CHAPTER IV

RESULTS AND DISCUSSION

All rice cracker samples including controls were made from similar cracker formulation. The difference between treatment samples and controls was the flour types used in the formulation. A mixed flour blend, or sometimes being referred as a formulated flour (FF), was used for all treatment rice crackers whereas negative and positive controls in this research were made of 100% commercial rice flour and 100% wheat flour, respectively. A mixed flour blend used rice flour to partially substitute wheat flour in the formulation. The formula has been modified from the original wheat cracker formulation (Ratanatriwong, 2007), and it is confidential from the manufacturer (Sin Salee Snack & Buiscuit, Ltd. Part., Bangkok).

Effects of raw material and primary processing of rice flour on rice crackers were studied. In this experiment, rice cultivars, flour milling types and flour particle sizes were varied. A series of experiment started with exploring the effect of rice cultivar, flour milling types and rice flour particle size, consequently. The selected rice cultivar, flour milling type and flour particle size was then used for the following experiments in the series.

Effect of rice cultivar and amylose content on rice cracker qualities.

1. Effect of rice cultivar and amylose content on physical and chemical properties of rice crackers.

For effect of rice cultivars, all samples including controls were made of dry milling flour with fixed particle size of 139 μm. Three rice cultivars including Chainat1, PathumThani1 and Surin1 were used and compared with controls.

The gel consistency is the method used to measure the flowing distance of cooled cooked rice flour gel. The measured distance of 26-40 mm., 41-60 mm., and 61-100 mm. corresponds to hard, intermediate soft and soft gel qualities, respectively. The amylose content of Surin1-rice flour was the highest followed by those of

Pathumthani1, Chainat1 and wheat flours, respectively. The protein content of wheat flour was higher than the others ($p \leq 0.05$).

The result showed that gel consistency value of Chainat1, PathumThani1 and Surin1 with the distance of 61-100 mm., were classified as soft gel quality (Keeratipibul, et al., 2008). The amylose content of Chainat1 rice flour was the highest followed by those of Pathumthani1, Surin1 and wheat flours, respectively. The protein content was calculated from Kjeldahl nitrogen multiplied by the factor 5.95, as based on the nitrogen content (16.8%) of the major rice protein (glutelin) (Juliano, 1985). No significant difference was found between those of Chainat1 and Pathumthani1, which were 7.14 and 7.28, respectively. The wheat flour had protein content higher than others. This was due to gliadins and glutenins that are storage protein which cover about 75% of total protein content in wheat grains (Belderok, Mesdag and Donner, 2000).

Table 5 Gel consistency, amylose and protein contents of various cultivar of rice Flour

Variety	Gel consistency (mm)	Amylose content (%)	Protein content (%)
Chainat1	$74.0^{b}\pm0.78$	$31.49^{a}\pm1.74$	$7.28^{b}\pm0.24$
Pathumthani1	$88.0^{ab}\pm1.44$	$23.55^{b}\pm3.61$	$7.14^{b}\pm0.59$
Surin1	$109.7^{a}\pm1.72$	$21.91^{b}\pm0.35$	$6.41^{c}\pm0.37$
Wheat	$48.0^{c}\pm0.00$	$9.61^{c}\pm0.15$	$11.46^{a}\pm0.07$

Note: Different letters in the same column indicated statistical differences ($p \leq 0.05$).

Table 6 Physical and chemical properties of rice crackers made of flour from different cultivars

sample	CRF	WF	Surin1	Chainat1	Pathumthani1
moisture content (%)	3.42±0.06[d]	5.60±0.04[a]	5.17±0.23[b]	5.07±0.22[c]	5.38±0.11[ab]
water activity (a_w)	0.20±0.01[c]	0.38±0.01[a]	0.36±0.02[ab]	0.34±0.02[b]	0.37±0.01[a]
hardness (kg.f.)	0.76±0.15[d]	2.04±0.24[c]	3.12±0.20[b]	3.80±0.25[a]	3.24±0.16[b]
puffiness (%)	20.33±8.53[c]	60.33±4.72[a]	40.25±1.10[b]	34.77±0.85[b]	35.78±0.78[b]
brightness (L*)	60.63±0.71[d]	64.88±0.34[a]	61.83±1.64[c]	63.17±0.63[b]	59.94±0.82[d]
redness (a*)	3.35±0.94[c]	5.66±0.46[a]	4.86±0.41[b]	4.73±0.38[b]	5.83±0.44[a]
yellowness (b*)	29.03±0.52[d]	31.38±0.63[b]	33.32±0.94[a]	32.60±0.75[a]	29.98±0.45[c]
hue angle	83.43±1.77[a]	79.78±0.82[c]	81.70±0.68[b]	81.73±0.71[b]	78.99±0.77[c]
chroma	29.24±0.57[d]	31.89±0.63[b]	33.68±0.95[a]	34.94±0.90[a]	30.55±0.48[c]

Note: Different letters in the same row indicated statistical differences ($p \leq 0.05$).

CRF (100% commercial rice flour) and WF (100%wheat flour)

The physical and chemical properties of rice crackers made from various rice-cultivar flours were presented in Table 6. The results showed that the moisture contents of rice crackers made of various rice cultivar flours were significantly different ($p \leq 0.05$). It was observed that Pathumtani1 and Surin1 rice crackers had their moisture contents closer to control wheat crackers ($p > 0.05$) whereas those of Chainat1 and control rice cracker were lower ($p \leq 0.05$). The negative rice cracker control (CRF) had the lowest moisture content. Likewise, the water activity values of Pathumtani1 and Surin1 rice crackers were close to wheat cracker but those of Chainat1 and control rice crackers were significantly lower ($p \leq 0.05$). The reason may be that dough from rice flour may have lower water holding capacity than wheat or the formulated-flour doughs, thus it led to the texture of CRF cracker being rather crumbly and brittle.

According to cracker texture, Chainat1 sample was the hardest followed by Pathumtani1, Surin1, wheat, and control rice crackers, respectively ($p \leq 0.05$). This may be due to the high amylose content in Chainat1 flour. However, all cracker samples were harder and less brittle than wheat and control rice crackers. For control rice cracker, the hardness was low because cracker was too crumbly and brittle. When considering with puffiness, it was obvious that wheat cracker was significantly puffier than others so sample had inner layers that resulted in the light crisp and brittle texture. Although, no significant difference was found in puffiness amongst various rice cultivars, Surin1 cracker had its puffiness closer to wheat cracker, causing texture to be less hard. The control rice cracker had the lowest puffiness because it was difficult for dough of 100% rice flour to hold the gas. In terms of color, control rice cracker was significantly paler with less redness and yellowness than others ($p \leq 0.05$) whereas when considering all color parameters, Pathumthani1 crackers seemed to have closer color values to wheat crackers ($p > 0.05$).

2. Effect of rice cultivars on rheological properties of rice crackers.

The rhelogical property describes the flow properties of a material that uses both stress- shear rates and viscosity curves. In addition, the rheometers measure the normal force within a system, its relaxation modulus, relaxation time, and compliance in unsteady flow. This allows rheometers to provide additional information such as elasticity on material undergoing testing (Weipert, 1987). A dynamic oscillatory rheometer can assess the frequency-dependent properties of materials being tested. The phase lag angle between stress and strain is measured by using a sinusoidally oscillating deformation of known magnitude and frequency. Then, it is used to calculate the elastic (storage modulus or G′) and viscous (loss modulus or G″) (Weipert, 1990). The deformation causes by high strains as shown in a frequency sweep from low of 0.01% and high of 100% strain are partly reversible (Weipert, 1987). In contrast, at very low strains (0.1%) dough would exhibit linear viscoelastic behavior.

The variation of storage modulus (G′) and loss modulus (G″) with frequency sweep from 10 to 0.1 Hz for treatment dough from various-rice-cultivar flour and controls was shown in Figure 4. The amplitude sweep test (strain sweep) shown in Figure 5 was used to identify the linear viscoelastic region by determining the linear viscoelastic range and the critical strain (LVE) of dough by fixing the frequency that helped explaining the structure stability or how sample resists moving by force under the fixing frequency. The frequency sweep test provided the information of dough rheological changes concerning the structure, molecular structure and viscoelastic behavior (Angioloni and Rosa, 2007). The storage modulus G' of commercial-rice-dough control was the highest followed by dough of Chainat1, Patumtanee1, Surin1 and control wheat flours, respectively (Figure. 4-5). All treatment samples made of a mixed flour blend also had higher critical strain values than controls, indicating that they needed more strain to move the sample than controls did. Figure 4 showed the frequency sweep test result, which provided information concern the structure, molecular structure and viscoelastic behavior. All samples had the storage modulus G' (elastic property) higher than the loss modulus G″ (viscous property), indicating that dough was more elastic than viscous. This to corresponded to previous with research on rice pasta dough that modulus value increased with frequency for all samples (Sozer, 2009). The control dough from commercial rice flour had a higher modulus than the other samples, showing tougher structure that the rest.

Based on results from both amplitude and frequency sweep tests, it was observed that, when kneading, the treatment dough was more rubbery-like elastic, which was probably due to the pregelatized flour in the blend that increased the elasticity. According to Sivaramakrishnan, et al., (2004), the moduli were higher for composite flour than that of wheat flour dough. This may be attributed to the difference between interaction of starch-gluten in composite flour and the interaction in 100% wheat dough that the starch granules in the dough act as filler that reinforces the gluten and produce strong bonds to given higher modulus. It was noticeably different from the wheat dough, which was more elastic, extensible and machaniability. According to high G' value of control rice dough, it was also observed that dough was harder to knead, and tended to be easily torn by kneading or layering the sheeted dough. Amongst all treatment samples, dough from Chainat1 also had higher storage modulus than others whereas that of Surin1 was close to the control wheat dough. This was also observed that dough from Surin1 was more elastic, more extensible and required less force to knead than samples from other cultivars. Thus, Surin1 flour was selected to use in the next following research steps.

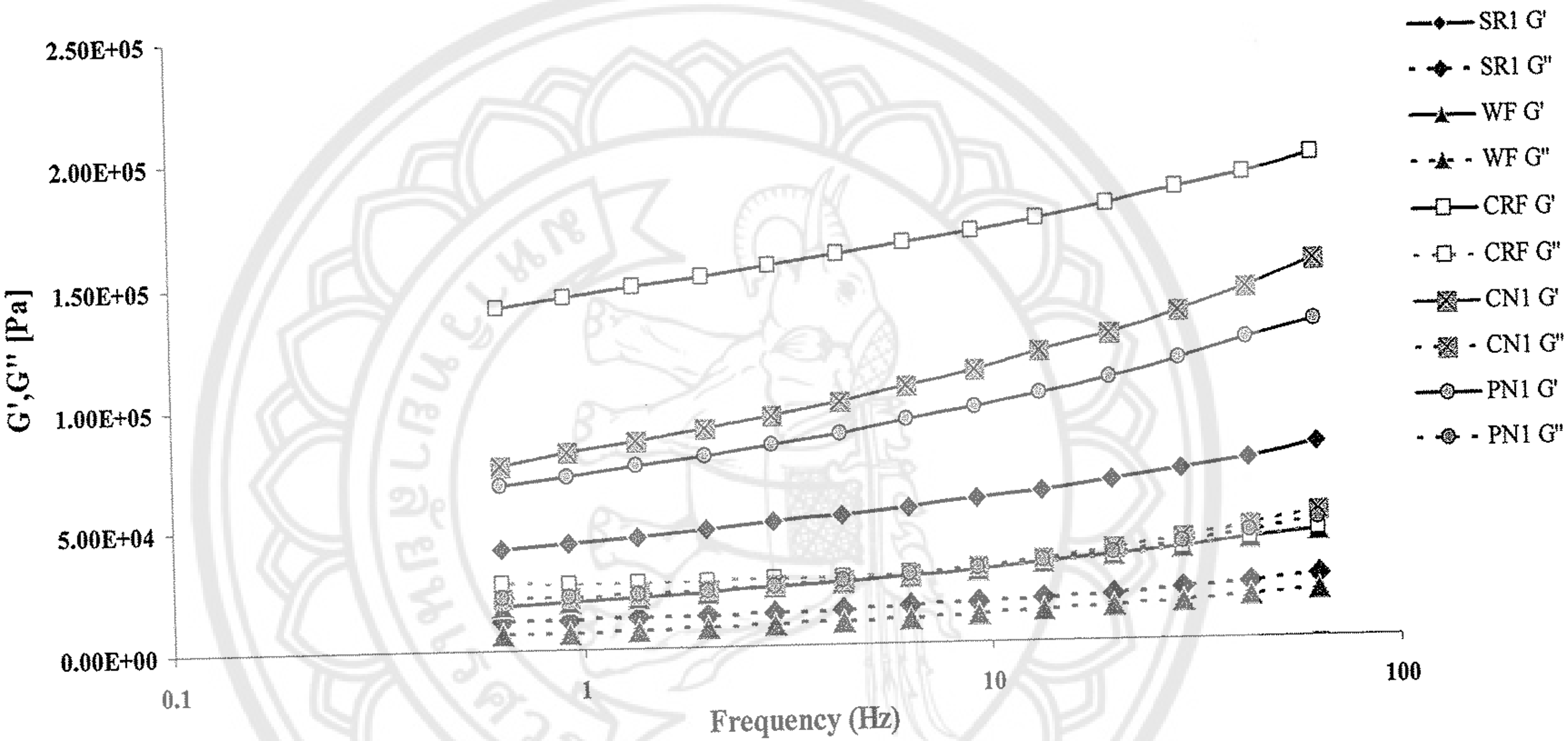


Figure 4 Effect of rice cultivars on rheological properties of rice cracker

Note: SR1, CN1 and PN1 referred to treatment crackers from Surin1, Chinat1 and Pathumthani1 rice flour. WF and CRF referred to controls from wheat and commercial rice flour.

