion on solubility of germinated brown rice flour

Table 4.59 shows solubility of germinated brown rice and pregelatinized flour at the temperature of 50 to 90 °C. Chainat 1 germinated brown rice flour gave lower solubility than KDML 105 germinated brown rice flour in all measured temperature. This result was also found in pregelatinized flour. It is due to the fact that amylose restricted swelling of starch granules, leading to less leaching of small fragments of amylopectin or amylose from the starch granules. Hence, lower solubility was discovered (34). This is in agreement with Yoshii (220) who revealed that solubility of low amylose starch was higher than high amylose starch. Pregelatinized flour from every condition had significantly higher solubility than germinated brown rice flour. Highest solubility was found in pregelatinized flour produced at the condition of 1:1 water:flour ratio at 60 °C.

Table 4.60 shows that variety of rice had significant effect on solubility of pregelatinized flour. Water:flour ratio had significant positive effects on solubility. Temperature had significant negative effects on solubility. This implied that increasing of water in the water:flour ratio caused increasing of solubility but increasing temperature decreased solubility. Water:flour ratio had significant positive quadatric effects only on solubility at 50 °C. Temperature had significant positive quadatric effects on solubility at all temperatures. Significant interaction between water:flour ratio and temperature was found. It had negative effect on solubility.

Colonna et. al. (221) stated that the increase in solubility was attributed to dispersion of amylose and amylopectin molecules after gelatinization. Increasing water content caused greater solubility because more gelatinization occurred in the process. In this study, increasing of temperature decreased solubility. This outcome was in agreement with Rolfe et. al. (222) and Menegass et al. (189) who reported that higher temperature diminished solubility. Decreasing of solubility of pregelatinized flour produced from high temperature could be explained by the loss of amylose and amylopectin due to the destruction during pregelatinization and the occurrence of amylose-lipid complexes (215).

Table 4.59 Solubility of germinated brown rice flour and pregelatinized flour by single screw extruder

Flour	Water :flour ratio	Tem-perature (ºC)	Solubility at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1 GBR			2.22^{n} (±0.02)	2.78^{m} (±0.03)	3.98^{l} (±0.04)	4.42^{n} (±0.06)	5.43^{p} (±0.20)
Chainat 1 Pregel	1:3	60	5.06^{k} (±0.02)	6.43^{j} (±0.03)	7.21^{i} (±0.11)	7.81^{k} (±0.08)	8.27^{lm} (±0.20)
	1:2	60	7.60^{h} (±0.05)	10.34^{h} (±0.09)	10.79^{g} (±0.21)	11.24^{i} (±0.10)	12.59^{j} (±0.32)
	1:1	60	11.38^{d} (±0.02)	12.30^{de} (±0.05)	13.43^{e} (±0.14)	14.57^{h} (±0.13)	15.75^{i} (±0.35)
	1:3	80	2.30^{n} (±0.03)	3.60^{l} (±0.09)	4.14^{l} (±0.05)	5.43^{m} (±0.09)	6.87^{o} (±0.16)
	1:2	80	3.62^{m} (±0.02)	4.57^{k} (±0.04)	5.06^{k} (±0.05)	6.41^{l} (±0.06)	7.31^{no} (±0.65)
	1:1	80	4.12^{l} (±0.02)	5.11^{k} (±0.08)	5.97^{j} (±0.10)	6.68^{l} (±0.11)	7.87^{mn} (±0.21)
	1:3	100	5.94^{j} (±0.03)	6.41^{j} (±0.04)	6.87^{i} (±0.10)	7.66^{k} (±0.09)	8.08^{m} (±0.13)
	1:2	100	6.12^{j} (±0.03)	6.94^{ij} (±0.10)	7.31^{hi} (±0.06)	8.33^{j} (±0.04)	8.84^{kl} (±0.05)
	1:1	100	6.94^{i} (±0.06)	7.33^{i} (±0.08)	7.85^{h} (±0.09)	8.59^{j} (±0.08)	9.12^{k} (±0.16)

Table 4.59 (cont)

Flour	Water :flour ratio	Tem-perature (ºC)	Solubility at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
KDML 105 GBR			3.60[m] (±0.35)	4.59[k] (±0.58)	5.32[k] (±0.51)	6.19[l] (±0.21)	7.08[o] (±0.08)
KDML 105 Pregel	1:3	60	12.01[c] (±0.54)	18.22[c] (±0.24)	23.11[b] (±0.63)	25.88[b] (±0.50)	29.11[e] (±0.39)
	1:2	60	12.84[b] (±0.16)	19.72[b] (±0.92)	23.39[b] (±0.66)	26.15[b] (±0.75)	31.19[c] (±0.60)
	1:1	60	20.95[a] (±0.61)	23.68[a] (±0.49)	26.41[a] (±0.35)	27.78[a] (±0.33)	36.97[a] (±0.32)
	1:3	80	7.27[hi] (±0.04)	10.91[gh] (±0.23)	12.73[f] (±0.65)	15.08[h] (±0.15)	22.94[h] (±0.08)
	1:2	80	7.66[h] (±0.03)	12.16[de] (±0.60)	13.18[ef] (±0.46)	16.00[g] (±0.47)	23.85[g] (±0.71)
	1:1	80	11.30[d] (±0.44)	12.59[de] (±0.44)	14.92[d] (±0.16)	17.68[e] (±0.38)	26.15[f] (±1.01)
	1:3	100	8.23[g] (±0.36)	11.47[fg] (±0.46)	13.49[e] (±0.25)	17.08[f] (±0.45)	26.11[f] (±0.21)
	1:2	100	9.50[f] (±0.52)	11.88[ef] (±0.84)	15.08[d] (±0.64)	20.34[d] (±0.46)	29.99[d] (±0.12)
	1:1	100	10.19[e] (±0.24)	12.73[d] (±0.36)	17.72[c] (±0.32)	23.85[c] (±0.31)	32.27[b] (±0.24)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.60 Model coefficient estimated by multiple linear regression for solubility of pregelatinized flour of germinated brown rice by single screw extruder as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	Solubility				
	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	5.433***	8.181***	9.099***	11.149***	15.725***
Linear					
x_1	-2.606***	-3.908***	-5.078***	-6.283***	-9.660***
x_2	2.006***	1.392***	1.562***	1.684***	2.229***
x_3	-1.909***	-2.828***	-3.001***	-2.298***	-1.623***
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	0.918**	ns	ns	ns	ns
x_3^2	3.684***	4.130***	5.054***	5.394***	4.856***
Interaction					
x_1x_2	-0.482**	ns	ns	ns	-0.642**
x_1x_3	1.070***	1.428***	1.436***	0.791*	ns
x_2x_3	-1.538***	-1.143***	-0.538*	ns	-1.015**
R^2	0.960	0.986	0.976	0.959	0.982

