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ขนมอบกรอบจากแป้งข้าวเหนียว

โดย

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สาขาวิชาเทคโนโลยีอาหาร

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EFFECT OF MODIFIED STARCH AND FLOUR ADDITION ON TEXTURAL PROPERTIES OF GLUTINOUS RICE CRACKER

By

Rawiwan Wongmaneethet

A Master's Report Submitted in Partial Fulfillment of the Requirements for the Degree

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การศึกษาคุณสมบัติทางเนื้อสัมผัสของโดที่ได้จากการผสมแป้งข้าวเหนียวกับแป้งและสตาร์ชดัดแปร 5 ชนิด ที่ปริมาณการเติมร้อยละ 2.5 5.0 7.5 และ 10.0 โดยน้ำหนักพบว่า โดแป้งข้าวเหนียวที่เติมแป้งและสตาร์ชดัดแปร ณ ทุกปริมาณการใช้จะมีค่าความแข็ง ความแน่นเนื้อ และ modulus of elasticity เพิ่มขึ้น ($p<0.05$) เมื่อเทียบกับตัวอย่างควบคุม โดยเฉพาะโดแป้งข้าวเหนียวที่เติมแป้งมันฝรั่งจะมีลักษณะเนื้อสัมผัสที่มีความแข็งมากที่สุด ทั้งนี้อาจเนื่องจากแป้งมันฝรั่งเป็นแป้งที่มีปริมาณอะมิโลสสูง จึงมีอัตราการเกิดรีโทรเกรเดชันได้อย่างรวดเร็ว ส่งผลให้โครงสร้างภายในสตาร์ชบีบตัวกันมากขึ้น เมื่อศึกษาคุณสมบัติทางเนื้อสัมผัสของขนมอบกรอบจากแป้งข้าวเหนียวพบว่า ขนมอบกรอบที่เติมสตาร์ชดัดแปรจากแป้งมันฝรั่งชนิด GTW ที่ปริมาณการเติมร้อยละ 2.5 และสตาร์ชธรรมชาติของแป้งมันฝรั่งที่ปริมาณการเติมร้อยละ 5.0 และ 7.5 มีค่าความแข็งลดลงร้อยละ 39.0 35.2 และ 33.9 ตามลำดับ เนื่องจากเนื้อโดมีความพองตัวสูง ส่งผลให้ผลิตภัณฑ์มีความแข็งลดลง และเมื่อวิเคราะห์ความสัมพันธ์ระหว่างคุณสมบัติด้านเนื้อสัมผัสที่วัดจากเครื่องมือวัดและผลการทดสอบทางประสาทสัมผัส สามารถสรุปได้ ค่าความแข็งที่วัดได้จากทั้งเครื่องมือและจากการทดสอบทางประสาทสัมผัสมีความสัมพันธ์ไปในทางเดียวกัน (ความสัมพันธ์เชิงบวก) แต่ค่าความแน่นเนื้อและค่าความเหนียวเหนอะ ที่วัดได้จากการทดสอบทั้งสองแบบกลับให้ผลตรงข้ามกัน โดยมีความสัมพันธ์เชิงลบ ดังนั้นขนมอบกรอบที่ทำจากแป้งข้าวเหนียวผสมกับแป้งมันฝรั่ง จะมีความแข็งลดลงโดยค่าความแข็งนี้สามารถวัดได้โดยตรงจากเครื่องมือวัดเนื้อสัมผัส เพราะให้ผลตอบสนองได้เช่นเดียวกันกับการทดสอบทางประสาทสัมผัส

ภาควิชาเทคโนโลยีอาหาร บัณฑิตวิทยาลัย มหาวิทยาลัยศิลปากร ปีการศึกษา 2547

ลายมือชื่อนักศึกษา..

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RAWIWAN WONGMANEETHET : EFFECT OF MODIFIED STARCH AND FLOUR ADDITION ON TEXTURAL PROPERTIES OF GLUTINOUS RICE CRACKERS. MASTER'S REPORT ADVISORS : BHUNDIT INNAWONG, Ph.D., ARUNSRI LEEJEERAJUMNEAN, Ph.D., AND EAKAPHAN KAEWMANEECHAI, Ph.D. 91 pp. ISBN 974-464-507-5.

The textural improvement of glutinous rice doughs and crackers added with 5 modified starches and flours was examined. The addition of modified starches and flours in the formulation remarkably contributed an increment ($p<0.05$) in hardness, firmness, and modulus of elasticity (as compare to control) with respect to the retrogradation process. Rice dough with potato starch exhibited the greatest hardness since potato starch normally comprised substantial amylose content. In contrast, rice dough with tapioca starch displayed the most stickiness in texture with regard to its cohesiveness during gel formulation. Glutinous rice cracker (Arare) supplemented with each modified starch and flour at 4 levels of usage individual distinguished in textural characteristics. Arare with 2.5% GTW, both 5.0% and 7.5% potato starch intensively decreased hardness up to 39.0%, 35.2%, and 33.9%, respectively. In addition of Arare with potato starch significantly soften in texture due to the formation of its strong network occurring in the puffing process. Regarding to the texture map, Arare with potato starch tended to be mushy in textural characteristics. For the further experiment, the Arare formulations using the selected starches and flours were measured by means of the instrumental texture analyzer and sensory evaluation. As expected, the hardness demonstrated the best correlation to both measurements. In contrast, the firmness and stickiness were considered as the complicated sensory perception, thus, it was unable to describe clearly by the instrumental testing. However, the graphical maps between both sensory and instrumental measurements compatibly confirmed that the potato starch was the most suitable source to increase the softness of Arare.

Department of Food Technology   Graduate School, Silapkorn University   Academic Year 2004

Student's signature ……………………..

Master's Report Advisors' signature 1……………….… 2………………… 3………….……….

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LIST OF CONTENTS

Page

Chapter

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Glutinous rice cracker (Arare) is one of the traditional snacks in Japan. It normally competes western style snacks due to its unique texture and flavor. Arare provides the puffy and porous in texture during baking process without the use of frying oil. Thus, it can be claimed as no cholesterol snacks. For these reasons, the sale volume substantially increases in each year, especially in the healthy snack market.

About 15 years ago, the production of rice cracker in Japan had serious problems with respect to the declination of raw material. Subsequently, both limitation and increase of rice price gradually pushed the manufacturer to transfer the production plants to Thailand, which considerably offered more available raw materials and high quality. In each year, Thai manufacturers are able to annually export rice crackers approximately 21,139 tons with the value of 1,633 million bahts and continue more 14-16% increasing rate each year (National Food Institute and the office of Industrial Economics, Thailand, 2003).

A critical problem of Arare production in Thailand is the fluctuation of rice quality since the physico-chemical changes of glutinous rice during aging directly impact the textural attributes of rice cracker. Noomhorm et al. (1997) reported the aged rice was lower water uptake than the fresh one. In addition, the aged rice tended to provide more hardness of rice crackers because of its low expansion. Another problem is the dry and porous texture of Arare unaccepted in some consumers who are familiar to the soft and light texture of the fried snacks. This problem directly influences the buying decision so Thai manufacturers and food agency attempt to solve this textural problem contributing from the rice quality via the improvement of the product softness for the competition with some popular fried snacks.

The texture of expanded snacks depends on a great variety of factors but a major constituent as starch plays a very important role to contribute the texture and appearance of the finished products (Wang, 1997). The utilization of some beneficial modified starches in the rice cracker may be the potential solution because modified starch could change the physico-chemical properties such as gelatinization, retrogradation, and interactions with other components (Sriroth and Piyachomkwan, 2000). Furthermore, it might alter the expansion ability of glutinous rice cracker without any change in taste and appearance. According to the Arare process, dough commonly called "Mochi" characterized excessively hard and firm to be sliced to desirable shape (Juliano, 1985). The hardness of dough evolved via the subsequent retrogradation. This rate of retrogradation differed from various factors but mainly relied on botanical sources (Jacobson et al., 1997). Thus, the combination of some modified starches or flours in Arare could devote to significant improving the dough physical characteristics.

There existed a great variety of procedures to engage in the studies of starch retrogradation. According to measure firmness and rigidity of glutinous starch dough, the deformation fundamental tests such as the compression and the empirical tests like penetration testing were applied to receive good correlations to the sensory texture attributes (Karim et al., 2000). On the other hand, the texture measurement of rice cracker usually related to determine the physical and chemical properties of products. Sensory evaluation has been the most unreliable method because of its high cost, time consuming, and also delivered the error data (Lewis, 1996). The alternative method replacing the sensory test is the instrumental texture measurement such as texture analyzer.

The correlation between instrumental and sensory measurement could contribute an important data to develop the desirable texture of rice cracker. In addition, the sensory attributes could be replaced using the instrumental tests that usually provided the more accurate, higher capacity and more durable measurement. Thus, this research was conducted to reduce the hardness of rice cracker without any change in processing and use to replaced the sensory testing.

CHAPTER 2

LITERATURE REVIEW

2.1 Starch

Starch is the predominant food reserve substance in plants and provides 70-80% of the calories consumed by humans worldwide. Commercial starches are obtained from several cereal grains and seeds, especially from corn, waxy corn (waxy maize), high-amylose corn, wheat, various rice, some from tubers and roots as potato, sweet potato, and tapioca (cassava). Most of starches usually are used as a thickening agent, a gelling agent, an absorber of water, a source of energy in fermentation, a bulking agent, or an anti-sticky/sticky agent depending on the industry applications. Starch utilized in foods industries almost contains the different water contents. For example, products such as dressings or drinks normally are added with starch containing a very high water content. On the other hand, the liquorices must use starch with a very low water content.