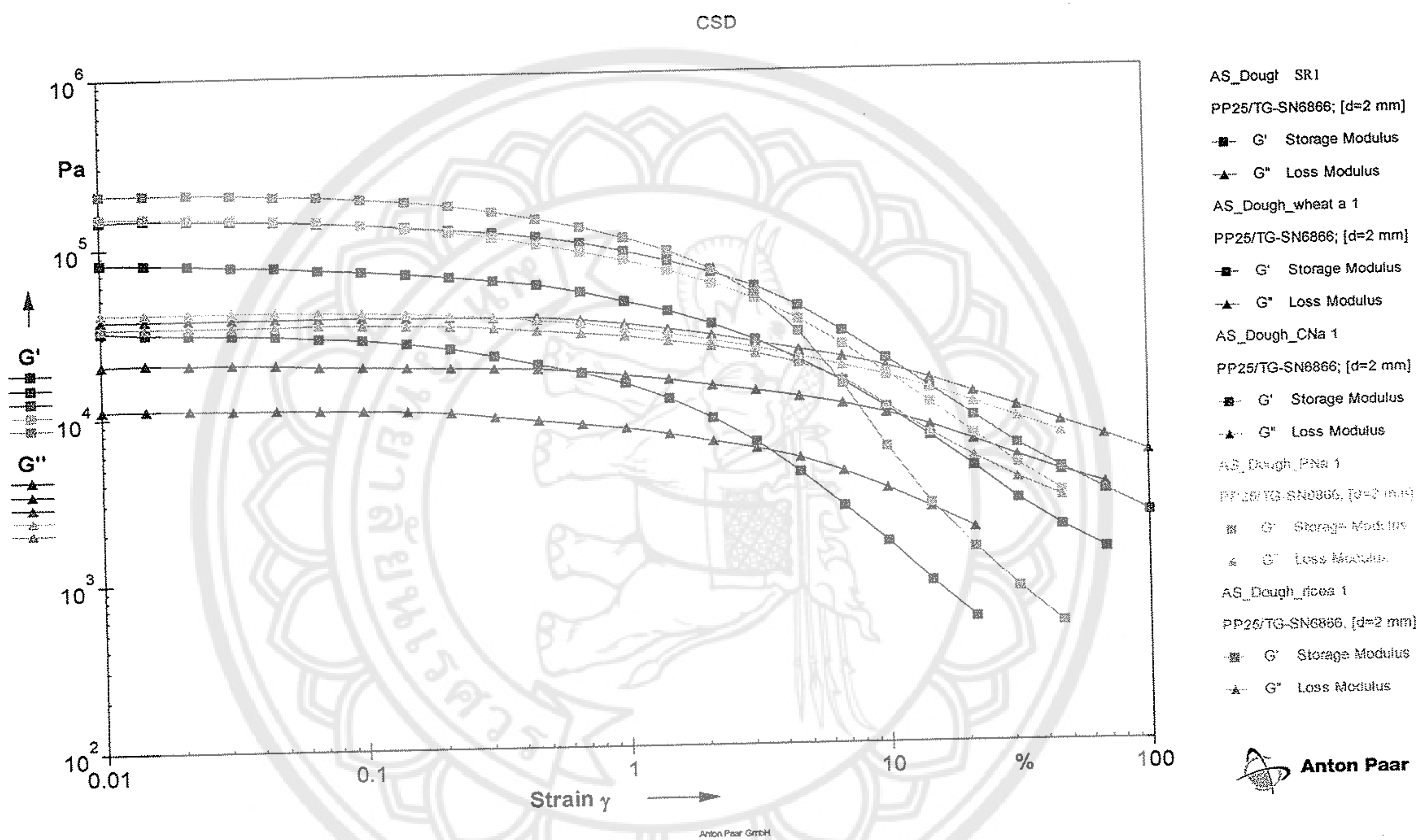


Figure 5 Rheological properties (amplitude sweep test) of rice cracker dough from different cultivars

Note: SR1, CN1 and PN1 referred to treatment crackers from Surin1, Chinat1 and Pathumthani1 rice flour.

WF and CRF referred to controls from wheat and commercial rice flour.

Effect of flour milling types on rice cracker qualities.

After the rice cultivar was chosen, flour milling type effect was explored. Samples were made of Surin1 rice flour with fixed particle size of 139 μm. The results of physical and chemical properties of rice crackers from different flour milling types were compared with negative (100% rice flour) and positive (100% wheat flour) controls and were presented in Table 7-8.

In this research, the starch damage of dry-milling and wet-milling Surin1 flours, which were used in this research, were 10.79% and 2.83% respectively. For rice cracker qualities, there were significant differences in moisture content, water activity (a_w), hardness, puffiness and color amongst rice cracker samples ($p \leq 0.05$) (Table 7-8). The moisture contents of cracker samples indicated that rice crackers made of wet milling flour and dry milling flour were not significantly different ($p > 0.05$) from wheat-flour cracker (positive control) but the negative control made of 100% rice flour, had the lowest moisture content ($p \leq 0.05$). This result was similar to that of Suksomboon and Naivikul, (2006) who reported higher water absorption index and protein content in dry milling flour as compared to wet milling flour.

Generally, the flour milling process damages starch granule, and dry milling process usually causes more mechanical damage than wet milling (Chiang and Yeh, 2002; Suksomboon and Naivikul, 2006; Yoenyongbuddhagal and Noomhom, 2002). The damaged starch can easily absorb a large amount of water, thus dry milling flour can absorb more water than wet milling flour. In addition, three more steps including soaking rice kernel, adding more water and removing excess water were added in the wet milling process (Juliano,1985; Suksomboon and Naivikul, 2005). By doing so, some of soluble protein, sugar and non-starch bound lipids were removed with excess water by their cleaning process, resulting in lower contents of these matters in wet milling flour (Suksomboon and Naivikul, 2005). Also, some of water-absorbed starch, which is mixed in the upper layer of protein, maybe washed away in wet milling flour as compared to dry milling flour.

In term of texture, rice cracker made of wet milling flour was the hardest followed by wheat, dry-milling-flour and rice crackers, respectively (Table 7). Dry milling flour samples had its hardness closer to wheat crackers than that of wet milling flour samples. The result was in the same manner as that of

Yoenyongbuddhagal and Noomhorm, (2005) who found that rice vermicelli made from dry milling flour was softer than that of wet milling. As of puffiness, wheat cracker was the puffiest followed by dry-milling-flour, wet-milling-flour and rice crackers, respectively (Table 7). No significant difference was found between dry milling and wet milling samples (p>0.05), but both of them were significantly more puffy than control rice crackers (p≤0.05).

Table 7 Physical and chemical properties of rice crackers made of flour from various milling types

properties	CRF	WF	Milling types	
			dry-mill flour	wet-mill flour
Moisture content (%)	3.42±0.06^{b}	5.60±0.04^{a}	5.22±0.13^{a}	5.41±0.17^{a}
Water activity (a_w)	0.20±0.01^{d}	0.38±0.01^{a}	0.33±0.01^{c}	0.36±0.01^{b}
Hardness (Kg.F.)	0.76±0.15^{d}	2.04±0.24^{b}	1.81±0.12^{b}	2.35±0.33^{a}
Puffiness (%)	20.33±8.53^{c}	60.33±4.72^{a}	43.66±2.53^{b}	35.37±1.93^{b}

Note: Different letters in the same row indicated statistical differences (p≤0.05).

CRF (100% commercial rice flour) and WF (100%wheat flour)

Table 8 Color value of rice crackers made of flour from various milling types

properties	CRF	WF	Milling types	
			dry-mill flour	wet-mill flour
Brightness (L*)	60.63±0.07[c]	64.89±0.34[a]	63.82±0.77[b]	65.11±1.06[a]
Redness (a*)	3.35±1.45[b]	5.66±0.46[a]	6.27±0.58[a]	6.05±0.73[a]
Yellowness (b*)	29.04±0.55[c]	31.39±0.63[b]	32.86±0.50[a]	32.95±0.86[a]
Hue angle	83.45±2.70[a]	79.78±0.81[b]	79.20±1.01[b]	79.60±1.01[b]
Chroma	29.24±0.71[b]	31.89±0.34[b]	33.46±0.49[a]	33.51±0.96[a]

Note: Different letters in the same row indicated statistical differences ($p \leq 0.05$).

CRF (100% commercial rice flour) and WF (100%wheat flour)

The color values of rice cracker made from dry milling flour and wet milling flour were shown in Table 7. The brightness (L*) of both samples were closer to control wheat samples, and were brighter than 100% rice samples. According to redness (a*), yellowness (b*), hue angle and chroma value, the color of both samples were golden-yellow, which were closer to wheat cracker than rice cracker control.

According to the above result, dry milling flour seemed to be more suitable for rice cracker than wet milling flour. Thus, dry milling flour was selected for the next experiment.

Effect of particle size on rice cracker qualities.

After rice cultivar and flour milling type effects were explored, the effect of flour particle size was determined. Flours was sieved through a series of standard sieves at 50 mesh (299 μm), 100 mesh (139 μm), 140 mesh (103 μm) and 230 mesh (63 μm), resulting in flour with four various particle size of 63-299 μm, respectively.

Based on the result from all above experiments about effects of raw material and its primary processing on rice crackers, the dry milling flour from Surin1 rice cultivar with the flour particle size between 103-139 μm was suggested to use for the next step of this research.

Rice cracker samples, using of mixed flour blend formulation, were prepared with rice flour from various particle sizes including 63 μm, 103 μm, 139μm and 299 μm respectively. The physical and chemical properties of treatment samples were compared with two controls including rice cracker (100% commercial rice flour) as negative control and wheat cracker (100% wheat flour) as positive control. All samples including controls were made of dry milling flour.

There were significant differences in all samples in moisture content, water activity (a_w), hardness, puffiness and color value ($p \leq 0.05$). Table 9 showed the physical and chemical properties of samples from various flour particle sizes. Samples from the smallest particle-size flour (63 μm) had the highest moisture content ($p \leq 0.05$). The moisture contents of all rice cracker samples were closer to wheat cracker and higher than control rice cracker. The result also showed that the water activity of samples were higher than control rice cracker. The water activity of samples ranged from 0.23-0.52, and there were significant differences amongst samples ($p \leq 0.05$). Samples made of flour with 63- and 103-μm particle sizes had the highest water activity. It was noticeable that as flour particle size decreased, the moisture content and water activity tended to increase. This may be due to the fact that starch damage can absorb a large amount of water (Suksomboon, 2006). The dry milling process, a hammer mill, used for grinding flour causes high temperature during grinding that has and mechanical impact to flour and starch granule, leading to more starch damage in small-particle flour than large-particle flour.

Table 9 Properties of rice crackers from various particle sizes

samples	Properties			
	Moisture content (%)	Water activity (a_w)	Hardness (kg.f.)	Puffing (%)
CRF	3.42±0.06^{e}	0.19±0.01^{d}	0.76±0.15^{d}	20.33±8.53^{c}
WF	5.60±0.03^{b}	0.38±0.01^{b}	2.03±0.24^{b}	60.33±4.72^{a}
63 µm	6.46±0.02^{a}	0.50±0.03^{a}	2.55±0.29^{a}	34.40±2.39^{b}
103 µm	4.94±0.12^{d}	0.52±0.01^{a}	1.75±0.29^{c}	40.25±1.11^{b}
139 µm	5.19±0.07^{cd}	0.28±0.02^{c}	2.30±0.24^{a}	39.72±1.12^{b}
299 µm	5.14±0.07^{bc}	0.23±0.01^{d}	1.60±0.22^{c}	35.67.±0.87^{b}

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF (100% commercial rice flour) and WF (100%wheat flour)

Table 10 Effect of particle size on color of rice crackers shown by values of *L, *a**, *b**, hue angle and chroma**

samples	Color parameter				
	*L**	*a**	*b**	Hue angle	chroma
CRF	60.63±0.07^{e}	3.35±1.45^{b}	29.04±0.55^{cd}	83.43±2.70^{c}	29.24±0.70^{b}
WF	64.89±0.34^{b}	5.66±0.46^{a}	31.39±0.63^{a}	79.78±0.81^{d}	31.89±0.30^{a}
63 µm	62.20±0.86^{d}	2.51±0.70^{c}	28.16±0.96^{d}	84.91±1.41^{b}	28.28±0.97^{c}
103 µm	63.89±0.62^{c}	2.69±0.38^{c}	30.16±1.17^{b}	84.89±0.85^{b}	30.28±1.15^{b}
139 µm	67.55±0.72^{a}	1.38±0.27^{d}	26.11±1.41^{e}	86.97±0.57^{a}	26.14±1.41^{d}
299 µm	63.37±1.38^{c}	3.39±0.98^{b}	29.37±0.70^{cb}	83.43±1.87^{c}	29.58±0.73^{b}

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF (100% commercial rice flour) and WF (100%wheat flour)

Likewise, rice cracker made of the finest particle was the hardest. As flour particle size decreased samples seemed to be harder, but the trend was not obvious. However, it seemed like crackers made from flours with particle size between 103-139 μm had the hardness closer to wheat cracker. This agreed with the case of akara made from fine cowpea flour that finer flour was denser than the coarse one (Kerr, et al., 1986). This exhibited a decrease in hydration and air incorporation. The presence of an enhanced starch network or the early build-up of viscosity, may also cause less air incorporation which resulted in denser texture in products made from fine cowpea flour (Kerr, et al., 2001). As for puffiness, no significant difference was found amongst treatment samples. They all were less puffy than wheat cracker but more puffy than rice cracker control ($p \leq 0.05$).

According to Table 10, the influence of flour particle size on color of rice crackers was obscure however treatment samples did have color values in all parameters significantly different from controls ($p \leq 0.05$). The brightness of treatment samples was closer to wheat crackers than control rice crackers. Some treatment samples appeared to have its yellowness closer to wheat crackers, but there was no clear trend on how it changed with changing particle size. The result was in similar manner with redness, hue angle and chroma values.