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.5.2 Effects of hot air oven drying on solubility of germinated brown rice flour

Table 4.61 shows solubility of germinated brown rice and pregelatinized flour by hot air oven at the temperature of 50 to 90 °C. ‘Chainat 1’ pregelatinized flour gave lower solubility than KDML 105 pregelatinized flour in all measured temperature. Pregelatinized flour from both rice cultivars gave similar results. Higher solubility was found in pregelatinized flour produced from higher water content in water:flour ratio. At 60 °C of pregelatinization, solubility was increased significantly. Increasing pregelatinization temperature to 80 and 100 °C decreased solubility. At the condition of water:flour ratio of 1:1 at the temperature of 60 °C, pregelatinized flour had the highest solubility.

Table 4.62 shows that variety of rice had significant effect on solubility of pregelatinized flour. Water:flour ratio had significant positive effects on solubility. Temperature had significant negative effects on solubility. This implied that increasing of water in the water:flour ratio caused increasing of solubility but increasing temperature decreased solubility. Only temperature had significant quadatric effects on solubility. Significant interaction between water:flour ratio and temperature was found. It had negative effect on solubility.

From the results, higher water content gave more solubility due to more starch degradation from gelatinization (110). Decreasing of solubility in pregelatinized flour produced from high temperature could be due to destruction of amylose and amylopectin during pregelatinization and loss of amylose due to the occurrence of amylose-lipid complexes (215). The result is in agreement with the study of Wadchararat et. al. (24) who reported that after flour was heated at 100 °C in hot air oven, solubility was decreased.

Table 4.61 Solubility of germinated brown rice flour and pregelatinized flour by hot air oven

Flour	Water :flour ratio	Tem-perature (ºC)	Solubility at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1 GBR			2.22^{i} (±0.02)	2.78^{i} (±0.03)	3.98^{k} (±0.04)	4.42^{m} (±0.06)	5.43^{lmn} (±0.20)
Chainat 1 Pregel	1:3	60	3.35^{h} (±0.04)	3.84^{gh} (±0.07)	4.12^{jk} (±0.04)	4.51^{lm} (±0.22)	5.96^{jkl} (±0.16)
	1:2	60	4.31^{g} (±0.01)	4.83^{de} (±0.07)	5.44^{h} (±0.08)	5.88^{ij} (±0.23)	6.37^{j} (±0.20)
	1:1	60	5.71^{cd} (±0.10)	6.12^{c} (±0.05)	6.59^{fg} (±0.10)	7.44^{h} (±0.12)	8.12^{h} (±0.18)
	1:3	80	2.34^{i} (±0.06)	3.66^{h} (±0.03)	3.99^{k} (±0.02)	4.20^{m} (±0.26)	4.89^{n} (±0.36)
	1:2	80	3.31^{h} (±0.10)	3.83^{gh} (±0.07)	4.28^{jk} (±0.07)	4.54^{lm} (±0.06)	5.21^{mn} (±0.20)
	1:1	80	3.42^{h} (±0.04)	4.11^{fgh} (±0.06)	4.60^{ij} (±0.11)	4.98^{kl} (±0.07)	5.68^{klm} (±0.32)
	1:3	100	3.60^{h} (±0.10)	4.38^{efg} (±0.06)	4.89^{hi} (±0.07)	5.22^{k} (±0.11)	6.05^{jkl} (±0.08)
	1:2	100	3.72^{h} (±0.06)	4.60^{def} (±0.05)	5.12^{hi} (±0.08)	5.45^{jk} (±0.14)	6.30^{jk} (±0.32)
	1:1	100	4.16^{g} (±0.05)	4.83^{de} (±0.07)	5.35^{h} (±0.07)	5.80^{ij} (±0.04)	6.59^{ij} (±0.39)

Table 4.61 (cont)

Flour	Water :flour ratio	Tem-perature (ºC)	Solubility at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
KDML 105 GBR			3.60[h] (±0.35)	4.59[def] (±0.58)	5.32[h] (±0.51)	6.19[i] (±0.21)	7.08[i] (±0.08)
KDML 105 Pregel	1:3	60	5.56[de] (±0.22)	6.02[c] (±0.40)	8.14[d] (±0.49)	9.46[f] (±0.46)	10.46[g] (±0.47)
	1:2	60	6.98[b] (±0.29)	7.16[b] (±0.75)	10.32[b] (±0.29)	14.72[b] (±0.42)	16.66[b] (±0.67)
	1:1	60	7.89[a] (±0.79)	8.24[a] (±0.32)	11.54[a] (±0.49)	15.88[a] (±0.56)	18.72[a] (±0.33)
	1:3	80	4.29[g] (±0.15)	4.97[de] (±0.32)	5.42[h] (±0.47)	8.46[g] (±0.22)	11.97[f] (±0.17)
	1:2	80	5.21[ef] (±0.15)	5.85[c] (±0.46)	6.11[g] (±0.44)	9.16[f] (±0.46)	13.37[e] (±0.41)
	1:1	80	6.11[c] (±0.04)	6.38[c] (±0.63)	7.24[e] (±0.39)	10.68[e] (±0.49)	14.46[d] (±0.24)
	1:3	100	4.88[f] (±0.12)	5.17[d] (±0.59)	6.80[ef] (±0.24)	12.22[d] (±0.52)	15.68[c] (±0.59)
	1:2	100	5.39[de] (±0.53)	5.81[c] (±0.25)	7.96[d] (±0.44)	13.55[c] (±0.31)	15.86[c] (±0.28)
	1:1	100	6.59[b] (±0.32)	6.99[b] (±0.56)	9.16[c] (±0.38)	14.48[b] (±0.32)	16.00[c] (±0.78)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.62 Model coefficient estimated by multiple linear regression for solubility of pregelatinized flour of germinated brown rice by hot air oven as affected by variety of rice (x_1), water:flour ratio (x_2) and temperature (x_3)