Starch is unique in the structural molecules of carbohydrates because it occurs naturally as discrete particles (granules). Starch granules are relatively dense and insoluble and would hydrate only slightly in cold water. They could be dispersed in water and produced low-viscosity slurries that could be easy to mix and pump with greater 35% of concentration. The viscosity-building (thickening) power of starch depended on only a slurry of granules when cooking. Heating 5% slurry of unmodified starch granules to about 80^{o}C (175^{o}F) with stirring produced very high viscosity. A second unique property of starch granules was its mixture of two polymers including an essentially linear polysaccharide called amylose, and a highly branched polysaccharide called amylopectin. (Eliasson and Gudmundsson, 1996)

2.1.1 Amylose and Amylopectin

Amylose is a linear chain of $(1\rightarrow4)$ –linked α-D-glucopyranosyl units. Many amylose molecules contain a few α-D $(1\rightarrow6)$ branches, about 1 in 180-320 units, or 0.3-0.5% of all the linkages. The branches in branched amylose molecules are either very long or very short, and the branch points are separated by large distance so that the physical properties of amylose molecules maintain in the linearity. The molecular weight of amylose molecules is about 10^6 Dalton and most starches contain about 25% amylose. The commercial starches are comprised amylose content about 52% to 70-75%.

Amylopectin is a very large and highly branched molecule because of constituting 4-5% of the total linkages. Amylopectin consists of a chain containing the only reducing end-group, called a C-chain, which had numerous branches, termed B-chains, to which one to several third-layer A-chains were attached. (A-chains are unbranched and B-chains are branched with A-chains or other B-chains). The branches of amylopectin molecules are clustered and occurred as the double helices. Molecular weights of amylopectin are from 10^7 to 5×10^8 Dalton so amylopectin molecules usually are the largest molecules found in nature.

Amylopectin presents in all starches, constituting about 75% of most common starches. Some starches consisting entirely of amylopectin are called waxy starches. Waxy corn (waxy maize), the first grain recognized the starch consisted only of amylopectin, is so termed because when the kernel is cut the new surface appears vitreous or waxy. Other all-amylopectin starches are also called waxy although, as in corn, there is no wax content.

Potato amylopectin is unique due to its phosphate ester groups attached most often (60-70%) at an 0-6 position, with the other third at 0-3 positions. These phosphate ester groups occur about once in every 215-560 α-D-glucopyranosyl units, and about 88% of them are on B chains (Eliasson and Gudmundsson, 1996).

2.1.2 Starch Granules

Starch granules are composed of amylose and amylopectin molecules arranged in radial structure. They contain both crystalline and noncrystalline regions in the alternating layers. The clustered branches of amylopectin occurred as packed double helices. It was the packing together of these double-helical structures forming the many small crystalline areas comprising the dense layers of starch granules that alternated with less dense amorphous layers. The crystallinity is produced by the orders of the amylopectin chains, waxy starch granules, the granules without any amylose, had the same amount of crystallinity as normal starches did. Amylose molecules could distribute within the amylopectin molecules and some of them could diffuse as the partially water-swollen granules. The radial arrangement of starch molecules in a granule could be investigated using the polarization light (white cross on a black background) seen in a polarizing microscope with the polarizers set 90^{o} to each other. The center of the cross was at the hilum, the origin of growth of the granule.

All starches retained small amounts of ash, lipid, and protein (Table 2.1). The phosphorus content of potato starch was about 0.06-0.1% due to the presence of the phosphate ester groups on amylopectin molecules. The phosphate ester groups in potato starch amylopectin provided a slight negative charge and resulted in some coulombic repulsion that might contribute to rapid swelling of potato starch granules in warm water. Several properties of potato starch pastes, namely, their high viscosity, good clarity, and low rate of retrogradation. Cereal starch molecules either did not have phosphate ester groups or have very much smaller amounts than occurred in potato starch (Eliasson and Gudmundsson, 1996).

Table 2.1 Composition of some selected starch granules

Starch Sources	Amylose (%)	Protein (g/100 g)	Lipids (g/100 g)
Cassava	17	0.1	0.1
Potato	21	0.06	0.05
Rice	12.2-28.6		0.63-1.11
Waxy rice	0-2.32		
Wheat	28	0.3	0.8
Wheat	29.2		0.85
A-granules	28.4-27.8		0.67-0.73
B-granules	27.5-24.5		0.73-0.91
Barley, waxy	2.1-8.3		0.30-0.49
Barley, normal	25.3-30.1		0.68-1.28
Barley, high amylose	38.4-44.1		1.05-1.69
Oat	25.2-29.4		1.35-1.52
Maize, normal	28.7	0.3	0.8
Maize, normal	25.8-32.5		0.61-0.82
Maize, waxy	1.4-2.7		0.02-0.14
Maize, high amylose	42.6-67.8		1.01-1.09
Fava bean	33	0.9	0.1
Pea	33	0.7	0.1

Source: Carbohydrates in food (Eliasson and Gudmundsson, 1996)

2.2 Retrogradation of Starch

The changes occurring in gelatinized starch, from initially an amorphous to more order or crystalline state, were termed retrogradation. These changes took place because gelatinized starch was not in thermodynamic equilibrium. The rheological properties would change, as evident in increased firmness or rigidity. Loss of water-holding capacity and restoration of crystallinity gradually increased during aging. This process exerted a major and usually unaccepted, especially in the texture of foods with rich starch. Starch retrogradation was an important factor introducing staling in bread and other baked products. The kinetics of retrogradation have been investigated to enlighten the molecular mechanism behind the phenomena but still completely unknown. As well as, the starch components, the retrogradation would not take place without a certain minimum amount of water in the gel. The water content together with the storage temperature were very important because they controlled both the rate and the degree of retrogradation. Many substances could interfere the retrogradation process. Most important of them were lipids and surfactants. The retrogradation tendency of starches varied among the different cultivars and unrelied on the ratio of amylose and amylopectin in starch granules.

The most common techniques to measure retrogradation (i.e., rate and extent of re-crystallization on aging) were the x-ray diffraction technique and the thermal measurements such as the DSC and the rheological technique. The retrogradation caused a excessive re-crystallization process and sequently changed in x-ray diffraction patterns. Thermal methods (e.g., DSC) compatibly fitted to monitor the rate and extent of retrogradation as the starch molecules progressively re-associate during aging. Aged gels and stale bread showed a characteristic melting endotherm around 55-60^{o}C, which was an absent in fresh gels and breads immediately after gelatinization. The gelatinization of starch suspension, especially the swelling and leaking of amylose/amylopectin would dramatically change the rheological properties of the starch suspension. The subsequent retrogradation would further modify the rheological properties.

The storage temperature greatly affected the retrogradation. Storage of starch gels within 45-50% water content at low temperatures but above the glass transition temperature ($T_g \approx -5.0^{o}C$), increased the retrogradation as compared to storage at room temperature, especially during the first day of storage. Storage at freeze temperatures below the T_g virtually inhibited recrystallization. Higher temperatures (above 32-40^{o}C) effectively reduced the retrogradation. Retrogradation, a non-equilibrium recrystallization process, was indicated by the fact that at low temperatures (4-5^{o}C) the crystallites formed were less perfect so they had lower melting temperature (T_c) than crystallites formed at higher storage temperature. A three-step mechanism of initial nucleation (junction point of two or more starch molecules), followed by the crystal growth/propagation and crystal perfection had been proposed.

Retrogradation was very sensitive to water content in starch gels. Crystallization during aging occurred only in gels with starch content between 10 and 80% and the maximum crystallization, measured with DSC, occurred in gels with 50-55% of starch. Several DSC studies had confirmed that the maximum crystallinity occurred in gels with 50-60% of starch. The rate and extent of retrogradation measured using the NMR technique were found to be the greatest at 50% starch content in the range of 12-50% starch content. The retrogradation only relied on the water content presenting during aging but not in gelatinization state.

The cultivars source was known as the major importance for the starch gel retrogradation. This was not only just true for starches varying in amylose content, but also for starches with very similar amylose contents. Some of the differences between, for instance, cereal starches, could discriminate the amylopectin/amylose ratio and lipid contents. However, these factors accounted only for some partial differences. Structural differences found in the amylopectin molecule could possibly cause the variations in the rate and extent of recrystallization (Eliasson and Gudmundsson, 1996).

2.3 Modified Starch

The modern food industry attended to use the modified starches to improve their product qualities and characteristics. For example, starch should be able to stand against high shear rates and shear forces during processing or in low pH condition, and could tolerate high temperatures used in the sterilizing process, or low temperatures (i.e., storage in the refrigerator or freezer). In addition, modified starch should also resist the heat during the microwave oven when the consumer prepared the product for consumption at home. Native starches usually did not meet all these requirements, so the starches had been modified in the different procedures. Chemical modification was the changes of starch molecules through the covalent linkages. Physical modifications involved the changes in starch structure or phase behavior without destruction of covalent linkages. Interactions between starch and other components (lipids, proteins) might also be classified as a physical modification. Genetic modification was the change in composition of amylose/amylopectin. The aim of all these modifications was to improve the functional properties of starch (Eliasson and Gudmundsson 1996).