Based on the result from all above experiments about effects of raw material and its primary processing on rice crackers, the dry milling flour from Surin1 rice cultivar with the flour particle size between 103-139 μm was suggested to use for the next step of this research.

Effect of different hydrocolloids on qualities of rice crackers.

1. Effect of different hydrocolloids on rice cracker physical and chemical properties.

Rice cracker samples made of mixed flour blend with rice flour partially substituted were prepared with adding various hydrocolloids including CMC, HPMC and xanthan gum. The physical and chemical properties of treated samples were determined and compared with non-hydrocolloid-added controls including commercial rice flour (CRF), wheat flour (WF) and formulated flour (FF) (Figure 6-9).

All samples had significant differences in moisture content, water activity (a_w), hardness, toughness and puffiness ($p \leq 0.05$). Addition of hydrocolloids increased in the moisture content of all hydrocolloid-added samples with increasing usage level of hydrocolloids when compared to rice-flour and formulated-flour controls (Figure. 6). This may be owing to water retention properties of modified polysaccharide derivatives for some hydrocolloids such as CMC and HPMC. The result may be due to the hydroxyl groups in the hydrocolloids structure that allow interaction through hydrogen bonding. Hydrocolloids addition increased the water absorption and the extent of increasing depends on the structure of the hydrocolloids which were added in bread product (Rosell et al., 2001). In addition, Barcenas and Rosell, (2005) reported that the HPMC network, which was formed during baking, could act as a barrier to the gas diffusion, which decreased the water vapour losses, hence it caused increases in moisture content of products with hydrocolloid addition. Likewise, the water activity value of rice cracker tended to increase with hydrocolloids additions (Figure 7). The trend was due to the water holding capacity of hydrocolloids as discussed above (Rosell, et al., 2001). This result was expected because hydrocolloids is known to help increasing the water holding capacity of samples due to the chemical structure of hydrocolloids and their interaction with the food ingredients (Lazaridou, et al., 2007; Rosell, et al., 2001).

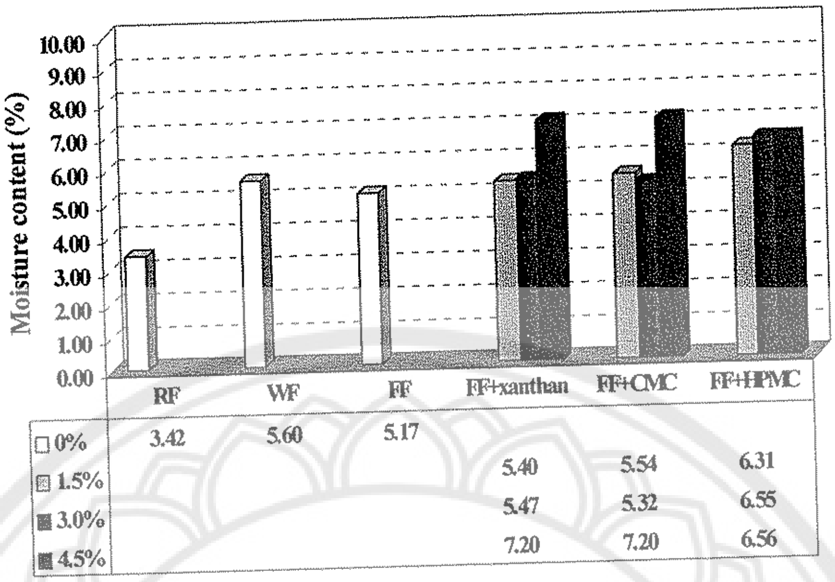


Figure 6 Effect of hydrocolloids on moisture content of mixed-flour blend rice crackers

Note: CRF (100% commercial rice flour) and WF (100%wheat flour)

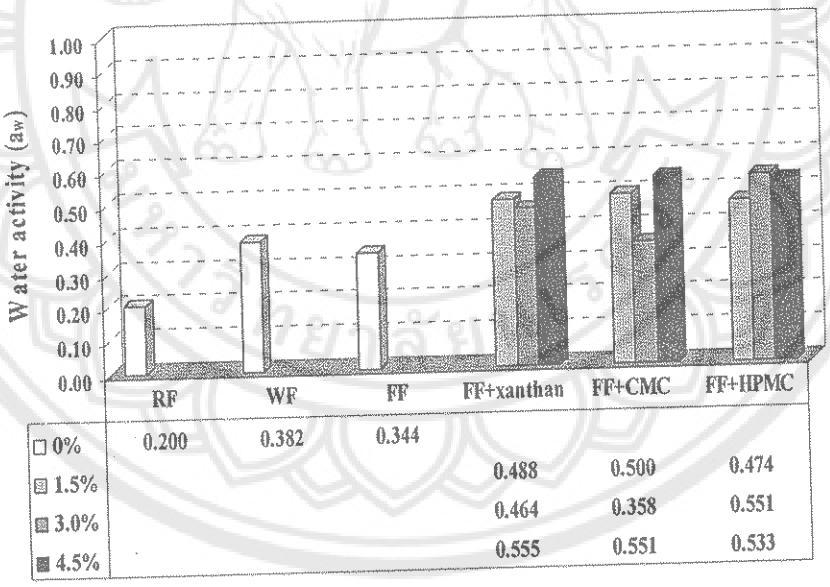


Figure 7 Effect of hydrocolloids on water activity of mixed-flour blend rice crackers

Note: CRF (100% commercial rice flour) and WF (100%wheat flour)

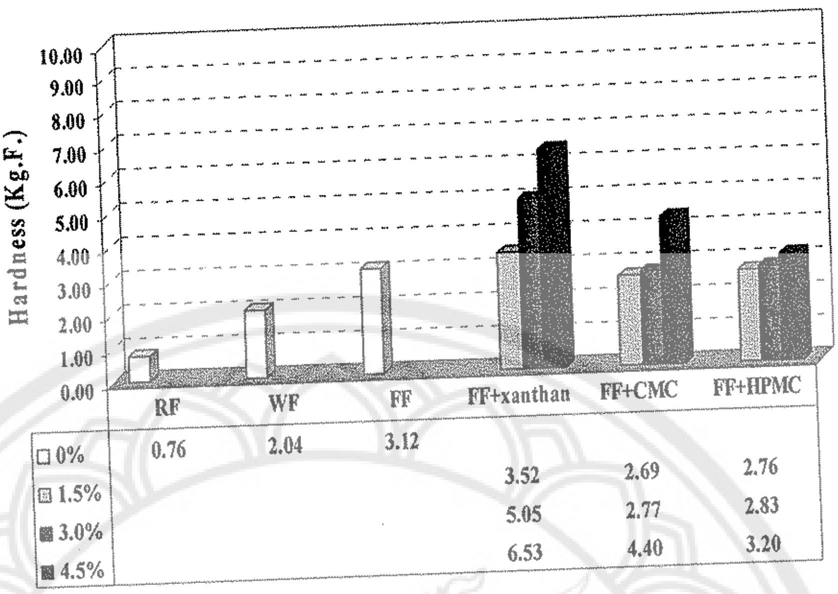
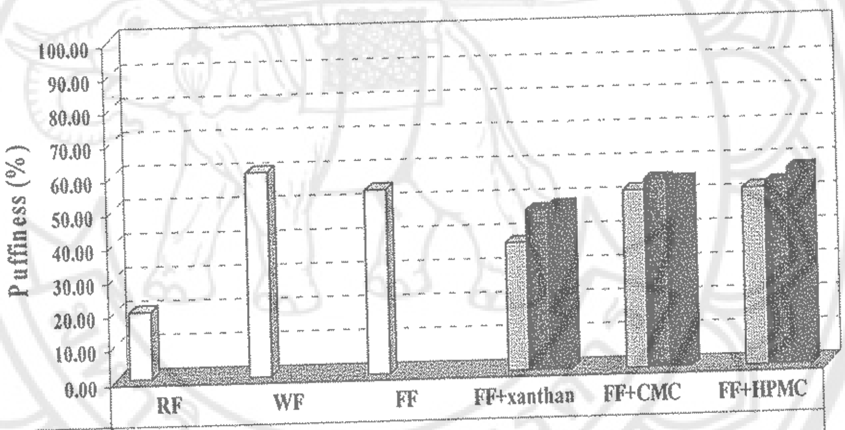


Figure 8 Effect of hydrocolloids on hardness of mixed-flour blend rice crackers

Note: CRF (100% commercial rice flour) and WF (100%wheat flour)

The result above complied with texture result (Figure 8) that addition of hydrocolloid improved texture of crackers that some hydrocolloid-treated samples, especially with 1.5% addition, had its hardness and toughness closer to wheat flour. No significant difference was found amongst rice cracker samples adding 1.5% and 3.0% of CMC and HPMC. However, when using CMC and HPMC at 4.5% and all usage levels of xanthan gum, rice cracker samples had very high hardness ($p \leq 0.05$). For control rice cracker, its texture was the most crumbly, least expansion and most brittle that cracked readily, whereas the rest of hydrocolloid-added formulated-flour samples and formulated-flour control were harder than wheat cracker (Figure 8). This was due to the lack of gluten in rice flour since gluten is the most important structure forming protein (Sivaramakrishnan, et al., 2004; Ashwini, et al., 2009). The formulated-flour control cracker with wheat flour partially substituted had slightly harder and tougher texture with less expansion than wheat cracker.

All of the above result agreed with other scientific reports that hydrocolloids helped increasing water absorption and gas retention of dough so specific properties of baked products such as texture were improved (Lazaridou, et al., 2007; Sivaramakrishnan, et al., 2004). However, texture of samples with 4.5% hydrocolloids were too hard and too tough. This may be due to the fact that dough system becomes too rigid to incorporate gas (Sivaramakrishnan, et al., 2004). In addition xanthan is reported to unexpectedly decrease the height of wheat-flour dough (Rosell, et al., 2001). It is explained that the interaction between these hydrocolloids and protein in wheat flour may conversely limit the free expansion of wheat dough during proofing, and they found in crumb xanthan gum added had a great increase of the crumb firmness probably due to the thickening of the crumb wall surrounding air spaces as leading to the strengthening of crumb in bread (Rosell, et al., 2001).



	RF	WF	FF	FF+xanthan	FF+CMC	FF+HPMC
0%	20.33	60.33	54.55			
1.5%				38.18	52.73	52.73
3.0%				47.64	55.64	54.18
4.5%				48.36	54.91	57.82

Figure 9 Effect of hydrocolloids on puffiness of mixed-flour blend rice crackers

Note: CRF (100% commercial rice flour) and WF (100%wheat flour)

The puffiness of all cracker samples with hydrocolloids was higher than control rice cracker, and some hydrocolloid-treated samples showed higher puffiness than formulated-flour control (Figure 9). Addition of CMC and HPMC had an influence on the puffiness of rice crackers that it slightly increased with an increase of usage levels. The CMC and HPMC-added samples had their percents of puffiness closer to that of wheat cracker.

For the influence of hydrocolloids on color of rice cracker samples, the result was shown in Table 11. According to the CIE value (L*, a*, b*), color of formulated flour crackers with hydrocolloid addition were slightly darker than wheat and formulated-flour controls with the color shade (hue angle) slightly more reddish-brown than yellow-brown for both controls. However, the color intensity (chroma) of hydrocolloid-treated samples was decreased to be closer to wheat crackers. Despite the color value measured by instrumental method, both formulated-flour crackers with- and without- hydrocolloid additions showed slight differences in color and surface appearance from wheat cracker as illustrated in Figure 12.

2 Effect of different hydrocolloids on rheological properties of dough.

Rheological properties of dough made from formulated flours with CMC, HPMC and xanthan gum added at 1.5% were compared with controls (Figure10). The result showed that when considering storage modulus value (G′), 100% rice dough was the highest followed by dough samples with hydrocolloids. Addition of hydrocolloids also increased the elastic modulus (G′) when compared with dough from formulated flours without hydrocolloids. Dough with CMC and xanthan gum additions were higher than dough with HPMC addition, which was closer to formulated-flour dough without hydrocolloids, whereas that of wheat dough was the lowest. According to Sivaramakrishnan, et al. (2004), the moduli were higher for composite flour than that of standard wheat-flour dough, and this increase might be due to the difference between interaction of starch-gluten in composite flour and the interaction in wheat flour. The starch granules in the dough act as filler that reinforces the gluten and produce strong bonds to given higher modulus (Sivaramakrishnan, et al., 2004). In addition, the control rice-flour dough had higher storage modulus value (G′) than control wheat dough. This occurrence in rice was due to the absence of a binding agent. So a system with a definable structure was not formed in the case of rice dough and there repulsive forces existing between the starch granules due to absence of binding agent (Sivaramakrishnan, et al., 2004). In this case, the formulated-flour with adding 1.5% HPMC addition showed similar rheological properties to wheat dough.