Coefficient	Solubility				
	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	4.107***	4.771***	5.308***	7.186***	9.427***
Linear					
x_1	-1.055***	-0.911***	-1.574***	-3.336***	-4.334***
x_2	0.821***	0.719***	0.927***	1.267***	1.214***
x_3	-0.454***	-0.370***	-0.573***	ns	ns
Quadratic					
x_1^2	-	-	-	-	-
x_2^2	ns	ns	ns	ns	ns
x_3^2	1.067***	0.866***	1.848***	2.547***	1.802***
Interaction					
x_1x_2	-0.156**	-0.189**	-0.337**	-0.551**	-0.633***
x_1x_3	0.140**	0.204**	0.441***	ns	ns
x_2x_3	-0.302***	-0.280**	-0.383**	-0.813***	-1.196***
R^2	0.957	0.910	0.928	0.940	0.965

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.5.3 Effects of spray drying on solubility of germinated brown rice flour

Table 4.63 shows solubility of germinated brown rice and pregelatinized flour by spray dryer. ‘Chainat 1’ pregelatinized flour had similar solubility to KDML 105 pregelatinized flour. Higher solubility was found in pregelatinized flour from both rice cultivars. In ‘Chainat 1’ pregelatinized flour produced from two temperatures had no significant difference from each other, whereas in KDML 105 pregelatinized flour, solubility of pregelatinized flour produced from higher temperature was found to be significantly higher in 80 °C of measurement temperature.

Table 4.64 shows that variety of rice had significant effect on solubility of pregelatinized flour. Temperature had no significant effect on solubility. This might be due to the small destruction of starch after spray drying as mentioned before (185).

Table 4.63 Solubility of germinated brown rice flour and pregelatinized flour by spray dryer

Flour	Temperature	Solubility				
	(ºC)	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1		2.22^{d}	2.78^{c}	3.98^{c}	4.42^{d}	5.43^{c}
GBR		(±0.02)	(±0.03)	(±0.04)	(±0.06)	(±0.20)
Chainat 1	100	3.75^{c}	4.75^{ab}	5.49^{b}	6.17^{c}	7.10^{b}
Pregel		(±0.06)	(±0.03)	(±0.08)	(±0.02)	(±0.08)
	120	3.80^{c}	4.88^{ab}	5.52^{b}	6.20^{c}	7.17^{b}
		(±0.06)	(±0.07)	(±0.09)	(±0.10)	(±0.10)
KDML 105		3.60^{c}	4.59^{b}	5.32^{b}	6.19^{c}	7.08^{b}
GBR		(±0.35)	(±0.58)	(±0.51)	(±0.21)	(±0.08)
KDML 105	100	4.80^{a}	5.24^{a}	6.54^{a}	7.24^{b}	9.40^{a}
Pregel		(±0.10)	(±0.48)	(±0.46)	(±0.54)	(±0.26)
	120	4.38^{b}	5.37^{a}	6.72^{a}	7.86^{a}	9.58^{a}
		(±0.28)	(±0.29)	(±0.78)	(±0.54)	(±0.23)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.64 Model coefficient estimated by multiple linear regression for solubility of pregelatinized flour of germinated brown rice by spray dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	Solubility				
	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	4.185***	5.066***	6.068***	6.868***	8.313***
Linear					
x_1	-0.407***	-0.254*	-0.562**	-0.679***	-1.176***
x_2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	0.117*	ns	ns	ns	ns
R^2	0.896	0.396	0.586	0.773	0.978

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.5.4 Effects of spouted bed drying on solubility of germinated brown rice flour

Solubility of germinated brown rice flour and pregelatinized flour are shown in table 4.65. ‘Chainat 1’ pregelatinized flour had similar solubility as KDML 105 pregelatinized flour. In ‘Chainat 1’ pregelatinized flour, there was no significant difference between the solubility of germinated brown rice and pregelatinized flour when measurement performed at 50 °C but the solubility of pregelatinized flour increased significantly when measurement performed at 60-90 °C. In KDML 105 pregelatinized flour, there was no significant difference between the solubility of germinated brown rice and pregelatinized flour when measurement performed at 50-70 °C, but the solubility of pregelatinized flour increased significantly when the measurement performed at 80-90 °C. The reason that higher temperature during measurement increased the solubility was because hydrogen bonds inside starch molecule of the pregelatinized flour were still strong. Hence, low temperature can not destructed the bond (24).

Table 4.66 shows that variety of rice had significant effect on solubility of pregelatinized flour. Temperature had no significant effect on solubility. Similar result with pregelatinized flour from spray drying was found. This was due to the short drying time. Different temperatures gave similar destruction of starch granule hence amylose and amylopectin leaked out of the starch granules in the same amount (186).

Table 4.65 Solubility of germinated brown rice flour and pregelatinized flour by spouted bed dryer

Rice cultivars	Temperature (ºC)	Solubility at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Chainat 1 GBR		2.22^{b} (±0.02)	2.78^{c} (±0.03)	3.98^{d} (±0.04)	4.42^{d} (±0.06)	5.43^{d} (±0.20)
Chainat 1 Pregel	100	2.22^{b} (±0.07)	3.33^{bc} (±0.09)	4.97^{c} (±0.09)	5.76^{c} (±0.12)	6.67^{c} (±0.10)
	120	2.25^{b} (±0.08)	3.45^{b} (±0.07)	5.02^{c} (±0.03)	5.85^{c} (±0.17)	6.76^{c} (±0.11)
KDML 105 GBR		3.60^{a} (±0.35)	4.59^{a} (±0.58)	5.32^{bc} (±0.51)	6.19^{b} (±0.21)	7.08^{b} (±0.08)
KDML 105 Pregel	100	3.86^{a} (±0.33)	4.75^{a} (±0.35)	5.76^{ab} (±0.35)	6.84^{a} (±0.05)	8.21^{a} (±0.21)
	120	3.89^{a} (±0.37)	4.87^{a} (±0.36)	5.84^{a} (±0.26)	6.90^{a} (±0.10)	8.40^{a} (±0.29)

GBR: Germinated brown rice

Data presented are averages of triplicate analyses.