2.3.1 Chemical Modification

Starch could be modified via different methods to alter the chemical structures of the starch molecules. Three distinctively different methods could be identified as hydrolysis (by acid or enzyme), substitution (the new groups were introduced into the molecules, monofunctional chemicals were used) and cross-linking (two starch chains were cross-linked through a chemical bond, and difunctional chemicals were used). The different modes of chemical modification are listed in Table 2.2.

Table 2.2 Chemical modification of starch: type of modifications, properties of modified starches, and their use in food industry

Oxidation

Reaction achieved: Depolymerization

Properties: Low-viscosity, high-solids dispersions, resistance to viscosity increases on gelling in aqueous dispersion

Use: Slightly oxidized starches in batters and breading

Cross-linking

Reaction achieved: Multifunctional reagents introduce intermolecular bridges

Properties: Restricted swelling of the granule during gelatinization, resistance to shear, high temperature, and low pH

Use: Continuous cookers, sterilization, canning

Esterification

Reaction achieved: Introduction of acetate groups

Properties: Hydrophobic, cationic, or anionic character; prevents or minimizes association of outer branches of amylopectin molecules; prevents cloudiness and syneresis, viscosity stability, and clarity at low temperature

Use: Canned, frozen, baked, and dry foods

Hydroxyalkyl starches

Reaction achieved: Hydroxyethyl or hydroxypropyl groups introduced

Properties: Dispersion stability, nonionic character, decreased gelatinization temperature, low-temperature stability

Use: Low-temperature food storage conditions

Starch Phosphate Monoesters

Reaction achieved: Introduce phosphate groups

Properties: Clarity, high viscosity, a long, cohesive texture, stability against retrogradation

Use: As emulsifiers

Source: Carbohydrates in food (Eliasson and Gudmundsson, 1996)

2.3.2 Physical Modification

There were various methods identified as physical modification. The most was pregelatinized starches, know as cold-water swelling starches. Pregelatinization methods included drum drying, spray cooking, solvent-based processing, and extrusion. Particle size adjustment by mechanical means was the process affecting starch properties and used as fat replacer. Other methods for physical modification were annealing and heat moisture treatment (Sriroth and Piyachomkwan, 2000).

2.3.3 Genetic Modification

Genetic modification was the changes in composition ratio of amylose/amylopectin such as high amylose starch that used as coating agents and waxy starch used as adhesive agents. The new type of genetic modified starch was resistant starch. It used for dietary fiber in many foods (Sriroth and Piyachomkwan, 2000).

2.3.4 Modified Starch Properties

1. Gelatinization Behavior

The gelatinization temperature of modified starches was the aim to modify and be inevitable. DSC had been used to study the effect of chemical modification on the gelatinization parameters. For most of modifications, the reduction of T_0 and T_m, as well as in ΔH, has been reported.

2. Rheological Behavior

One reason for the use of modified starch was to elevate the viscosity and stability of starch paste. Changes in rheological properties were thus notable and available. Peak viscosity as well as setback values for hydroxypropyl distarch phosphate waxy maize incremented when compared with its unmodified counterpart. Fundamental rheological measurements had shown that a cross-linked waxy maize starch gave G'values similar to a normal maize starch, whereas the unmodified waxy maize starch provided very low values.

3. Cold Storage and Freeze-Thaw Stability

An important improvement of the modified starches was freeze-thaw stability. It had been observed that the storage of a starch gel for 7 days at 4^{o}C resulted in more syneresis than one freeze-thaw cycle. The syneresis was observed as the exudates of liquid and the degree of syneresis was lower with an increase in the degree substitution for several modified starches.

4. Interactions with Other Components

Amylose in starch molecules was modified and possibly changed in the formation of the amylose-lipid complex (Eliasson and Gudmundsson, 1996).

2.4 Glutinous rice

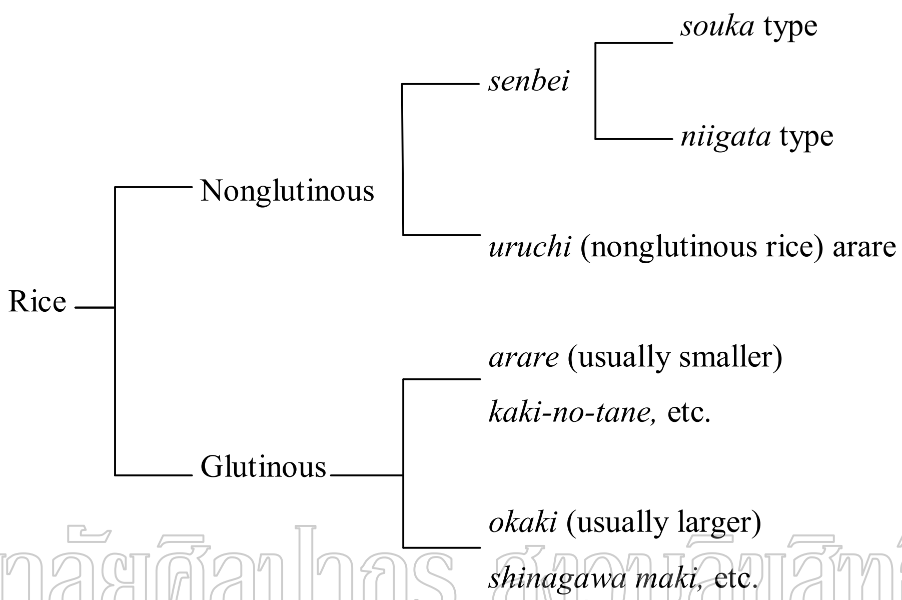
Glutinous rice, sweet or waxy rice comprises most of chalky opaque endosperm and the cut surface of which has the appearance of paraffin wax. The starch from glutinous rice gives a reddish-brown color with iodine and also it contains amylose less than 1%. However, the glutinous rice starch contains the molecules, which are low or medium molecular weight and profusely branch and intermediate in structure between amylopectin and glycogen. Flour produced from waxy rice is used as a thickener in processed foodstuffs since it can well resist the freeze/thaw cycling, so it can be utilized for puddings and cakes (Kent, 1983). During heating, waxy rice containing higher levels of free sugar, specifically maltooligosaccharides (Johnson, 1990) and the kernels of all glutinous rice being sticky and adhering to one another, provided a product with definitely different texture when compared to non-waxy rice (Noomhorm et al., 1997). In the Orient, the variety of rice snack foods still be more available in Asia market including either glutinous rice or non-glutinous rice, and the combination of them. According to the difference in sticky characteristics of glutinous rice, the glutinous rice snack is desirable in some group of customer. As a result of its ability to expand and porous texture, glutinous rice is a competitive source used in baked and popped snacks (Luh, 1991).

2.5 Rice Cracker

Arare and Senbei are one of Japanese baked rice crackers and still be the major and traditional snacks in Japan. Their unique in flavor and characteristics are quite different from Western snacks, which are rich in the flavor of butter or cheese. Although, in past years, Japanese traditional snacks and cakes have competed with Western-style snacks and cakes, rice crackers have been annually increasing in sales. The many problems in the Japanese rice cracker industry mainly relate to the techniques of manufacturing, which are still kept in patent and traditionally hand-performed. Moreover, the government control of rice distribution and an increase in price of rice have limited the accessibility of this raw material (Luh, 1991). The rice crackers produced in Thailand mainly exported to Japan and had major market share in Japan about 86%. The export volume of rice cracker was about 21,139 tons with value of 1,633 million bahts and increasing rate of 14.67-15.48% by year. The advantage of rice cracker manufacturer in Thailand is the high quality of product and raw material (National Food Institute and the office of Industrial Economics, Thailand, 2003).

2.5.1 Classification of Rice Crackers

Rice crackers made from glutinous rice are generally called Arare or Okaki. They contain unique textural characteristics and can be easily dissolved in the mouth after chewing. Rice crackers made from non-glutinous rice are known as Senbei, which had a hard and rough texture. The classification of rice crackers (Li and Luh, 1980) was presented in Fig. 2.1.