Table 11 Effect of hydrocolloids on color of mixed-flour blend rice crackers shown by values of L^*, a^*, b^*, hue angle and chroma

samples	Color parameter				
	L^*	a^*	b^*	Hue angle	chroma
CRF	60.63 ± 0.07^{b}	3.39 ± 1.45^{g}	29.04 ± 0.55^{bcd}	83.45 ± 2.70^{a}	29.24 ± 0.71^{bcd}
WF	64.89 ± 0.34^{a}	5.66 ± 0.46^{f}	31.39 ± 0.63^{ab}	79.78 ± 0.81^{b}	31.89 ± 0.34^{b}
FF	61.74 ± 1.65^{b}	9.66 ± 1.08^{de}	33.33 ± 1.03^{a}	73.77 ± 1.21^{c}	35.56 ± 1.32^{a}
FF+xanthan 1.5%	51.09 ± 1.74^{g}	9.70 ± 1.74^{de}	28.57 ± 2.08^{cde}	70.91 ± 2.62^{d}	30.25 ± 1.80^{bc}
FF+xanthan 3.0%	50.06 ± 2.13^{g}	11.79 ± 0.72^{a}	26.93 ± 2.49^{cde}	66.23 ± 2.30^{f}	29.42 ± 2.29^{bcd}
FF+xanthan 4.5%	53.73 ± 2.52^{f}	10.94 ± 1.08^{bcd}	27.99 ± 2.53^{cde}	70.64 ± 3.19^{d}	29.68 ± 2.19^{bcd}
FF+CMC 1.5%	54.49 ± 2.28^{ef}	11.00 ± 1.28^{abcd}	26.48 ± 2.16^{de}	67.05 ± 3.24^{ef}	28.72 ± 2.23^{cd}
FF+CMC 3.0%	60.18 ± 2.12^{bc}	11.69 ± 1.18^{ab}	29.48 ± 2.68^{bc}	68.25 ± 2.81^{def}	31.75 ± 2.50^{b}
FF+CMC 4.5%	58.00 ± 1.33^{cd}	10.08 ± 1.27^{cde}	28.10 ± 2.12^{cde}	68.21 ± 1.88^{def}	30.28 ± 2.27^{bc}
FF+HPMC 1.5%	53.51 ± 2.03^{f}	9.74 ± 1.83^{de}	27.48 ± 2.21^{cde}	68.36 ± 2.83^{def}	29.61 ± 2.48^{bcd}
FF+HPMC 3.0%	55.79 ± 1.46^{def}	11.24 ± 1.58^{abc}	26.75 ± 2.37^{cde}	69.42 ± 2.08^{de}	28.61 ± 2.66^{cd}
FF+HPMC 4.5%	56.53 ± 1.78^{de}	9.24 ± 1.53^{e}	25.88 ± 1.42^{e}	70.44 ± 2.29^{d}	27.50 ± 1.77^{d}

Note: Different letters in the same column indicate statistical differences ($p\leq0.05$).

CRF, WF and FF were controls and were made of 100% rice flour, 100% wheat flour and formulated flour blend, respectively.

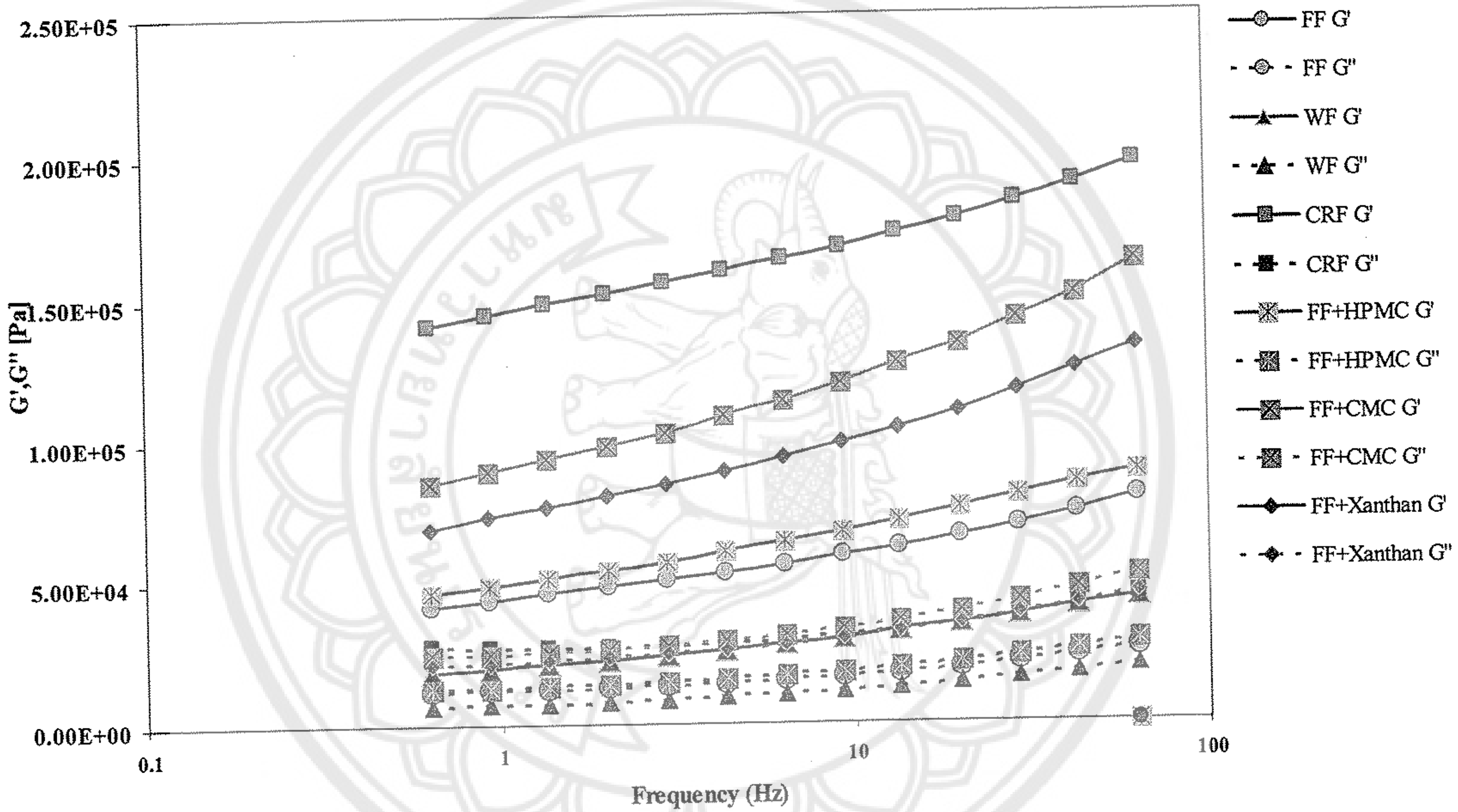


Figure 10 Effect of different hydrocolloids on rheological properties of rice cracker based on the frequency sweep test

Note: FF, WF and CRF referred to controls from formulated flours without hydrocolloids, wheat and commercial rice flour

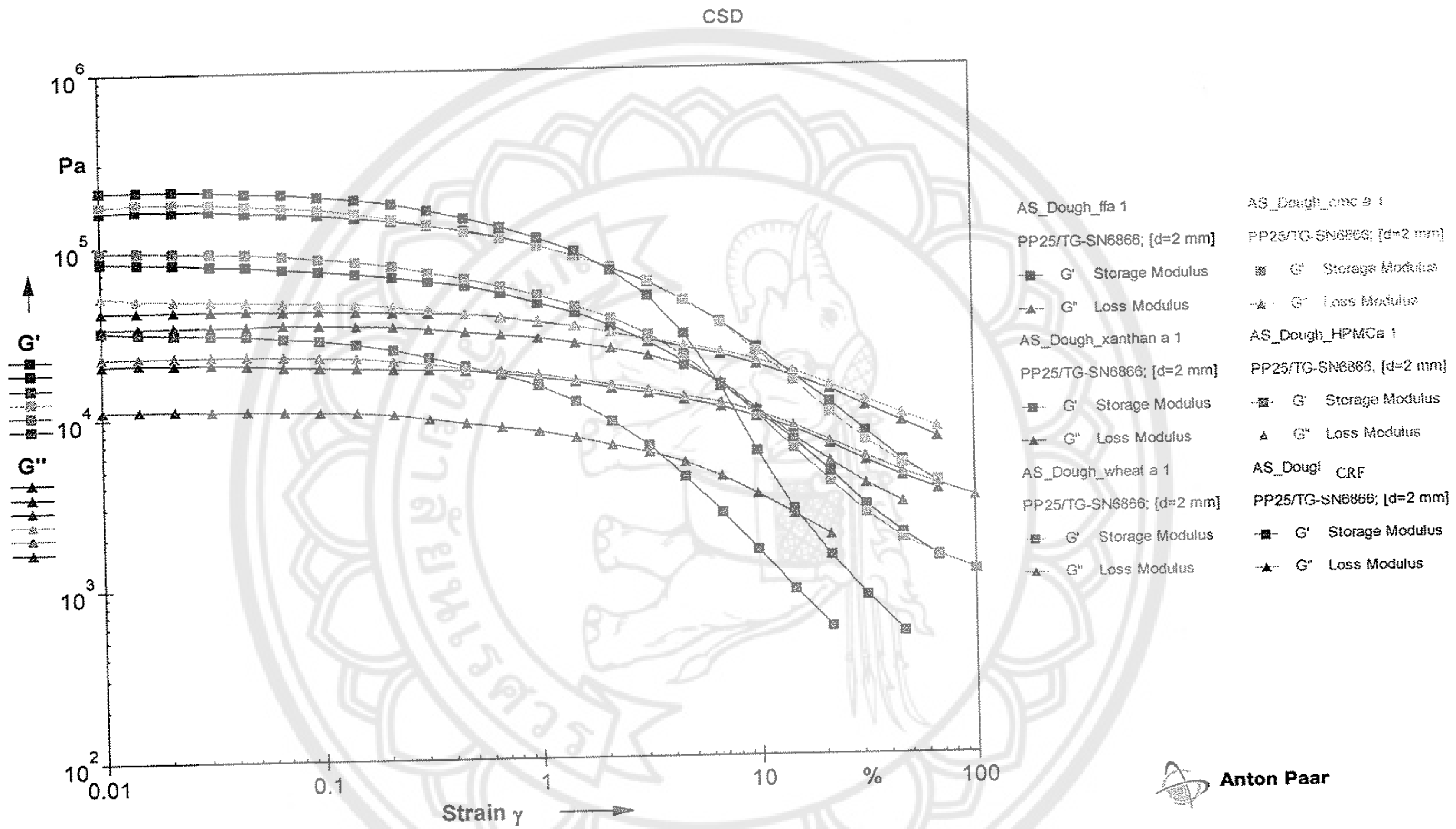


Figure 11 **Rheological properties, based on the amplitude sweep test, of rice cracker dough with different hydrocolloid addition**

Note: FF, WF and CRF referred to controls from formulated flours without hydrocolloids, wheat and commercial rice flour

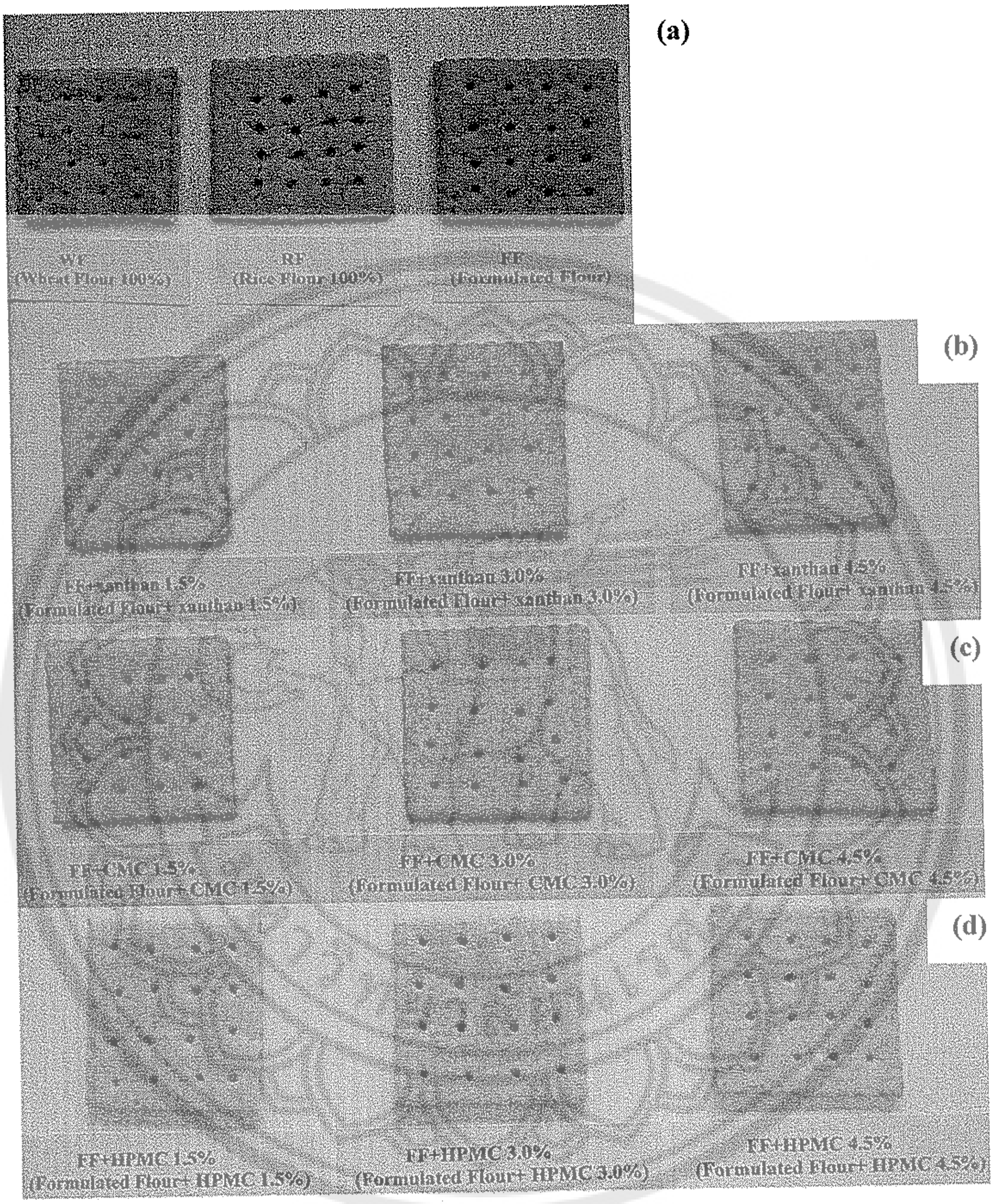


Figure 12 Effects of hydrocolloids on the surface appearance of mixed-flour blend rice crackers comparing (a) controls: 100% commercial rice flour (CRF), 100% wheat flour (WF) and formulated flour blend (FF) to samples with additions of (b) xanthan, (c) CMC, and (d) HPMC at various levels

3. Effect of different hydrocolloids on surface appearance of rice crackers.

Control sample made of rice flour 100% showed some roughness and cracks on its dry surface appearance as compared to hydrocolloid-added samples and other controls (Figure 12 a-d). This result was expected because hydrocolloids was known to help increasing the water holding capacity of samples due to the chemical structure of hydrocolloids and their interaction with the food ingredients (Lazaridou, et al., 2007 and Rosell, et al., 2001).