Samples means with different letters (±standard deviation) in the same column are significantly different at $p<0.05$.

Table 4.66 Model coefficient estimated by multiple linear regression for solubility of pregelatinized flour of germinated brown rice by spouted bed dryer as affected by variety of rice (x_1) and temperature (x_2)

Coefficient	Solubility				
	at 50 ºC	at 60 ºC	at 70 ºC	at 80 ºC	at 90 ºC
Constant (b_0)	3.058***	4.099***	5.395***	6.338***	7.511***
Linear					
x_1	-0.820***	-0.711***	-0.403***	-0.532***	-0.796***
x_2	ns	ns	ns	ns	ns
Interaction					
x_1x_2	ns	ns	ns	ns	ns
R^2	0.917	0.892	0.769	0.956	0.950

ns: not significant; *significant at $p < 0.05$; **significant at $p < 0.01$; *** significant at $p < 0.001$; R^2 = the adjusted R^2

4.3.6 Effects of pregelatinization on morphological properties of germinated brown rice flour

4.3.6.1 Effects of extrusion on morphological properties of germinated brown rice flour

Scanning electron micrographs illustrate morphological properties of Chainat 1 and KDML 105 germinated brown rice flour and pregelatinized flour by single scew extruder (Figure 4.2 and 4.3). Germinated brown rice flour from both rice cultivars had a rough surface and irregular shape. Flour is composed of both small and large particles due to the mechanical action during the grinding process (223). There were a greater number of small particles than large particles in pregelatinized flour as a result of high shear and pressure in extrusion process which caused the destruction of flour (224). SEM micrographs of pregelatinized flour produced from low temperature (60 °C) and high water content (1:1 flour:water ratio) showed greater content of small particles than the flour produced from higher temperature. This was in agreement with the solubility results in which highest solubility was found in the previously mentioned condition referred to more degradation of flour. Large particles were found in pregelatinized flour produced from high temperature (100 °C) and high water content (1:1 flour:water ratio) more in than the pregelatinized flour produced from the opposite condition. This result was in accordance with the swelling power results.

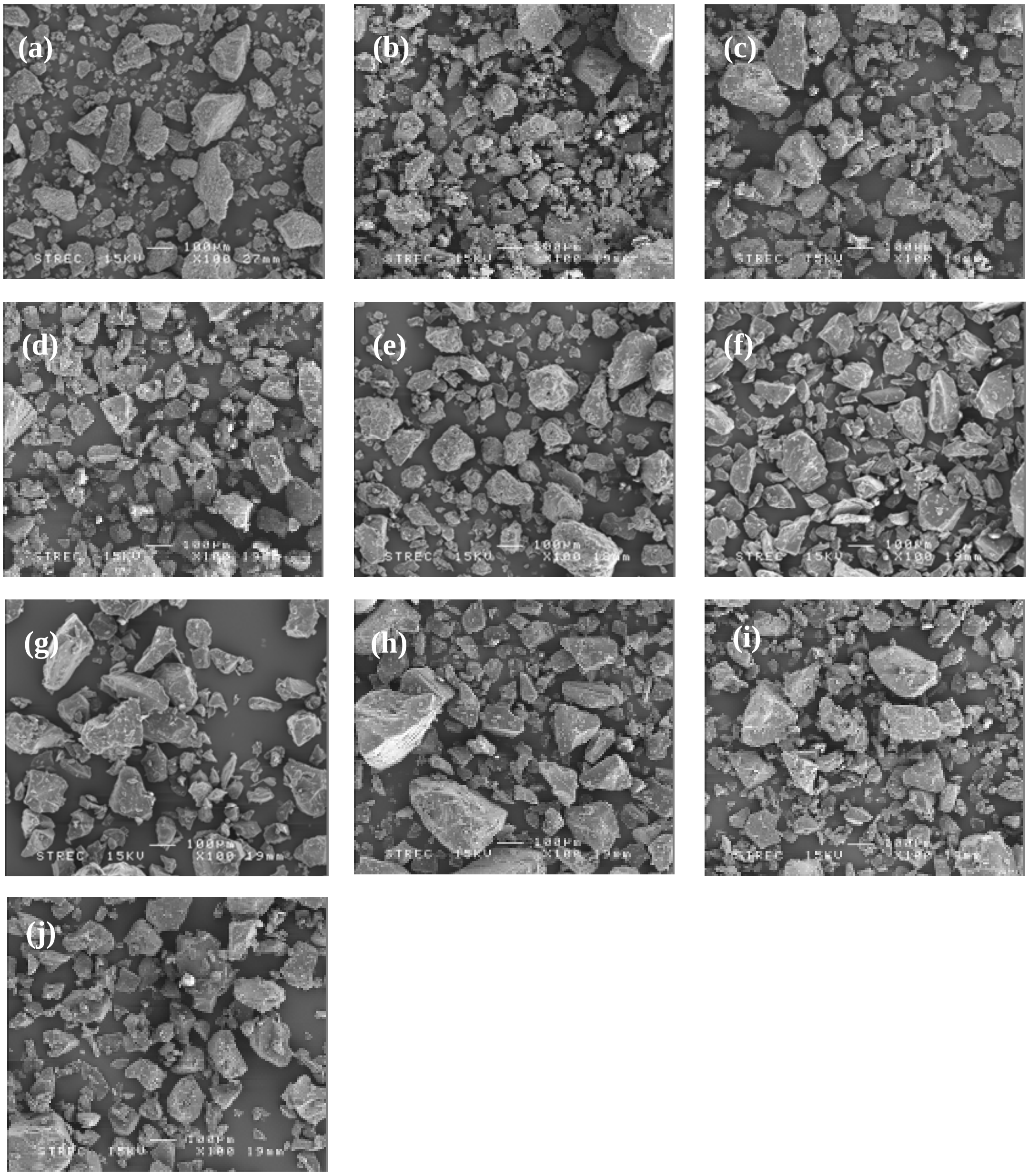

Fig. 4.2 Scanning electron micrographs (SEM) of flours from different conditions in single screw extruder: **(a)** Chainat 1 germinated brown rice flour **(b)** Pregelatinized flour produced at 3:1 flour:water ratio at 60 °C **(c)** Pregelatinized flour produced at 2:1 flour:water ratio at 60 °C **(d)** Pregelatinized flour produced at flour:water ratio 2:1 at 60 °C **(e)** Pregelatinized flour produced at flour:water ratio 3:1 at 80 °C **(f)** Pregelatinized flour produced at flour:water ratio 2:1 at 80 °C **(g)** Pregelatinized flour produced at flour:water ratio 1:1 at 80 °C **(h)** Pregelatinized flour produced at flour:water ratio 3:1 at 100 °C **(i)** Pregelatinized flour produced at flour:water ratio 2:1 at 100 °C **(j)** Pregelatinized flour produced at flour:water ratio 1:1 at 100 °C