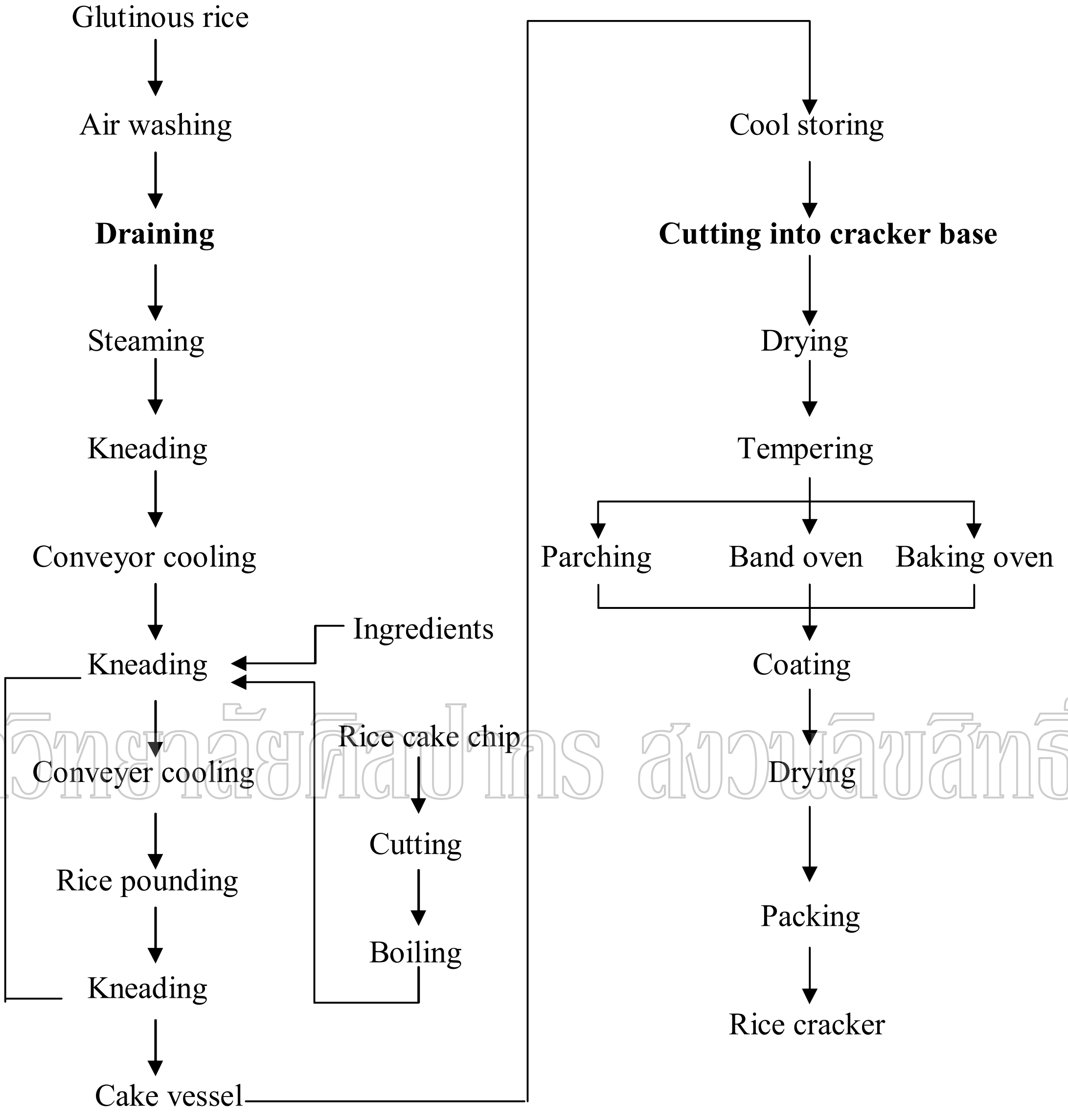
Source: Rice snack foods (Li and Luh, 1980)

Fig. 2.1 Classification of rice crackers

2.5.2 Processing of Rice Cracker

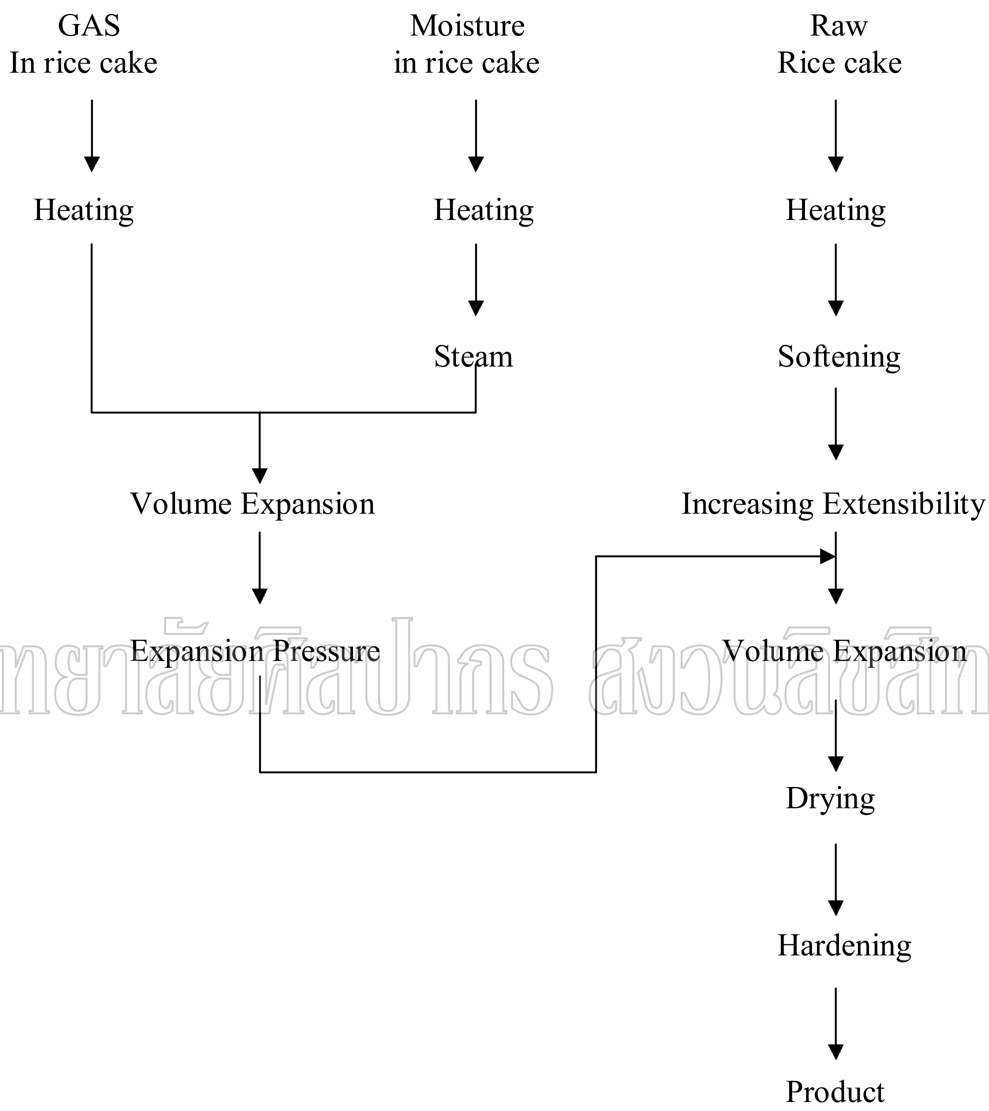
Glutinous rice cracker process was shown in Fig. 2.2. At the beginning, glutinous rice was washed in a rice-washing machine and soaked for 16-20 hr to sift water at temperatures below 20°C. After draining, the rice containing about 38% of moisture, was crushed using the rollers into a fine powder, passed through an 80-mesh sieve, and then steamed for 15-30 min. After cooling for 2-3 min, it was kneaded three times. This kneaded cake was placed in a cake vessel and quick-cooled to 2-5°C for several days to harden cake. The hard cake was then cut into various desirable shapes depending on the consumer demand and hot air dried at 45-75°C to obtain the final moisture content of 20%. This cake was aged for overnight and subsequently placed in the continuous baking machine or the oven. After baking, it was coated with soy sauce, spices, and other seasoning materials and then re-dried in a convectional dryer at 90°C for 30 min.

The mechanism of expansion was the greatly important step dealing with the quality and production of rice cracker. The changes when the dry raw rice cake was baked are shown in Fig. 2.3. Raw rice cake could be modified its textural characteristics depending on the moisture content and air temperature upon heating. Raw rice cake softens gradually into a glasslike state and increased in extensibility. In response to expansion pressure, the raw rice cake expanded, dried, and hardened to form the products. The expansion pressure was the result of the changes in the moisture and air content with rising temperatures. For raw rice cake in a glasslike state, moisture was sealed and the cake acted like a tightly sealed container. If the extensibility of the cake was strong after it was heated to 100°C, an outer pressure formed within the outer cake shell, and the evaporating temperature would increase. The cake would continue to expand until the steam pressure and extensibility was balanced. For this reason, the evaporation of moisture and the physical state of the rice cake controlled the expansion of raw rice cakes (Luh, 1991).



Source: Rice snack foods (Luh, 1991)

Fig. 2.2 Flowchart of rice cracker



Source : Rice snack foods (Luh, 1991)

Fig. 2.3 Changes in raw rice during baking process

The rice cake expansion may be measured via the amount of raw rice cake baked and its product volume or the changes in temperature during the baking processes. When the raw rice cakes were baked in the oven at 220°C, the volume of product decreased as the amount of baked increases. The temperature changed in the baking of rice cake had transition points at about 145-165°C; where the temperature rate lowered, the expansion was taking place at this point too. In addition, the period of this transition point had a close relationship to the volume expansion by the shorter period receiving the more expand. In other words, the formation resulting from expansion pressure was not related to the volume of steam generated from moisture; instead, it was controlled by the speed of evaporation (Luh, 1991).

2.5.3 Effect of Process on Rice Cracker Quality

Distribution of water absorption. The Distribution of water absorption in rice varied due to its compactness. The outer layer of a rice grain, especially the layer of rice bran, was composed mostly of protein; therefore, the water-absorption rate in this portion was the highest as compared to others. The layer next to the rice bran, the outer layer of the milled rice, exhibited the lowest water-absorption rate. The rate of water absorption elevated as the core of the rice grain was approached.