4. Effect of different hydrocolloids on dough microstructure.

Figure13 (a)-(e) represented the comparison of dough microstructure from control wheat flour (WF), control rice flour (CRF) and 1.5%-hydrocolloid-added formulated-flour crackers. Only the dough microstructure of formulated-flour samples with 1.5% hydrocolloids were shown because the hardness and toughness were closer to wheat crackers. It was visible in all samples (Figure13a-13d) except control rice flour (Figure 13e) that starch granules were embedded in the matrix. In wheat cracker or positive control, the starch granules clearly appeared to be wrapped by protein matrix (Figure 13d), which corresponded to its being the highest puffiness shown in Figure 9. This is because gluten, as an essential structure-building protein, contributes to qualities of bakery products (Lazaridou, et al., 2007; Rosell and Barcenas, 2005; Aibara, et al., 2005). As for commercial rice flour crackers, starch granules were seen but dough structure was indistinguishable (Figure 13e) due to the fact that rice flour is widely known as lacking gluten. Therefore, dough structural formulation is primarily due to starch gelatinization which ultimately results in many large pores in dough (Koh, et al., 2009) and final product with brittle structure and cracks on product surface (Sivaramakrishnan, 2007; Koh, et al., 2009). This complied with the noticeably dry surface appearance and cracks in control rice flour crackers illustrated in Figure13 (a) although pores in rice dough in this study were not as clearly visible as shown by Koh, et al., (2009) due to the limitation of an instrument.

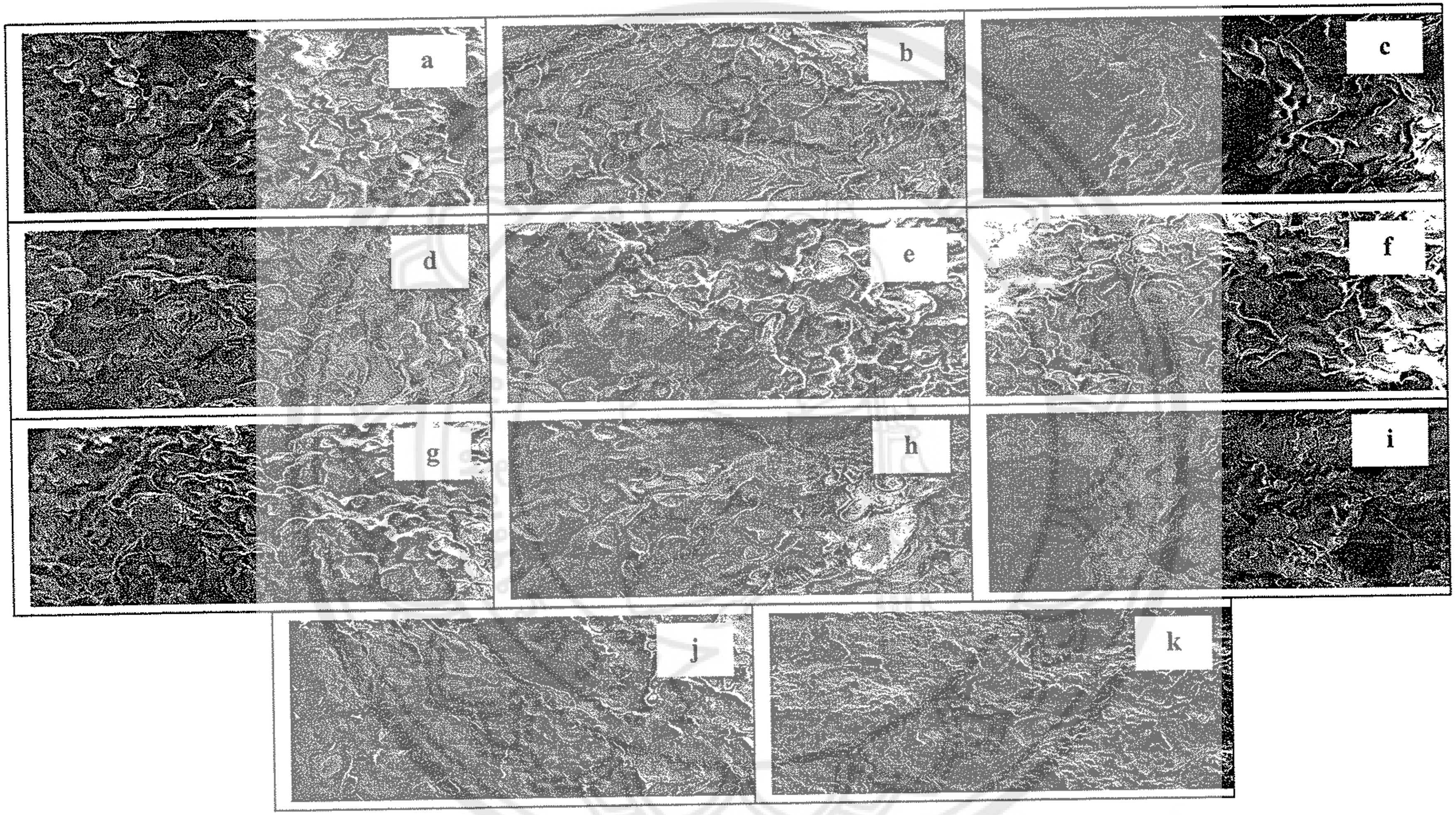


Figure 13 (a-k) Effect of hydrocolloids on the dough microstructure of mixed-flour blend rice crackers. (xanthan 1.5, 3.0, 4.5%(a, b, c) CMC1.5, 3.0, 4.5%(d, e, f) HPMC1.5, 3.0, 4.5% (g, h, i) (×300) Wheat flour 100%(j) (×300) Commercial rice flour 100% (k) (×300)

Table 12 **Effect of hydrocolloids on sensory characteristic of cracker samples**

Sample	Attribute						
	color	surface	odor	taste	hardness	crispness	overall acceptance
CRF	5.63 ± 1.61^{d}	4.38 ± 1.57^{c}	6.18 ± 1.62^{bc}	5.51 ± 1.56^{b}	5.69 ± 1.60^{bc}	5.97 ± 1.71^{bc}	5.65 ± 1.33^{c}
WF	6.45 ± 1.78^{bc}	6.40 ± 1.79^{a}	5.57 ± 1.91^{c}	6.00 ± 1.68^{b}	6.24 ± 1.42^{ab}	6.26 ± 1.59^{b}	6.26 ± 1.38^{b}
FF	6.10 ± 1.68^{cd}	5.46 ± 1.63^{b}	6.22 ± 1.72^{bc}	5.81 ± 1.49^{b}	5.69 ± 1.34^{bc}	5.73 ± 1.51^{bc}	5.89 ± 1.35^{bc}
FF+1.5%CMC	7.08 ± 1.03^{a}	6.59 ± 1.06^{a}	6.71 ± 1.39^{ab}	5.69 ± 1.54^{b}	4.67 ± 1.61^{d}	4.73 ± 1.70^{d}	5.79 ± 1.38^{bc}
FF+1.5%HPMC	7.18 ± 1.37^{a}	7.00 ± 1.38^{a}	7.08 ± 1.30^{a}	7.18 ± 1.13^{a}	6.71 ± 1.69^{a}	7.18 ± 1.14^{a}	7.46 ± 1.17^{a}
FF+1.5%XN	6.97 ± 1.29^{ab}	6.75 ± 1.18^{a}	6.69 ± 1.31^{ab}	5.93 ± 1.40^{b}	5.26 ± 1.59^{cd}	5.42 ± 1.39^{d}	6.06 ± 1.00^{bc}

Note: Different letters in the same column indicate statistical differences ($p\leq0.05$).

CRF, WF and FF were controls and were made of 100% rice flour, 100% wheat flour and formulated flour blend, respectively

5. The acceptances of rice crackers with various hydrocolloids.

Fifty screened untrained panelists participated in the acceptance test of rice crackers with various hydrocolloids versus controls using a 9-point hedonic scale on color, surface appearance, odor, taste, hardness, crispness and overall acceptance. The result was shown in table 12. There were significant differences amongst samples in all attributes ($p \leq 0.05$). Rice cracker with HPMC received the highest overall acceptance followed by wheat cracker whereas that of control rice cracker was the least. For color, surface appearance and odor, all samples with hydrocolloid additions received higher liking scores than all controls. Only sample with HPMC received higher liking scores of taste, hardness and crispness than controls whereas the others were lower ($p \leq 0.05$). Therefore, based on this result, rice cracker with 1.5% HPMC was selected for experiments in further steps.

Sensory evaluation of rice crackers

1. Information and consuming behavior of consumers

The untrained panelists were randomly screened, based on their cracker product interests and consumptions, from coffee shops and supermarkets in Pitsanulok province, Thailand. Demographic data of consumer was shown in Figure 14 (a-g). There were 150 consumers participating in the survey; 37% female and 73 % male. The average ages of consumers spread over 5 categories that the overwhelming majority of respondents were concentrated in three categories of between 15-45 years old. The consumer salaries per month spread over 5 categories from lower-than 4,000 to higher-than 30,000 baht. Half of panelists in this group were in both government and private sectors followed by college students, housewives and others. The educational backgrounds of panelist spread over 6 categories, and about 55% of panelists had their bachelor degrees. Almost 50% of panelists have lived with 3-4 members in the same household. In regards to rice product consumption, 79% of consumers indicated their interests in consuming rice products. Panelists of 64% expressed their interests in purchasing the rice crackers whereas about 30% were uncertain on their purchase decisions and only 2% refused to purchase the product.

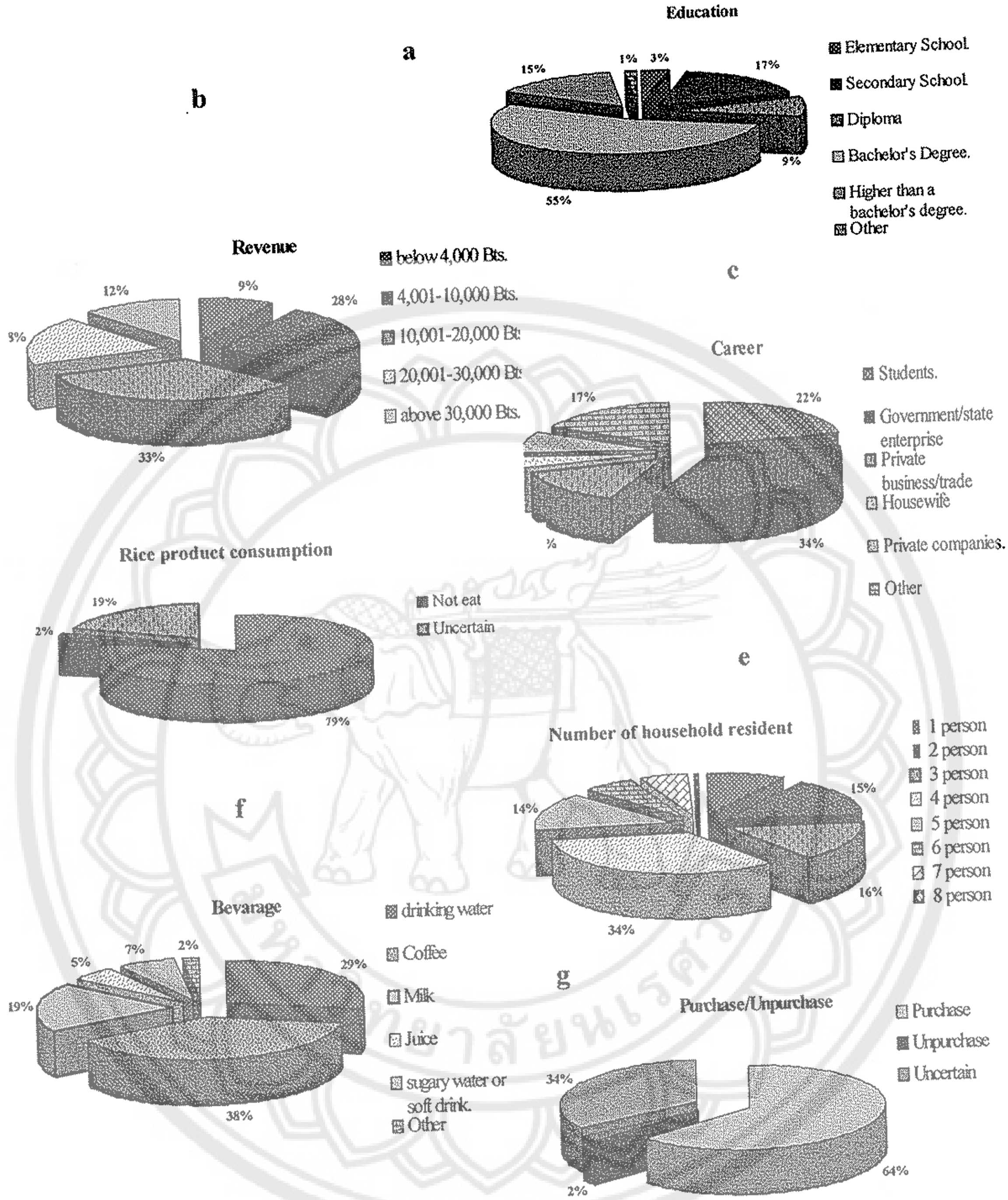


Figure 14 (a-g) Demography of consumer including Education (a), Revenue (b), Career (c), Rice product consumption (d), Number of household resident (e), Beverage choices (f) and interest in product purchase (g)

2 Consumer acceptance of rice cracker

The acceptance tests were conducted by 150 untrained panelists, selected from coffee shops and supermarkets in Phitsanulok province, Thailand. Selected panelists were screened prior to the test based on their interests and consumptions of bakery products. The selected rice cracker, made of formulated flour with 1.5% HPMC (FF+1.5% HPMC), was compared with wheat cracker in an acceptance test using the 5-point Just-about-right (JAR) scale. Trend of consumer acceptances on rice crackers based on nine attributes including color, surface appearance, butter odor, odor, sweetness, saltiness, taste, crispness and crumbness were evaluated.