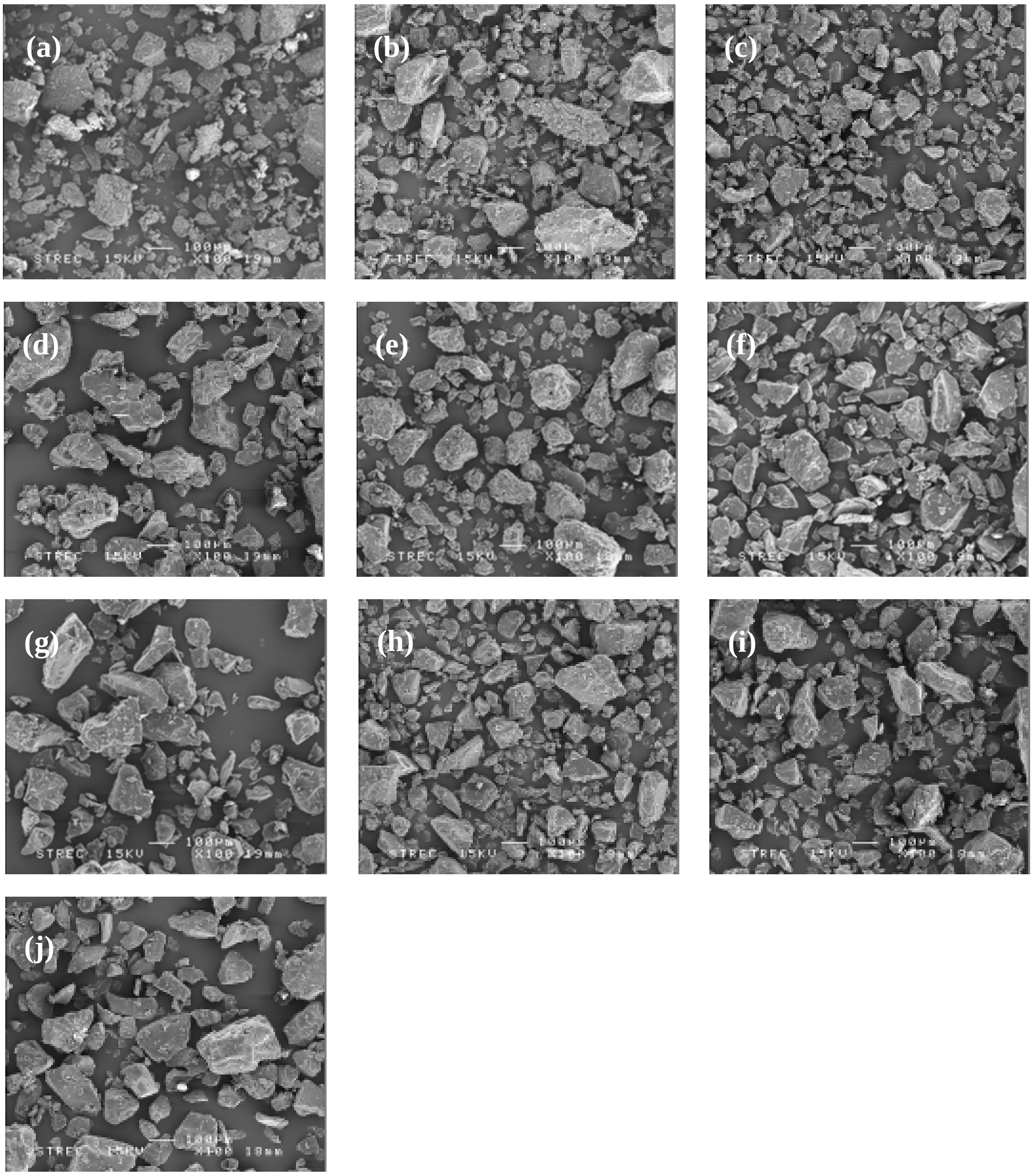

Fig. 4.3 Scanning electron micrographs (SEM) of flours from different conditions in single screw extruder: **(a)** KDML 105 germinated brown rice flour **(b)** Pregelatinized flour produced at 3:1 flour:water ratio at 60 °C **(c)** Pregelatinized flour produced at 2:1 flour:water ratio at 60 °C **(d)** Pregelatinized flour produced at flour:water ratio 2:1 at 60 °C **(e)** Pregelatinized flour produced at flour:water ratio 3:1 at 80 °C **(f)** Pregelatinized flour produced at flour:water ratio 2:1 at 80 °C **(g)** Pregelatinized flour produced at flour:water ratio 1:1 at 80 °C **(h)** Pregelatinized flour produced at flour:water ratio 3:1 at 100 °C **(i)** Pregelatinized flour produced at flour:water ratio 2:1 at 100 °C **(j)** Pregelatinized flour produced at flour:water ratio 1:1 at 100 °C

4.3.6.2 Effects of hot air oven drying on morphological properties of germinated brown rice flour

Figure 4.4 and 4.5 show scanning electron micrographs of Chainat 1 and KDML 105 germinated brown rice flour and pregelatinized flour by hot air oven. Morphological properties of pregelatinized flour were similar to those of germinated brown rice flour but pregelatinized flour exhibited larger particles than germinated brown rice flour. Increasing temperature and water content increase the particle sizes of pregelatinized flour. The particles were larger with the increasing of swelling power, indicating the loss of hydrogen bond in the starch granules. Small particles which indicated the degradation of pregelatinized flour were slightly increased compared with germinated brown rice flour. At low temperature (60 °C), more small particles were found to be in agreement with the solubility results.