Granular size after grinding. Granular size of flour was one of the significant factors. If the moisture content of soaked was higher, the rice could be ground further to a finer consistency. As result of less moisture in the outer portion of rice grain, the granules were coarser after grinding. The finer granules were easier to gelatinization also the finer powder provided the expand products compared to coarser powder.

Kneading. Rice flour was steamed and kneaded by a machine for different periods of time and made into rice crackers. Rice crackers kneaded for shorter or longer periods had a non-uniform texture and a relatively longer period contributed a greater expansion rate than the flour shorter kneaded (Luh, 1991).

2.6 Puffing Behavior of Various Starches

The use of cereal flours and meals as the predominant ingredients in puffed snacks had been the low cost natural sources and also exhibited the excellent expansion of products. The extension of puffiness and the texture of the finished snack usually influenced by the amylose and amylopectin ratio. In contradiction, high amylopectin content starches tended to give fragile products of low density while amylose gave adequate resistance to breakage and texture that were acceptable. On the other hand, the products containing only corn, red milo, and tapioca starches would be hard in texture and too high in density. The texture could be softened somewhat by the addition of plasticizers such as sucrose, dextrose, or sorbitol, but normally 50% or more amylopectin was required for a good quality product. A starch system containing 5-20% amylose was suggested as the most suitable.

In baked-type puffed snacks, pre-extrusion moisture content in the range of 20-35% and a starch having about 80-100% amylopectin content were necessary to yield acceptable products. Some modified and derivative starches were reported about the limitation for application in puffed snacks. Chemical modification processes included cross-bonding, pregelatinizing, and forming phosphate, acetate, and hydroxypropyl derivatives (Matz, 1996).

2.7 Starches and Starch Derivatives in Expanded Snacks

Both amylose and amylopectin significantly affected the starch expansion. In expanded snack foods, manipulating the amylose-amylopectin ratio could alter the final texture. Amylose was film-forming and more resistant than amylopectin. The appropriate ratio between amylose and amylopectin capable to set up crunchiness and strength were required in the product. Amylose increased the shape retention qualities of the dough, which could better withstand further treatments such as cutting and drying.

The branched amylopectin formed a network in the dough matrix. During the extrusion process, some of the water was converted to steam. The escaping steam associated the expansion of dough network to create the porous texture. Amylopectin increased the expansion ability of a snack, therefore contributing crispiness and puffiness to the product. The expansion ratio of a starch generally increased with increasing amylopectin content irrespective of starch amylose content or chemical and physical treatments.

Indirect-expanded snacks made by two steps. First, the low moisture and non-expanded pellets were formed by the application of dehydration. Secondly, either baking or frying was employed to achieve the final volume increase. The pellets could be formed using a one-step single-screw extruder or by mixing in a blender, then followed to shape by roller. The moisture content of the dough was approximately 20-30%. Typically, the temperature of the heating zone was from 75 to 120^{o}C. The dough went through a cooling zone before reaching the cutting head, where the temperature was at or below 90^{o}C. The extrudate would be further dried to reach moisture content of 6-10% before reconstitution. When pellets expanded by baking, the internal temperatures of the baked products increased much slower than those in the extrusion process.

Starch gelatinization was a key factor for expansion. Due to the limited moisture and heat, pregelatinized starches were preferred to cook up starches in this application. However, due to the loss of granular integrity, pregelatinized starches may cause sticky, gummy dough that did not retain their shape well after forming. Cold-water-swelling, crude starch derivatives hydrated and swelled in cold water. This type of granular starch improved the handling and forming properties of the dough used to make the half-product. The shelf life of the half-product was very stable. The starches were used to provide uniform moisture distribution, good gas-holding capacity, and the non-expanded structure of the extrudate (Wang, 1997).

2.8 Selecting an Optimum Starch for Baked Snack Development

Key concerns for developers of baked snacks included texture, product shape, and surface color. Baking developed the product's structure, made it edible and aesthetically desirable. Baking concerned encompass internal product temperature, which slowly increases compared with extrusion or frying. Pregelatinized starches, also known as instant or cold water-swelling starches, were submitted for this application. These starches were preferred due to the slow cooking process and also there was a minimum of water in the snack dough.

With their fine starch granule size, waxy-based starches were the most suitable for baked snack products because they permitted easy sheeting and good binding, which resulted in minimal breakage. Carefully chosen specialty starches could improve texture and forming, and reduced cracking and breakage. For texture improvement, a modified, pregelatinized starch derived from waxy maize would serve well. To minimize forming and shaping problems, a bland, modified food starch mimic fat or a modified, cold water-swelling starch would provide good results. Resistant starches, high-amylose corn starch, and modified high-amylose starches could be used to reduce cracking and breakage that resulted in excessive losses (Huang, 2001).

2.9 Texture of Foods

Texture was an important determinant of food quality. In the mastication process the forces that a food was subjected to be complex. Chewing broke the food down and made it more digestible. During the process, information was transmitted from various sensory receptors in the mouth to specific parts of the brain, where it was integrated with other incoming information as well as information stored in the memory to express an overall impression of texture.

Texture of foods directly related to physical and chemical properties, perceived via eyes prior to consumption, the sense of touch in handling the food, various sensory receptors in the mouth during consumption and the sense of hearing.

Thus, the consumer was aware of a whole host of textural characteristics, which derived from various physicochemical properties of the food such as overall size and shape, particle size, fat content, structure and mechanical properties. Therefore, strictly speaking, texture could only be measured by sensory methods involving the use of both trained and untrained sensory assessors. However, sensory methods were very time consuming and the reliability of the results depended very much on the correct design and skillful implementation of the experiments, and the aptitude and cooperation of the sensory assessors.

One method which had been developed over the last 20 years and now extensively used was sensory texture profiling, a strong case that well-conducted texture profile techniques were objective tests, they were free from hedonic bias, and that result from different panels were reproducible to a high degree. Texture profiling involved the used of a panel of trained sensory assessors to develop a list of 'texture words' to describe the textural characteristics perceived in range of samples that were typical of a particular food or product. Textural characteristics were often associated to fairly distinct stages of the chewing process, consisting of: the first bite impression, impression during mastication and residual impression. Once, the panel had decided a complete list of appropriate descriptors, the magnitude of each textural characteristic could then be quantified on rating, category, or graphic scales. Overall interpretation of texture profile data usually required the fairly sophisticated statistical techniques, such as analysis of variance and principal component analysis. For texture evaluation, that relied upon the deformation of a sample. These were usually classified under three heading.

2.9.1 Fundamental methods

This group consisted of methods designed to measure one (or more) well-defined physical property of a sample under test and to relate this property to textural characteristics assessed sensory. Such physical properties were stress-strain relationships, visco-elastic behavior, plastic-visco-plastic materials, and liquid foods: viscous behavior. In all these cases, the rheological behavior of the food can be described mathematically and related to sensory characteristics.

2.9.2 Imitative methods

This group of instruments which attempted to simulate, to some degree, the forces and deformations that the food was subjected to whilst the food was being consumed. Texture was mainly assessed from the sensations caused when the food came into contact with the hard and soft parts of the mouth. In addition, the teeth, the tongue, cheeks, palate and all other oral structures also played some parts in the mastication process and in textural measurement.

2.9.3 Empirical methods

These methods measured properties of materials that were often not well defined and could not easily be expressed in fundamental terms. However, for certain types of food had been found to relate to one or more textural attributes and so they could be used as an indirect measurement of that attribute. The force could be applied in a wide variety of ways, such as penetration, shear, compression, extrusion, cutting, flow, and mixing (Lewis, 1996).

2.10 Texture Measurement of Cookie and Cracker

Instruments for measuring textural properties of cookies and crackers could be classified relatively to the principle of measurement utilized. Such classification emphasized the importance of understanding the theories of engineering materials testing, precisely which rheological measurement was accomplished by an instrument, and the resulting units of measurement. The ideal instrumental method produced from the mechanical properties of cookies and crackers and presented as a mathematical analogue accurately predicting human response. If used correctly, the basic instruments, engineering mechanical terms, methods, and analyses for materials rheology studied can easily be the study of cookie and cracker texture even though the classic underlying theoretical conditions were not completely satisfied.

Texture-measuring instruments that operated on the force/deformation principle were the most useful for cookie and cracker testing and could be grouped into penetrometers (with probes), compressimeters, shearing devices, and masticometers. Cutting instruments normally used knife like blades or wires to cut through a sample or to break a sample. The resistance to this action was measured. Masticometers had been designed to apply force similar to actual mastication of food. Actions represented as biting, crushing, and compression.

Reporting data in the proper units was another crucial aspect of force/deformation measurement. The recommendation was the use and reporting of international scientific (SI) units, and in particular, the use of the Newton to report force when measured in units of mass, for example, kilograms. The conversion was 9.807 N, were equivalent to 1 kg force. One must known which force was applied by an instrument or procedure and the rate and direction of that force.

Most instrumental methods for texture assessment were destructive to the sample. While that was usually not a problem in commercial production applications, sample destruction might be costly in research and development applications (Gaines, 1994).

2.10.1 Texture Measure Instruments

Various instruments were available to measure force measure/deformation. Most were quite versatile and could accomplish compression, tension, penetration, punching, probing, snapping, and bending. The manufacturers usually supplied the sample devices/holders necessary for most of those testing principles. Also important in many investigator or routine applications was compatibility of measurement data with computer hardware and manufacturer-supplied computer software, designed to statistically manage and display data for many applications. Table 2.3 listed a few of the instruments likely to be applicable to texture evaluation of most cookies and crackers, and their manufacturers (Gaines, 1994).