The JAR scale determined how panelists accept samples based on their ideal product. Generally, Just-about-right (JAR) scales measure the desirability of a specific attribute, and are used to determine the optimum levels of attributes in a product (Lawless and Heymann, 1999; Xiong and Meullenet, 2006). It can be a diagnostic tool to understand the basis for preference or acceptance which aims to provide sensory information for product development. The information could be the product attributes that need to be adjusted and the direction of adjusting (Prinyawiwatkul, 2010). In addition, the advantages of JAR usage are that it provides actionable product guidance and identifies an ideal level of an attribute. The attribute that are not JAR but have no impact on product acceptance can be ignored during reformation or refinement (Prinyawiwatkul, 2010).

In this experiment, the JAR scales were divided as following; not nearly enough (nn), slightly not enough (sn), just right (jr), slightly too much (sm) and much too much (mm). The JAR results of all attributes were illustrated as the observation frequencies (a) and percent of responses (b) as shown in Figure 15-23 (a-b). The binomial test was used to analyze JAR data to determine % difference from norm or expected JAR based on the consumption that norm of samples in this study was 60% (Bi, 2006; Prinyawiwatkul, 2010). Stuart Maxwell and McNemar was used to determine JAR distributions between two samples (formulated rice cracker and wheat cracker) (ASTM, 2009; Prinyawiwatkul, 2010). The binomial test results of attributes were shown in Table 13-21. The critical value was acquired from Table 35 (Bi, 2006) shown in Appendix for minimum number of correct responses for difference and preference tests using forced-choice at (α=0.05, two-tailed)(Prinyawiwatkul, 2010).

According to binomial results on appearance attributes (Table 13-14), consumer already accepted the color of both FF+1.5% HPMC and wheat crackers as just right ($p \leq 0.05$) (Figure15) whereas only wheat cracker had just-right surface appearance and that of FF+1.5% HPMC cracker needed to be adjusted since it was slightly too rough ($p \leq 0.05$) (Figure 16).

For odor attributes (Table 15-16), the butter odor and overall odor of wheat cracker were rated as just right however those of FF+1.5% HPMC cracker were significantly slightly not enough ($p \leq 0.05$) (Figure 17-18). This may cause by the odor of the formulated flour blend that slightly omitted the butter odor however this could be easily adjusted in the formulation.

The binomial results of taste attributes including sweetness, saltiness and overall taste were shown in Table 17-19 and Figure 19-21, respectively. The saltiness of both samples was already just right. However the sweetness of both samples was slightly not enough for consumers ($p \leq 0.05$), and that may cause both samples to be slightly lacking of overall taste ($p \leq 0.05$). However, these attributes could be easily adjusted to match consumer desire by adjusting the ingredients in the formulation.

According to texture aspects, crispness and crumbness of samples were assessed by consumer and shown in Table 20-21 and Figure 22-23. The crispness and crumbness of wheat cracker were as just right as consumer accepted however those of FF+1.5% HPMC cracker were slightly not enough ($p \leq 0.05$). This result correlated with the hardness measured by the universal testing machine shown in Figure 8 that FF+1.5% HPMC cracker was significantly harder than wheat cracker ($p \leq 0.05$). Therefore, when consumer assessed the sample they need it to be slightly more crispy and crumbly like crusty wheat crackers.

Table 13 The binomial test for percent observation frequency on the color of samples

Sample	Jar n,%	Jar≥60 %?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	66 44.00	Yes	62 41.33	22 14.66	84	48	32	N/A
WF	95 63.33	Yes	36 24.00	19 12.67	55	29	21	N/A

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much.

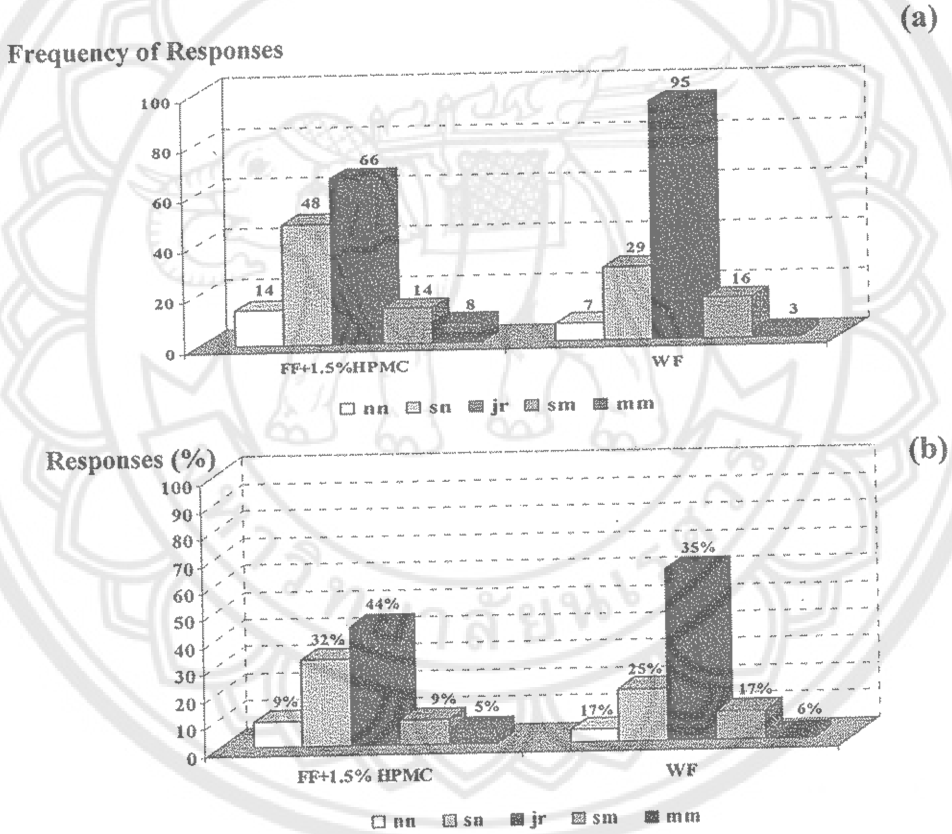


Figure 15 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the color of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right, sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

Table 14 The binomial test for percent observation frequency on the surface appearance of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	55 36.67	No	39 26.00	56 37.33	95	39	27	Yes
WF	82 54.67	Yes	21 14.00	47 31.33	68	44	29	N/A

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much.

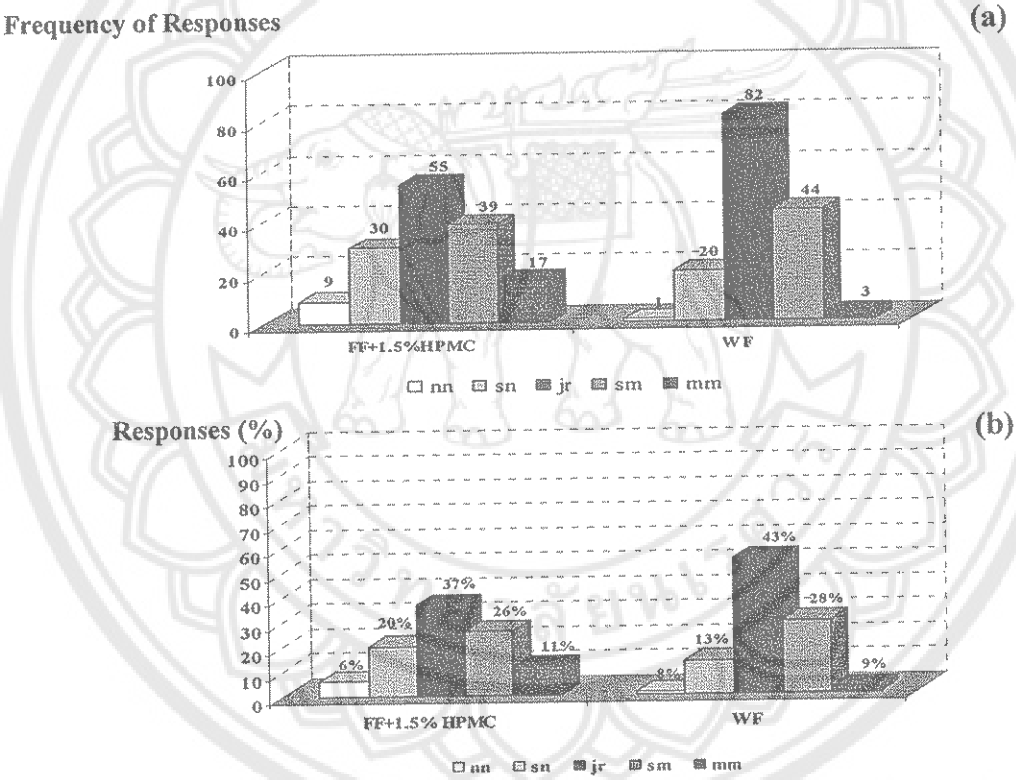


Figure 16 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the surface appearance of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,

sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

Table 15 The binomial test for percent observation frequency on the butter odor of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	51 34.00	No	81 54.00	18 12.00	99	53	35	Yes
WF	64 42.67	Yes	68 45.33	18 12.00	86	53	35	N/A

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much.

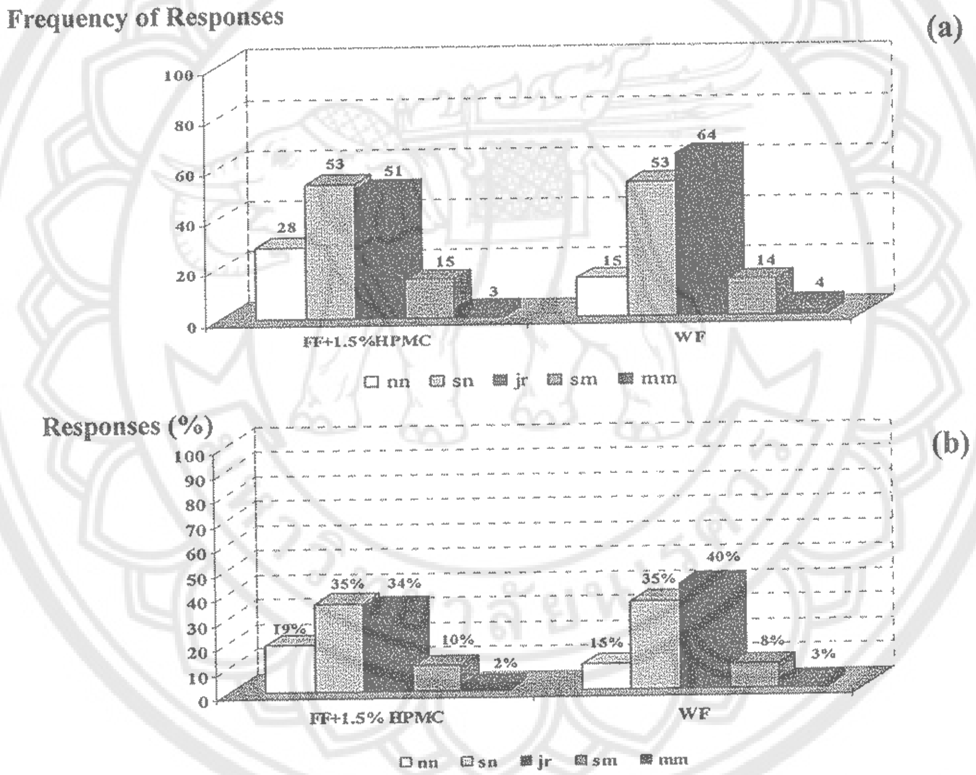


Figure 17 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the butter odor of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,

sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

Table 16 The binomial test for percent observation frequency on the odor of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	59 39.33	No	69 46.00	22 14.66	91	58	37	Yes
WF	75 50.00	Yes	53 35.33	22 14.67	75	47	31	N/A