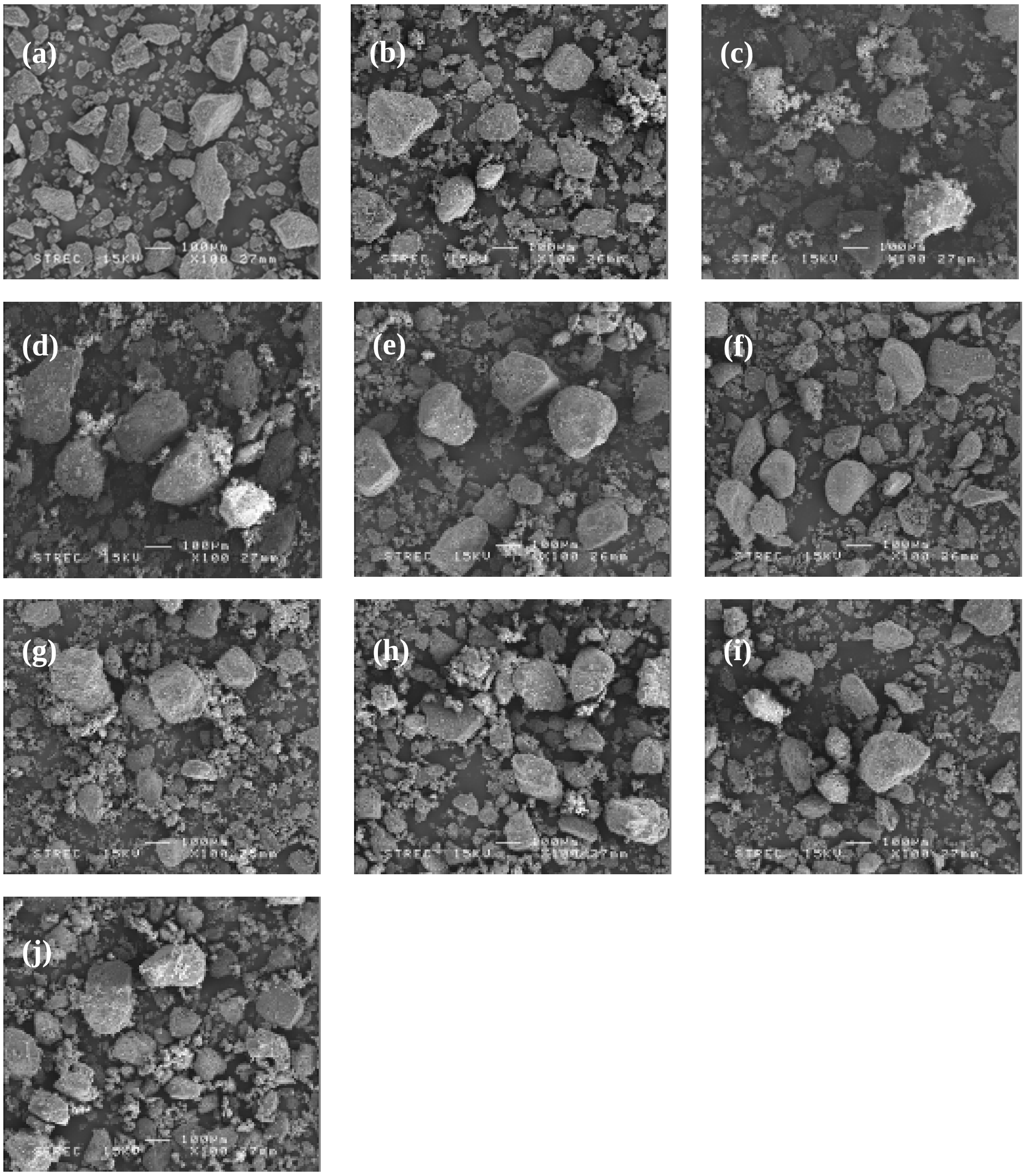

Fig. 4.4 Scanning electron micrographs (SEM) of flours from different conditions in hot air oven: **(a)** Chainat 1 germinated brown rice flour **(b)** Pregelatinized flour produced at 3:1 flour:water ratio at 60 °C **(c)** Pregelatinized flour produced at 2:1 flour:water ratio at 60 °C **(d)** Pregelatinized flour produced at flour:water ratio 2:1 at 60 °C **(e)** Pregelatinized flour produced at flour:water ratio 3:1 at 80 °C **(f)** Pregelatinized flour produced at flour:water ratio 2:1 at 80 °C **(g)** Pregelatinized flour produced at flour:water ratio 1:1 at 80 °C **(h)** Pregelatinized flour produced at flour:water ratio 3:1 at 100 °C **(i)** Pregelatinized flour produced at flour:water ratio 2:1 at 100 °C **(j)** Pregelatinized flour produced at flour:water ratio 1:1 at 100 °C