Table 2.3 Several texture-measuring instruments applicable to cookies and crackers

Instrument	Manufacturer	Computer Hardware	Computer Software
Ottawa Texture Measuring System	Canners Machinery Ltd.	X	X
Electron Force Gauge	Chatinllon Force Measurement	X	X
Struct-O-Graph	C.W. Brabender Instrument, Inc.		
Texture Test/Management System	Food Technology Corp.	X	X
Universal Testing Machine	Instron Corp.	X	X
TA.XT2 Texture Analyzer	Texture Technologies Corp.	X	X
Biscuit Texture Meter	Werner Lehara		

Source: Objective assessment of cookie and cracker texture (Gaines 1994)

2.11 Partial Least Squares (PLS) Regression

PLS regression is a recent technique that generalizes and combines features from principal component analysis and multiple regressions. It is particularly useful to predict a set of dependent variables from a (very) large set of independent variables (i.e., predictors). It originated in the social sciences, specifically economy, but became popular first in chemometrics (i.e., computational chemistry) due in sensory. But PLS regression is also becoming a tool of choice in the social sciences as a multivariate technique for non-experimental and experimental data alike. It was first presented as an akin algorithm to the power method (used for computing eigenvectors) but was rapidly interpreted in a statistical framework.

The goal of PLS regression is to predict y from x and to describe their common structure. When y is a vector and x is full rank, this goal could be accomplished using ordinary multiple regression. When the number of observations, x is likely to be singular and the regression approach is no longer feasible. Several approaches have been developed to cope with this problem. One approach is to eliminate some predictor, using stepwise methods, and another one, called principal component regression, is to perform a principal component analysis (PCA) of the x matrix and then uses the principle components of x as regressors on y. The orthogonality of the principal components eliminates the multicolinearity problem. But, the problem of choosing an optimum subset of predictors remains. A possible strategy is to keep only a few of the first components. But they are chosen to explain x rather than y, and so, nothing guarantees that the principal components, which "explain" x, are relevant for y. By contrast, PLS regression finds components from x that are also relevant for y. Specially, PLS regression searches for a set of components (called latent vectors) that performs a simultaneous decomposition of x and y with the constraint that these components explain as much as possible of the covariance between x and y. This step generalized PCA. It is followed by a regression step where the composition of x is used to predict y (Abdi, 2004).

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CHAPTER 3

EFFECT OF STARCHES AND FLOURS ADDITION ON TEXTURAL PROPERTIES OF GLUTINOUS RICE DOUGH

ABSTRACT

The effects of 6 types and 4 different level usages of modified starches and flours added in glutinous rice dough were examined. The dough was prepared and stored at 5-7°C for overnight and then performed the shear test and puncture test. Hardness, firmness and modulus of elasticity of dough added with all starches and flours were higher as compared with the control ($p<0.05$). The more amounts of starches and flours added in dough, the more hardness, firmness, modulus of elasticity were obtained ($p<0.05$). Shear force of dough with modified tapioca starch (Tapple 25), modified waxy corn starch (Maps 281), and potato starch increased 37.8%, 40.2%, and 63.4%, respectively. Texture maps of dough with additional starches tended to toughness and brittleness than the control. The results of changes in textural characteristics were described by the starch retrogradation, involving ratio of amylose and amylopectin. Dough with potato starch exhibited the highest rigid due to high amylose content. In contrast, dough with waxy corn starch contributed high rigid due to great proportion of long chain branches of degree of polymerization (DP) 14-24. Tapioca starch and derivatives exhibited the high stickiness dough because of its cohesive characteristic.

Keywords: glutinous rice flour, glutinous rice dough, Mochi, texture analysis

INTRODUCTION

Glutinous rice cracker (Arare) produced by Thailand manufacturer is commonly used RD6 and RD8 glutinous rice as the based raw materials (Noomhorm et al., 1997). According to the use of the different glutinous rice cultivars from the traditional one making in Japan, there exist some problems in harder textural properties of Arare. The possible method that can resolve this problem is the addition of some modified starches and flours in Arare formulation.

According to the process of glutinous rice cracker, glutinous rice dough normally called “Mochi” was placed into the cake vessel and quickly frozen for a few days. The cooling treatment was employed to ensure the dough uniformly solidified before cutting to the desirable shape (Juliano, 1985). The addition of some modified starches/native flours in the glutinous rice cracker could alter the dough textural properties. In addition, the Mochi cutting machines were designed for the hardened dough. From this reason, if the dough texture was not hard or firm enough, it could loose out of the machine core, be sticky with the blade, or not be sliced into the appropriate shape and dimension.

The rheological changes of the glutinous rice dough on cooling storage were known as the process of retrogradation (Watanabe et al., 1999) as indicated via an elevation of dough firmness and rigidity (Eliasson and Gudmundsson, 1996). Retrogradation tendency of dough varied from many factors such as botanical source (Jacobson, Obanni and BeMiller, 1997; Fredriksson et al., 1998), ration of amylose and amylopectin (Wang and Wang, 2002; Fredriksson et al., 1998; Sasaki et al., 1999), time and temperature of storage condition (Jacobson and BeMiller, 1998; Ribotta et al., 2003), and also concentration of starch (Morikawa and Nishinari, 2000).

The use of native starch in foods was limited by its physical and chemical properties. Chemical modification of starch had been used to improve gelatinization and retrogradation. Many researchers were concentrated to study the effects of modification of starch on dough properties. Rosalina and Bhattacharya (2002) found that the higher degree of cross-linking applying, the more shear-resistant gel obtained. On the other hand, Morikawa and Nishinari (2000) also confirmed that little increase in the degree of modification could remarkably resist the retrogradation in the starch gel. Senthil et al. (2002) measured texture of the dough from blends of wheat flour and soya flour and found the addition of soya flour resulted in the compression force. Obanni and BeMiller (1997) suggested that the amylograph data of some starch mixtures behaved like a chemical modified starch. The objective of this experiment was to investigate the changes in textural properties of glutinous rice dough added with various modified starches and flour.

MATERAILS AND METHODS

Raw materials

Milled RD6 glutinous rice from Udornthani located in the northeastern part of Thailand were used as raw material in this experiment. The rice samples were well tighted seam and stored at room temperature (25^{o}C).

Commercial 8 different starches and flours obtained from the suppliers were used in the research including waxy corn starch “Mazaca”, cross-linked waxy corn starch “Maps 281” (Nutrition Limited Partnership, BKK, Thailand), tapioca starch and esterified tapioca starch “Tapple 25” (Tapioca Development Corp, BKK, Thailand), cross-linked tapioca starch “Gelpro M” (Potential Marketing Co., Ltd., BKK, Thailand), potato starch, potato granules “GTW”, and potato flake (Winner Group Enterprise Ltd., BKK, Thailand). Moisture contents of all starches and flours samples were measured using moisture analyzer (model MX-50, AND, Japan) and then rehydrated to confirm the final moisture content being 40% before further use in the production of dough.

Preparation of Glutinous Rice Dough

Milled glutinous rice was weighed 500 g, washed, and then soaked in 700 ml of water at 15^{o}C for overnight (approximately 16 hr). After soaking, the moisture content of drained rice was about 38-40%. The drained rice was crushed using blender (model MX-T1PN, National, Taiwan) into fine powder and then sieved through 200 mesh stainless-sieve (Endecotts Ltd., England). Glutinous rice flour was steamed using a steam cooker (model PFC-20BM, Toshiba, Japan) for 45 min and kneaded for 5 min. The dough was placed in squared plastic box and allowed to harden for overnight at 5-7^{o}C. The chilled dough was cut into 28 X 30 X 3 mm individual chip and randomly collected to further analyze. The moistened starch and flour were replaced glutinous rice four and mixed through sieving before steaming at 2.5, 5.0, 7.5, and 10% by weight.

Textural Determination

Texture was determined using a Texture Analyzer (model TA-XT2i, Stable Micro System Co., Ltd., UK) in combination with a 5 kg load cell. The instrument was set as follows:

Puncture Test

Sample was placed on a spring-loaded clamp plate with a 16 mm dia. hole. 5 mm dia. cylindrical flat-end punch was mounted and programmed to punch pass through sample completely. The pre-test speed, test speed and post-test speed were set at 5 mm/s. The punch traveled 15 mm into sample to measure peak force and area under force-deformation curves. 7 tested samples were randomly selected to measure textural characteristics. All experiments were run in triplicates.

Shear Test

Sample was placed across the bottom of Warner Bratzer Blade Set (‘v’ slot blade). The blade was driven downward at pre-test and test speed of 5 mm/s. The post-test speed was set at 10 mm and the blade traveled 30 mm through sample completely to measure peak force and area under force-deformation curves. 7 tested samples were randomly selected to measure textural characteristics. All experiments were run in triplicates.

Data collection and analysis were accomplished using software of TA-XT2i analyzer (Texture Expert Ver.1.22) in N and mm. The instrumental parameters of puncture test were calculated as hardness, normal stress, normal strain, firmness, stickiness, and modulus of elasticity and the instrumental parameters of shear test were determined to evaluate hardness, shear stress, shear strain, firmness, stickiness, and shear modulus (Fig. 3.1).