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much

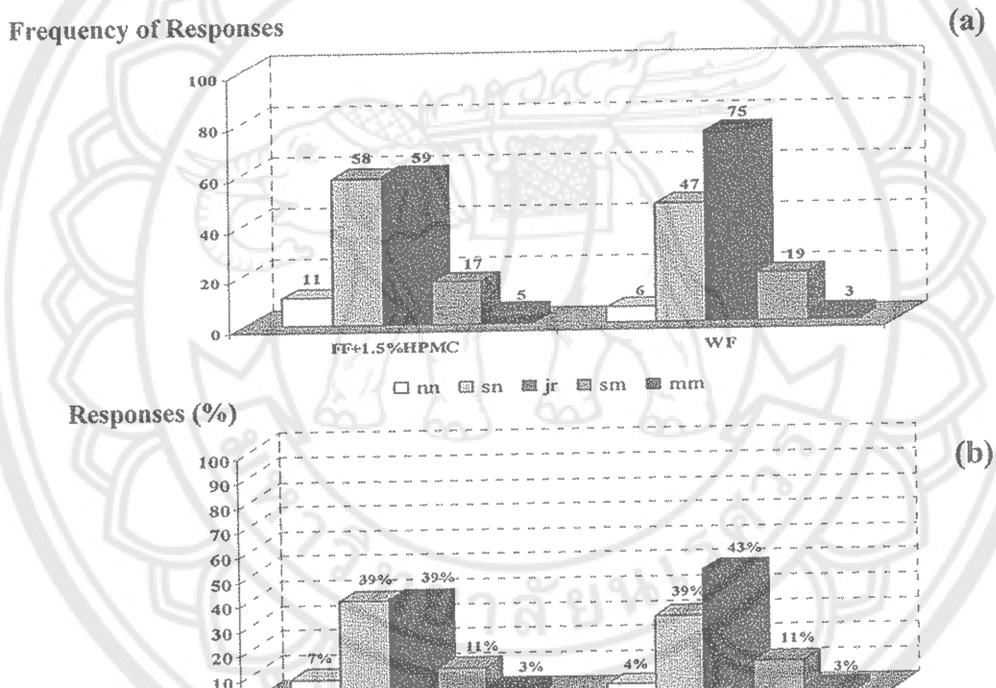


Figure 18 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the overall odor of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,

sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

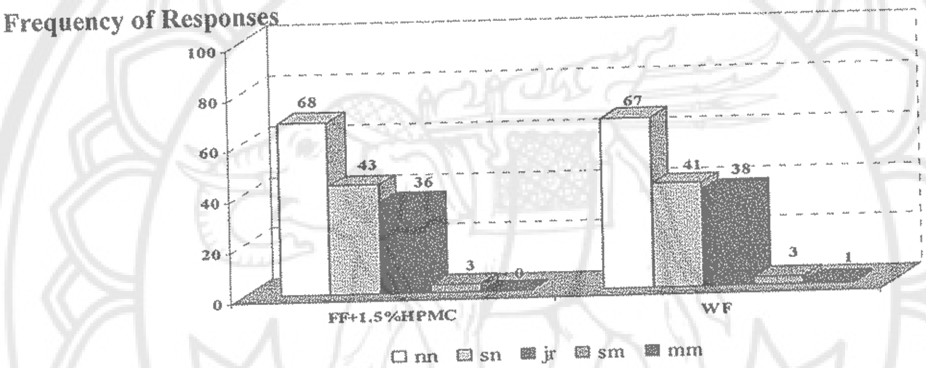
Table 17 The binomial test for percent observation frequency on the sweetness of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	36 24.00	No	111 74.00	3 2.00	114	68	43	Yes
WF	38 25.33	No	108 72.00	4 2.67	112	67	42	Yes

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much.

(a)



(b)

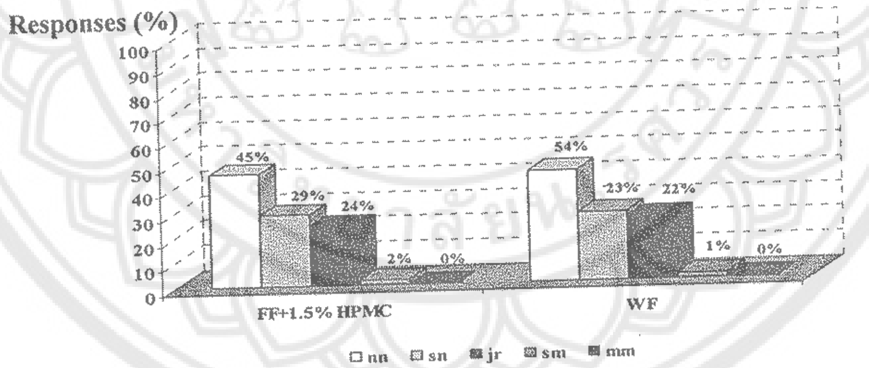


Figure 19 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the sweetness of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,

sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

Table 18 The binomial test for percent observation frequency on the saltiness of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	64 42.67	Yes	48 32.00	38 25.34	86	30	21	N/A
WF	72 48.00	Yes	37 24.67	41 27.33	78	33	23	N/A

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much.

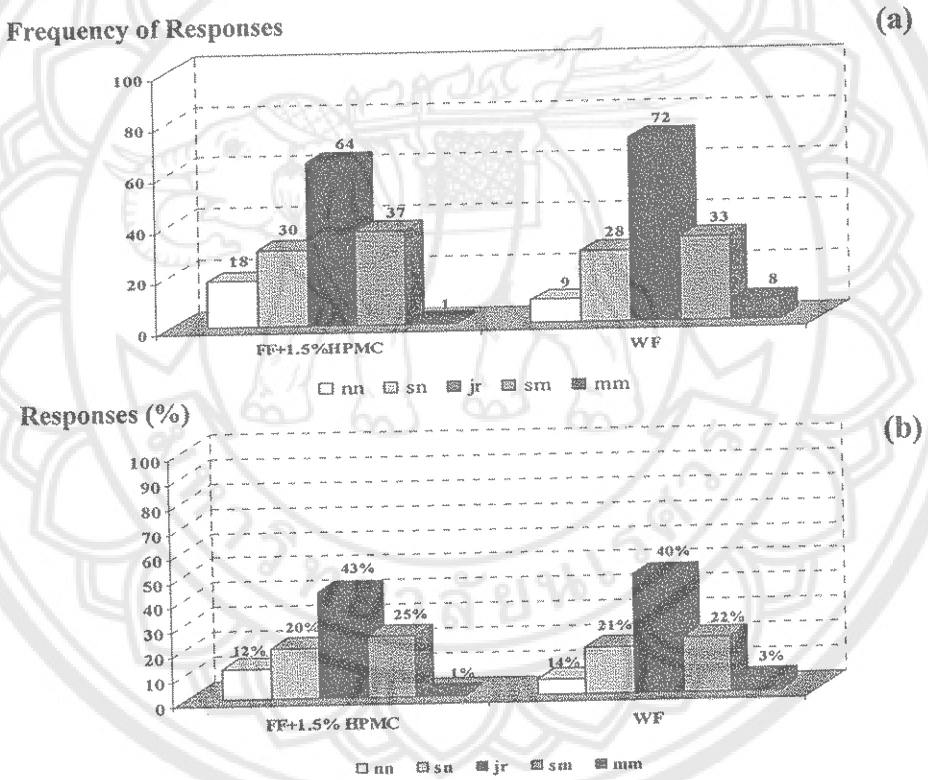


Figure 20 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the saltiness of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,

sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

Table 19 The binomial test for percent observation frequency on the taste of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	46 30.67	No	68 45.33	36 24.00	104	41	28	Yes
WF	55 36.67	No	57 38.00	38 25.33	95	39	27	Yes

Note: Below jar are sum of not nearly enough and slightly not enough.
Above jar are sum of slightly too much and much too much.

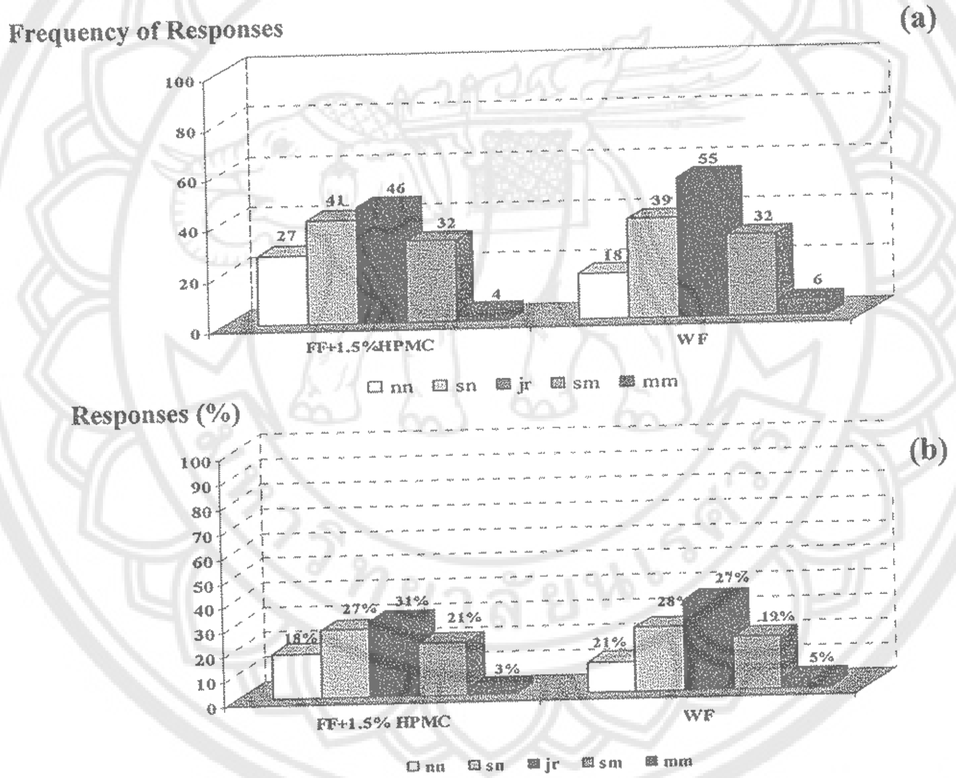


Figure 21 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the taste of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,
sm = slightly too much, mm = much too much
FF (formulated flour) and WF (100% wheat flour)

Table 20 The binomial test for percent observation frequency on the crispness of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	59 39.33	No	60 40.00	31 20.67	91	50	33	Yes
WF	71 47.33	Yes	62 41.33	17 11.33	79	48	32	N/A

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much.

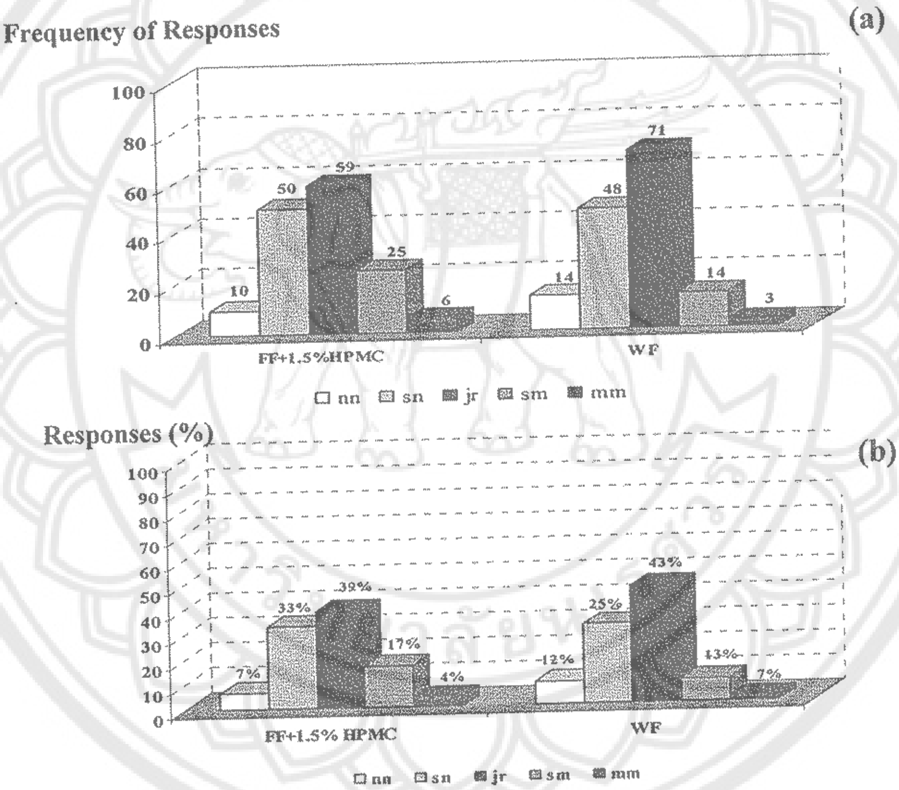


Figure 22 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the crispness of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,

sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

Table 21 The binomial test for percent observation frequency on the crumbness of samples

Sample	Jar n,%	Jar≥60%?	Below Jar n,%	Above Jar n,%	Sum (or n)	Max	Critical Value (0.05)	Are 1, 2 different than 4, 5
FF+1.5%HPMC	43 28.67	No	34 22.66	73 48.66	107	50	33	Yes
WF	82 54.67	Yes	37 24.67	31 20.67	68	30	21	N/A

Note: Below jar are sum of not nearly enough and slightly not enough.

Above jar are sum of slightly too much and much too much.

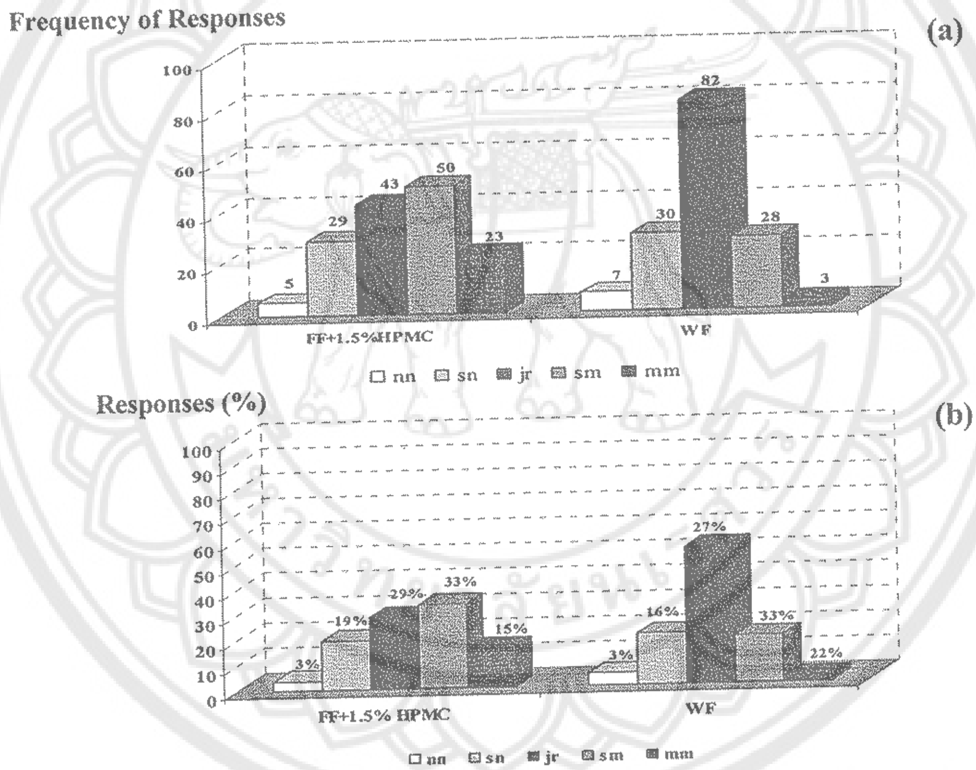


Figure 23 Trend of consumer acceptance illustrated as observation frequency (a) and percent of responses (b) on the crumbness of samples

Note: nn = not nearly enough, sn = slightly not enough, jr = just right,

sm = slightly too much, mm = much too much

FF (formulated flour) and WF (100% wheat flour)

Shelf-life Study of rice cracker during 6 month storage.