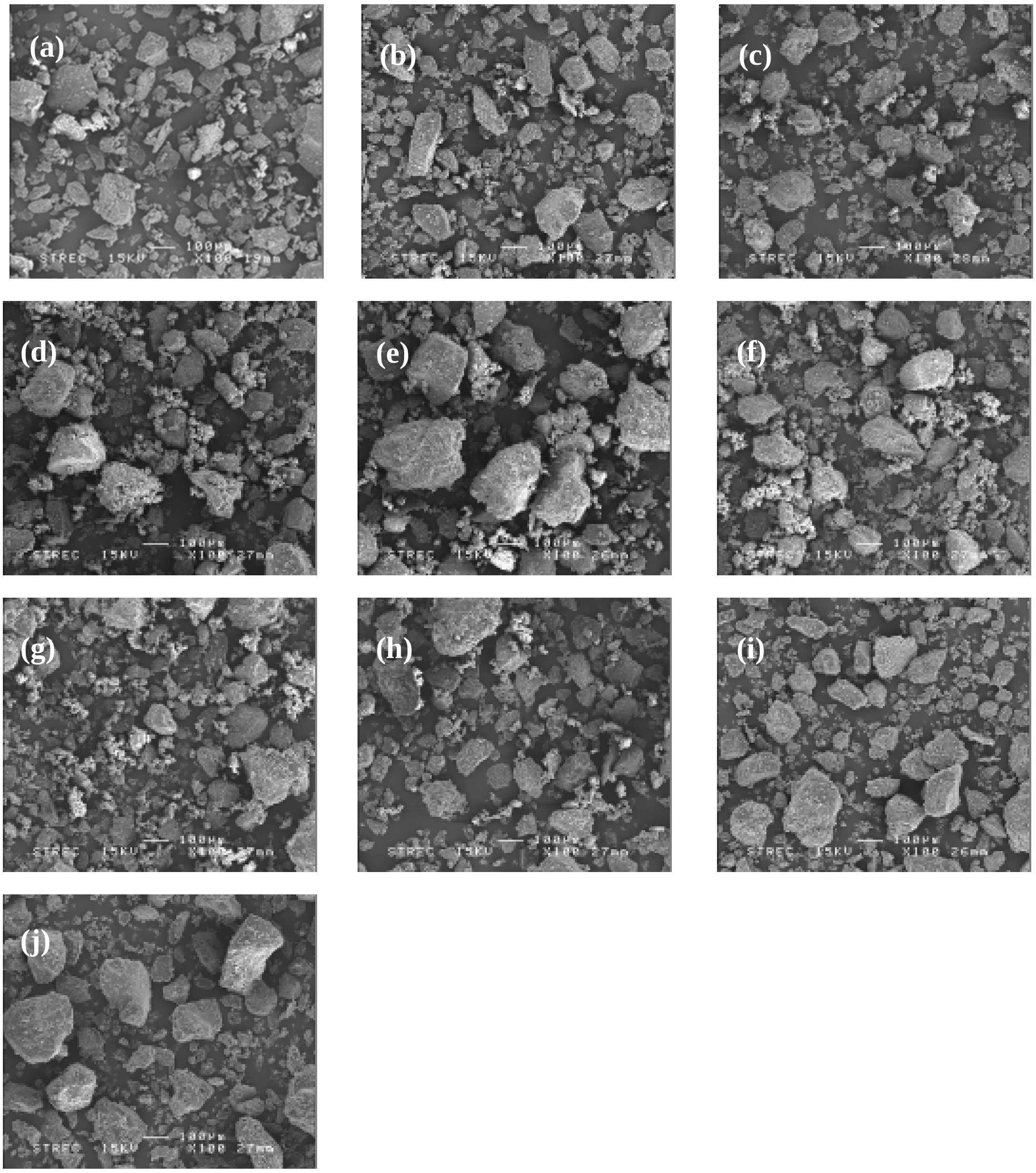

Fig. 4.5 Scanning electron micrographs (SEM) of flours produced from different conditions in hot air oven: **(a)** KDML 105 germinated brown rice flour **(b)** Pregelatinized flour produced at 3:1 flour:water ratio at 60 °C **(c)** Pregelatinized flour produced at 2:1 flour:water ratio at 60 °C **(d)** Pregelatinized flour produced at flour:water ratio 2:1 at 60 °C **(e)** Pregelatinized flour produced at flour:water ratio 3:1 at 80 °C **(f)** Pregelatinized flour produced at flour:water ratio 2:1 at 80 °C **(g)** Pregelatinized flour produced at flour:water ratio 1:1 at 80 °C **(h)** Pregelatinized flour produced at flour:water ratio 3:1 at 100 °C **(i)** Pregelatinized flour produced at flour:water ratio 2:1 at 100 °C **(j)** Pregelatinized flour produced at flour:water ratio 1:1 at 100 °C

4.3.6.3 Effects of spray drying on morphological properties of germinated brown rice flour

Figure 4.6 shows morphological properties of germinated brown rice flour and pregelatinized flour by spray dryer. Pregelatinized flour consisted in both small and large particles. Similar morphological properties with germinated brown rice flour were found. This was according to the physical properties of flour which barely changed, only viscosity was decreased significantly.

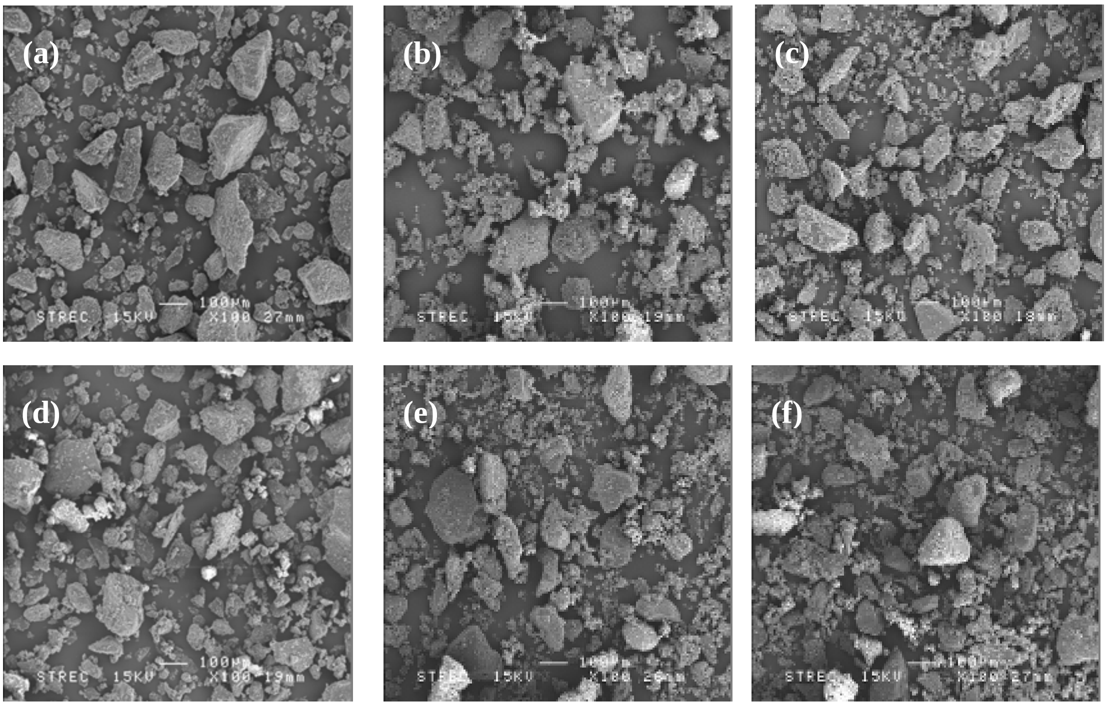

Fig. 4.6 Scanning electron micrographs (SEM) of flours produced from different conditions in spray dyer: **(a)** Chainat 1 germinated brown rice flour **(b)** Chainat 1 pregelatinized flour produced at 100 °C **(c)** Chainat 1 pregelatinized flour produced at 120 °C **(d)** KDML 105 germinated brown rice flour **(e)** KDML 105 Pregelatinized flour produced at 100 °C **(f)** KDML 105 Pregelatinized flour produced at 120 °C

4.3.6.4 Effects of spouted bed drying on morphological properties of germinated brown rice flour

Figure 4.7 shows morphological properties of germinated brown rice flour and pregelatinized flour by spouted bed dryer. Pregelatinized flour consisted in both small and large particles similar to those of germinated brown rice flour. This was conformed to the minimal change in physical properties.