Statistical analysis

All data were performed using the General Linear Model of the Statistical Analysis System software (Ver.8.1, SAS Inst., Cary, NC, USA). Significant calculated means were compared by least significant difference (LSD) at 95% confidence level.

RESULTS AND DISCUSSIONS

All the addition of various starches and flours significantly increased the force required to deform the dough ($p<0.05$) from 14.5 N to 23.9 N (potato starch) and also elevated shear force ($p<0.05$) to 37.8-63.4%. The firmness and stickiness of prepared dough were different in each starch addition. The rice dough with Gelpro M, potato flake, Tapple 25, Maps 281, GTW and potato starch augmented in modulus of elasticity, the resistance to deformation, respectively (Table 3.1).

The hardness of glutinous rice doughs with starches and flours normally were contributed by the composition of starch. Regarding to cooling and aging processes, the behavior of the gelatinized starches subsequently changed by retrogradation. This increased rigidity and firmness of the swollen granules to a solid or solid-like material by the recrystallization process. The rate of retrogradation depended on many factors, especially the ration of amylose and amylopectin (BeMiller and Whistler, 1996). The differences obtained from the short-term development of gel structure via amylose crystallization and the long-term reordering of amylopectin (Singh et al., 2003). Then the addition of starches and flours in glutinous rice flour (0-2% amylose) would alter the hardness of dough.

This studied exhibited the same agreement with the report of Fredriksson et al. (1998) and Singh et al. (2003). They reported that the potato starches yielded the highest retrogradation due to the composition of high amylose and several percents of the intermediate substance called, "thymol-amylopectin" which distinguished the structure and properties from amylose and amylopectin (Lisinska and Leszczynski, 1989). However, the tendency of starch retrogradation did not depend only on the amylose/amylopectin ratio, but also several factors, especially the modification of starches.

In general, Maps 281 (cross-linked waxy corn starch) and native waxy corn starch usually contained low amylose content (BeMiller and Whistler, 1996). However, Maps 281 incredibly provided high rigid dough and more increased the hardness of dough than modified tapioca starch as shown in Table 3.1. Native waxy corn starch displayed the similar hardness as dough made from potato starch and tapioca starch. These may result in the presence of more opened structures and swelling powers that correlated to the storage modulus of starch gel (Li and Yeh, 2001). In addition, the retrogradation of waxy starches was directly proportional to the mole fraction of branches with degree of polymerization (DP) 14-24, and inversely proportional to DP 6-9. Thus, the high degree of retrogradation of waxy starches had been attributed to the high proportion of long chain branches of DP 14-24 (Singh et al., 2003).

Texture maps of glutinous rice dough was generated and shown in Fig. 3.2. Both normal and shear stress-strain curves presented the tendency of changing in the dough toughness with respect to the addition of modified starches and flours. Potato starch and GTW tended to produce brittle dough whileas modified tapioca and waxy con starch gave the rubbery dough. These results could be described by the different rates of retrogradation. Long-term reordering of amylopectin which a much slower process, and also only overnight of aging process showed it did not provide enough time to recrystallization. For the dough with tapioca starch, Chen and Ramaswamy (1999) found the tapioca starch gel was higher viscosity than potato starch and corn starch at the same concentration and it had the long (cohesive) and medium tendency to retrogradation so it may result in rubbery characteristic.

The more modified starches and flours added in dough, the more hardness gained ($p<0.05$) (Fig. 3.3). At the additional levels of 2.5-10.0%, modified tapioca starch, modified waxy corn, and potato starch intensively increased shear force of dough from 16.57-75.8%, 38.8-48.1%, and 22.1-93.9%, respectively.

Texture maps of dough with different modified starches and concentrations measured by puncture test as shown in Fig. 3.4. The doughs with higher modified starches and flours significantly increased toughness. At 5% addition of native tapioca starch provided the same characteristic to 7.5% of Tapple 25 and 10.0% of Gelpro M and at 5.0% addition of native waxy corn provided the same characteristic to 2.5% of Maps 281. The dough with 5.0% potato starch provided the more toughness characteristic than 10.0% of potato flake and GTW, respectively.

The effects of concentration of starches and flours were investigated. The greater amount of starches and flours added in dough directly affect an increase in rate of the retrogradation and the changes in dough texture.

The comparison of texture properties between doughs with native and modified starches addition had been observed. Hardness, firmness, shear stress, normal stress, and modulus of elasticity of dough added with modified starches were significantly lower than native starch ($p<0.05$). Cross-linked starch, the derivatization of starch using a bi or poly functional chemical reactions reacting with two or more different hydroxyl groups (Thomas and Atwell, 2004), was designed for the prevention of granule rupture and loss of viscosity (Wurzburg, 1987), thus it could resist to retrogradation process. Like esterified starch, starch acetate containing 0.5-2.5% acetyl groups and normally used as stabilized starch, it incredibly resisted to retrogradation process (Sriroth and Piyachomkwan, 2000). For potato flake and GTW, the physical modified flour used in extrusion process; comprised other components such as lipid, protein, ash, and phosphorus that may affect the retrogradation.

CONCLUSIONS

The starch and flour addition in glutinous rice flour remarkably exhibited to the different textural characteristics of dough. All starches and flours directly increase the hardness and stickiness as compared with the control (100% glutinous rice flour). In addition, the higher concentrations of starches obtained, the higher parameters were observed. The use of chemical modified starch in rice dough resulted in lower hardness, stickiness, and modulus of elasticity than the use of native starch. According to texture maps, the doughs with the additional of starches tended to be more toughness as compared to the control. This study provided the valuable information for glutinous rice cracker process, especially the changes in dough texture. They were useful for glutinous rice dough (Mochi) manufacturing which need to reduce the retention time during dough hardening storage due to an increase in retrogradation rate.

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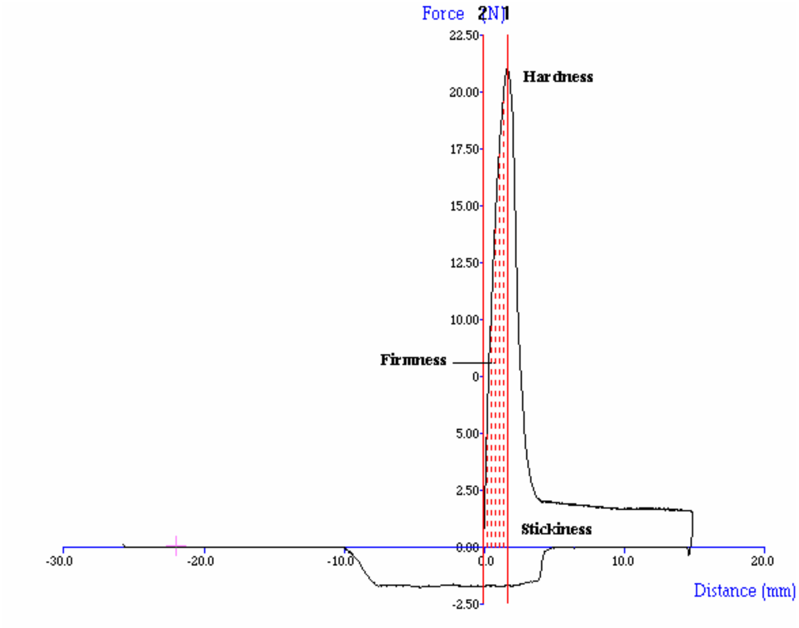
Table 3.1 Textural properties of glutinous rice doughs with starch and flour addition[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	14.5 ± 1.3^{g}	16.7 ± 3.2^{d}	29.6 ± 4.9^{d}	11.3 ± 1.3^{g}	8.2 ± 0.5^{e}	0.8 ± 0.2^{cd}
Tapple25	20.5 ± 2.7^{d}	23.8 ± 2.7^{b}	39.1 ± 10.4^{b}	17.1 ± 4.6^{d}	11.3 ± 2.6^{d}	1.3 ± 1.4^{b}
Gelpro M	19.2 ± 2.4^{f}	22.5 ± 3.5^{c}	35.8 ± 7.0^{c}	14.9 ± 2.6^{f}	12.8 ± 1.7^{b}	1.4 ± 0.9^{b}
Maps281	21.3 ± 1.4^{c}	23.5 ± 2.7^{b}	40.5 ± 8.9^{ab}	17.8 ± 2.5^{c}	11.5 ± 0.9^{d}	1.7 ± 1.4^{a}
GTW	21.6 ± 1.1^{b}	22.3 ± 2.0^{c}	35.7 ± 5.6^{c}	18.8 ± 1.9^{b}	12.2 ± 1.3^{c}	1.3 ± 1.1^{b}
Potato flake	19.8 ± 1.9^{e}	21.9 ± 3.3^{c}	35.1 ± 5.3^{c}	16.2 ± 2.4^{e}	11.5 ± 1.3^{d}	1.0 ± 0.5^{c}
Potato starch	23.9 ± 2.5^{a}	26.1 ± 2.8^{a}	41.3 ± 7.8^{a}	19.9 ± 2.9^{a}	13.4 ± 2.3^{a}	1.3 ± 0.6^{bc}