The quality change, including physical, chemical and microbiological properties, of crackers during storage were investigated. The selected rice cracker sample was the formulated flour with 1.5% HPMC, which was compared with controls of rice flour 100% and wheat flour 100%. All samples were packed in sealed polyproplylene bags and stored at room temperature (30°C). The results were shown in Table 22-32.

From Table 22, the moisture content of samples increased with increasing storage time. The formulated flour with HPMC 1.5% had its moisture content closer to wheat cracker whereas that of control rice cracker was the lowest. This is because rice flour lacks of gluten network inside the structure to help retaining gas and water holding that is different from crackers made of wheat flour and formulated flour. The mixture of rice flour, wheat flour, waxy rice flour and pregelatinized tapioca starch in the formulated flour blend would have the structure network with higher water holding capacity than 100% rice cracker. According to Sajilata and Singhal, (2005), the pregelatinized starch can form dough that expands when heating which is due to water evaporation, resulting in products with cracker or cookie-like appearance and texture. In addition, adding HPMC in rice cracker samples can increase water retention ability in cracker which results from the hydrophilic nature of HPMC (Barcenas and Rosell, 2005).

Table 22 The moisture content of cracker during storage times

cracker	Moisture contents (%)						
	storage (months)						
	0	1	2	3	4	5	6
CRF	3.72±0.06[b]	4.57±0.11[b]	5.11±0.93[b]	5.24±0.16[b]	6.23±0.02[c]	5.78±0.18[e]	6.69±0.24[a]
WF	5.10±0.132[a]	5.86±0.02[a]	6.38±0.13[a]	6.59±0.08[a]	7.37±0.02[a]	6.45±0.10[b]	6.80±0.30[a]
FF+1.5%HPMC	5.18±0.10[a]	5.71±0.08[a]	6.39±0.18[a]	6.76±0.10[a]	6.97±0.14[b]	7.14±0.17[d]	6.78±0.15[a]

Note: Different letters in the same column indicate statistical differences ($p \le 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 23 The water activity value (a_w) of cracker during storage times

cracker	Water activity (a_w) storage (months)						
	0	1	2	3	4	5	6
CRF	0.122 ± 0.015^{c}	0.195 ± 0.002^{c}	0.216 ± 0.032^{c}	0.209 ± 0.015^{c}	0.353 ± 0.002^{c}	0.358 ± 0.016^{b}	0.416 ± 0.004^{c}
WF	0.294 ± 0.006^{b}	0.314 ± 0.009^{b}	0.338 ± 0.007^{b}	0.373 ± 0.006^{b}	0.400 ± 0.001^{b}	0.463 ± 0.002^{a}	0.501 ± 0.014^{a}
FF+1.5%HPMC	0.400 ± 0.004^{a}	0.423 ± 0.011^{a}	0.431 ± 0.002^{a}	0.455 ± 0.022^{a}	0.449 ± 0.003^{a}	0.461 ± 0.002^{a}	0.472 ± 0.004^{b}

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 24 The Hardness of cracker during storage at times

cracker	Hardness (Kg.F.)						
	storage (months)						
	0	1	2	3	4	5	6
CRF	0.57±0.121 c	0.71±0.230 b	1.09±0.205 b	0.66±0.156 c	0.61±0.483 c	0.51±0.127 c	0.54±0.120 c
WF	3.26±0.240 a	2.82±0.433 a	2.73±0.356 a	3.68±0.478 a	3.43±0.490 a	3.86±0.465 a	4.21±0.235 a
FF+1.5%HPMC	2.87±0.338 b	2.77±0.358 a	2.42±0.348 a	2.62±0.320 b	2.41±0.288 b	3.18±0.775 b	2.86±0.350 b

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 25 The 2-Thiobarbituric acid value (TBA.) of cracker during storage times

cracker	TBA no. (mg.MDA/kg.)						
	storage (months)						
	0	1	2	3	4	5	6
CRF	0.30 ± 0.012^{c}	0.35 ± 0.028^{c}	0.44 ± 0.008^{ab}	0.42 ± 0.016^{a}	0.24 ± 0.005^{b}	0.30 ± 0.009^{a}	0.25 ± 0.005^{c}
WF	0.48 ± 0.13^{a}	0.62 ± 0.035^{b}	0.47 ± 0.005^{a}	0.39 ± 0.023^{a}	0.23 ± 0.008^{b}	0.30 ± 0.005^{a}	0.29 ± 0.008^{b}
FF+1.5%HPMC	0.47 ± 0.021^{b}	0.68 ± 0.055^{a}	0.40 ± 0.040^{c}	0.47 ± 0.012^{b}	0.44 ± 0.012^{a}	0.23 ± 0.008^{b}	0.42 ± 0.009^{a}

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 26 The Brightness (L*) of cracker during storage at times

cracker	Brightness (L*) storage (months)						
	0	1	2	3	4	5	6
CRF	67.84 ± 1.63^{a}	68.25 ± 2.27^{a}	68.69 ± 2.13^{a}	62.38 ± 0.23^{a}	66.96 ± 0.12^{e}	65.96 ± 0.20^{b}	65.67 ± 0.33^{b}
WF	61.18 ± 0.93^{c}	66.06 ± 2.09^{b}	63.51 ± 1.86^{b}	63.72 ± 0.14^{a}	66.78 ± 0.84^{b}	65.44 ± 0.29^{b}	65.53 ± 0.35^{b}
FF+1.5%HPMC	62.60 ± 1.50^{b}	63.91 ± 2.83^{c}	64.41 ± 1.58^{b}	63.38 ± 1.84^{a}	65.30 ± 0.05^{d}	66.34 ± 0.08^{a}	66.99 ± 0.36^{a}

Note: Different letters in the same column indicate statistical differences ($p\leq0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 27 The Redness (a*) of cracker during storage at times

cracker	Redness (a*)						
	storage (months)						
	0	1	2	3	4	5	6
CRF	8.52 ± 0.06^{c}	8.74 ± 0.11^{c}	7.71 ± 0.93^{b}	8.48 ± 0.16^{b}	7.38 ± 0.02^{c}	7.48 ± 0.18^{c}	6.42 ± 0.24^{e}
WF	13.12 ± 0.132^{a}	9.63 ± 0.02^{ab}	11.25 ± 0.13^{a}	11.28 ± 0.08^{b}	11.71 ± 0.02^{a}	10.02 ± 0.10^{a}	11.77 ± 0.30^{a}
FF+1.5%HPMC	11.70 ± 0.10^{b}	10.12 ± 0.08^{a}	12.25 ± 0.18^{a}	10.39 ± 0.10^{a}	9.71 ± 0.14^{b}	9.02 ± 0.17^{b}	8.77 ± 0.15^{b}

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 28 The Yellowness (b*) of cracker during storage at times

cracker	Yellowness (b*)						
	storage (months)						
	0	1	2	3	4	5	6
CRF	31.26±1.89 ^{b}	32.06±1.93 ^{a}	31.38±2.54 ^{c}	26.62±0.29 ^{c}	26.12±0.15 ^{b}	23.67±0.25 ^{b}	28.25±0.15 ^{b}
WF	34.33±1.41 ^{a}	31.48±2.03 ^{b}	34.34±1.41 ^{b}	32.34±0.21 ^{b}	32.72±0.32 ^{a}	32.89±0.32 ^{a}	35.48±0.29 ^{a}
FF+1.5%HPMC	31.46±1.16 ^{b}	31.73±1.45 ^{b}	36.22±1.13 ^{a}	33.50±1.98 ^{a}	32.72±0.12 ^{a}	32.89±0.07 ^{a}	35.48±0.19 ^{a}

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 29 The Chroma value of cracker during storage at times

cracker	Chroma						
	storage (months)						
	0	1	2	3	4	5	6
CRF	32.40±2.02 c	33.23±2.08 a	32.32±2.50 c	27.94±0.35 c	27.43±0.16 b	24.83±0.23 b	29.21±0.09 b
WF	36.75±1.75 a	32.93±2.37 b	35.41±1.05 b	32.76±0.18 b	33.22±0.28 a	33.27±0.26 a	36.32±0.42 a
FF+1.5%HPMC	33.57±1.35 b	33.32±1.61 a	38.24±1.49 a	35.08±0.13 a	33.22±0.09 a	33.27±0.07 a	36.32±0.18 a

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 30 The Hue angle value of cracker during storage at times

cracker	Hue angle						
	storage (months)						
	0	1	2	3	4	5	6
CRF	74.78 ± 1.09^{a}	74.78 ± 1.12^{a}	76.13 ± 1.83^{a}	72.33 ± 0.54^{b}	72.21 ± 0.15^{c}	72.46 ± 0.77^{a}	75.28 ± 0.86^{c}
WF	69.13 ± 1.26^{b}	73.07 ± 1.73^{b}	71.45 ± 2.75^{b}	74.40 ± 0.27^{a}	80.10 ± 1.56^{b}	81.31 ± 0.83^{b}	77.65 ± 1.00^{b}
FF+1.5%HPMC	69.62 ± 1.34^{b}	72.33 ± 1.34^{b}	71.36 ± 1.45^{b}	72.78 ± 0.88^{b}	82.43 ± 0.48^{a}	84.36 ± 0.46^{a}	85.34 ± 0.27^{a}

Note: Different letters in the same column indicate statistical differences ($p\leq0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

The change of water activity value (a_w) during storage for 6 month was shown in Table 23. The water activity value also increased with increasing storage time storage, which was similar to the moisture content result.

The hardness results of samples shown in table 24 were significantly different ($p \leq 0.05$). The hardness of formulated flour with 1.5% HPMC was slightly softer than wheat cracker but higher than 100% rice cracker which was brittle and crumbly. According to Barcenas and Rosell, (2005), HPMC is a good antistaling agent in regards to the crumb hardening and the amylopectin retrogradation. The mechanism for explaining the antistaling effect of this hydrocolloid is that the interaction between starch and the HPMC modifies the starch structure which, in consequence, affects the gelatinization and retrogradation processes of samples (Fanta and Christianson, 1996; Rojas, Rosell and Benedito, 1999; Barcenas and Rosell, 2005). The hardness of wheat cracker also clearly showed an increase tendency during storage (Table 24).

The TBA test quantifies the terminal product of the liquid peroxidation due to the fact that they are reactive with the TBA, and would primary be malondialdehyde (MDA) to include the other aldehydes (Martel and Pascal, 2000; Frutos and Hernandez-Herrero, 2005), The result was shown in Table 25. The tendency of Malondialdehyde content increased rapidly during the first month then decreased continuously after that. It indicated the lipid oxidation in samples. According to Frutos and Hernandez-Herrero (2005) reported that the reduction in TBA value must be due to the loss of aldehydes from the samples by evaporation during storage at 50°C in bread product. The TBA number was used as a rancidity indicator. The result correlated with the verdicts from three trained judges that the 1st-month sample started to have rancid odor but it was still acceptable. However, samples were no longer acceptable when being kept for two months and further.

The color values of samples were shown in Table 26-30. The lightness (L*) of rice cracker samples and wheat crackers gradually increased during storage times. The redness-brownness in all samples tended to decrease during storage. However the yellowness and chroma value slightly increased in crackers made of formulated and wheat flour whereas that of control rice cracker slightly decreased during storage ($p \leq 0.05$).

Table 31 Total plate count during storage for 6 month

cracker	Total plate count (cfu./g.)						
	Time storage (month)						
	0	1	2	3	4	5	6
FF+1.5%HPMC	<10	<10	<10	<10	<10	<10	<10
CRF	<10	<10	<10	<10	<10	<10	<10
WF	<10	<10	<10	<10	<10	<10	<10

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

Table 32 Yeast and mold during storage for 6 month

cracker	Yeast and mold (cfu./g.)						
	Time storage (month)						
	0	1	2	3	4	5	6
FF+1.5%HPMC	<10	<10	<10	<10	<10	<10	<10
CRF	<10	<10	<10	<10	<10	<10	<10
WF	<10	<10	<10	<10	<10	<10	<10

Note: Different letters in the same column indicate statistical differences ($p \leq 0.05$).

CRF, WF and FF were controls and were made of 100% commercial rice flour, 100% wheat flour and formulated flour blend, respectively.

For the microbiological evaluation of rice cracker samples during storage, the results were shown in Table 31-32. All samples were stored at room temperature (30°C) for 6 months. The total plate count and total yeast and mold counts were evaluated, and there were less than 10 cfu./g. in all samples throughout storage times ($p > 0.05$). According to the cracker standard (TCPS 523/2004), the samples were still acceptable as safe for consumption based on the microbial aspect (Thai Industrial Standards Institute, 2004).