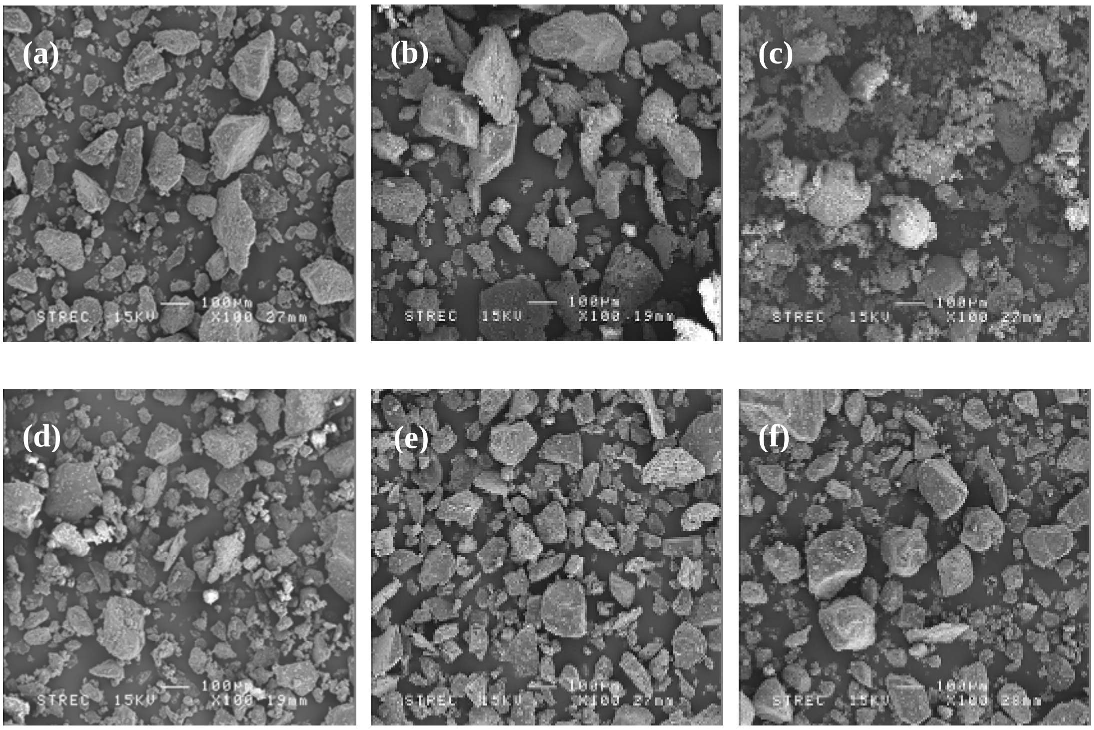

Fig. 4.7 Scanning electron micrographs (SEM) of flours produced from different conditions in spouted bed dyer: **(a)** Chainat 1 germinated brown rice flour **(b)** Chainat 1 pregelatinized flour produced at 100 °C **(c)** Chainat 1 pregelatinized flour produced at 120 °C **(d)** KDML 105 germinated brown rice flour **(e)** KDML 105 Pregelatinized flour produced at 100 °C **(f)** KDML 105 Pregelatinized flour produced at 120 °C

4.4 Comparison of different pregelatinization methods on physico-chemical properties of pregelatinized flour

Pregelatinization by every method had no effect on GABA and protein content because the temperature used in this study was lower than the destruction temperature of the substances.

Pregelatinization by extrusion gave pregelatinized flour with intermediate vitamin B1 content compared to other methods. On physical properties, the lowest pasting temperature, gelatinization and retrogradation temperature, onset temperature of storage modulus, viscosity, enthalpy and maximum storage and loss modulus were found in pregelatinized flour by this method. On the other hand, highest degree of gelatinization, % retrogradation, swelling power and solubility were found. These results could be explained by in extrusion, starch was heated and crushed with shear and pressure in the barrel which caused starch gelatinization and fragmentation. While in other methods, flour was only treated with heat, no shear was involved.

Even though in hot air oven drying, the time used in this process (30 minutes) was longer than extrusion (7 minutes) but pregelatinized flour resulted in intermediate pasting temperature, gelatinization and retrogradation temperature, onset temperature of storage modulus, viscosity, enthalpy, maximum storage and loss modulus, degree of gelatinization, % retrogradation, swelling power and solubility. As expected, lowest vitamin B1 content was found. The intermediate changes of physical properties were due to heat which was the only factor that caused gelatinization of flour.

Spray drying and spouted bed drying had similar technique which used high temperature but very short time (185). Although in these processes, temperature was higher than in extrusion and hot air oven but pregelatinized flour had highest vitamin B1, pasting temperature, gelatinization and retrogradation temperature, onset temperature of storage modulus, viscosity, enthalpy, maximum storage and loss modulus but lowest degree of gelatinization, % retrogradation, swelling power and solubility. This happened because the short time (15-30 seconds) in processing was not enough for heat to penetrate the flour and gelatinize the starch (185).

When the physical properties of germinated brown rice pregelatinized flour were compared with other pregelatinized flour, it was found that germinated brown rice pregelatinized flour produced from this study had higher pasting temperature, gelatinization and retrogradation temperature, onset temperature of storage modulus, viscosity, enthalpy, maximum storage and loss modulus but lower in degree of gelatinization, % retrogradation, swelling power and solubility. This might be due to the conditions used in this study were less severe than in other studies i.e. lower temperature, shorter barrel length and slower screw speed (186-189, 216).