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

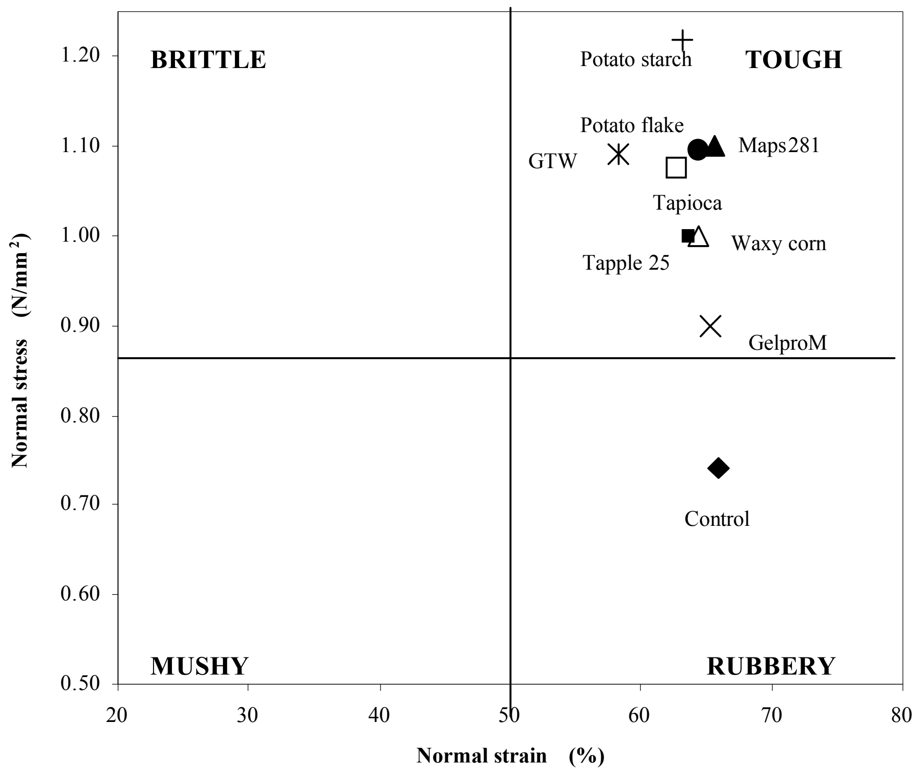


Definition of the instrumental parameters

Name	Description
Hardness	Maximum force value (N) of the compression or shear test
Normal stress	The force per unit area applied perpendicular to the plane (N/mm^2)
Normal strain	The change in length per unit of length in the direction of the applied normal stress
Shear stress	The force per unit area acting in the direction parallel to the surface of the plane (N/mm^2)
Shear strain	The change in the angle formed between two planes that are orthogonal prior to deformation which results from the application of shear stress
Firmness	The work while cutting under specific condition (N.mm)
Stickiness	The work required to release the probe from the product (N.mm)
Modulus of elasticity	The ratio of the stress to the strain
Shear modulus	The shear stress divided by the shear strain

Source: Definition of properties measured by the Texture analyzer (Stable Micro Systems Ltd., 2003).

Fig. 3.1 Force-distance curve and definitions



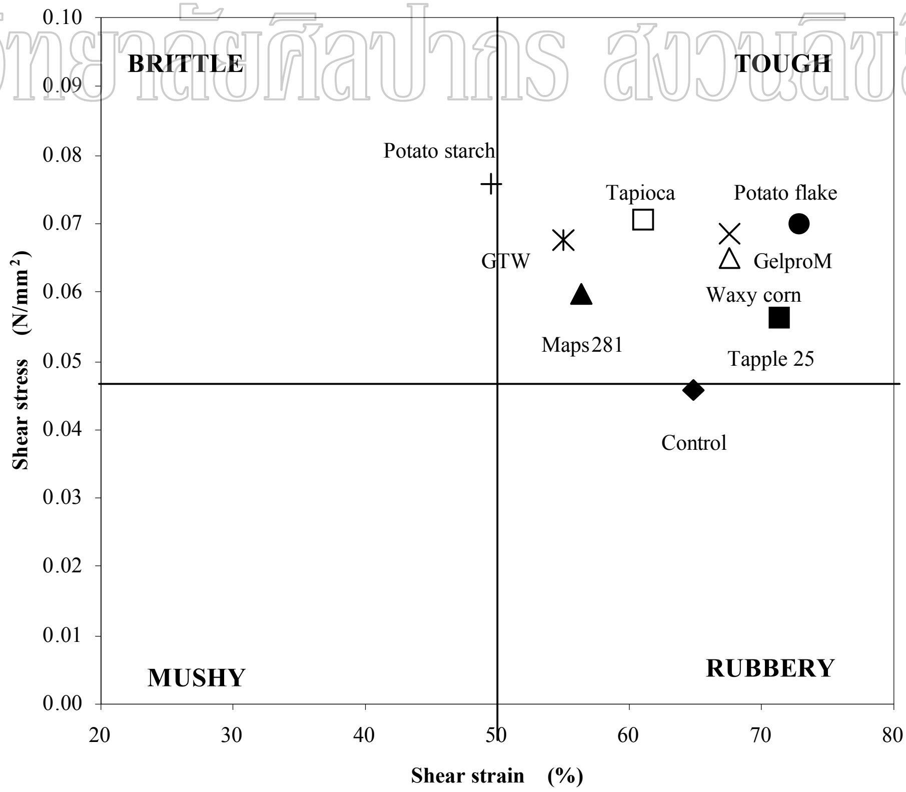


Fig. 3.2 Texture maps of glutinous rice doughs with 5% starch and flour addition

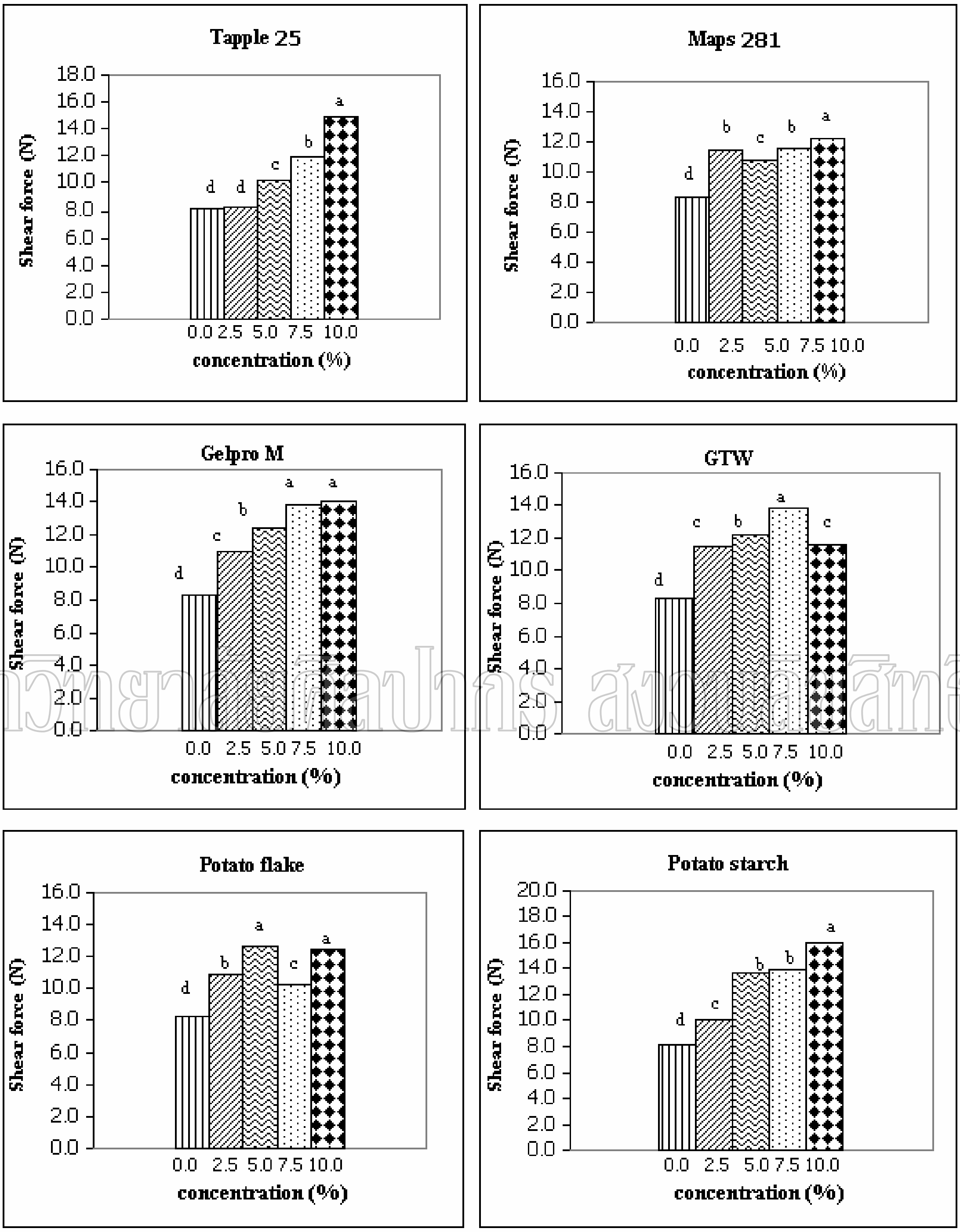


Fig. 3.3 Shear forces of doughs with various concentrations

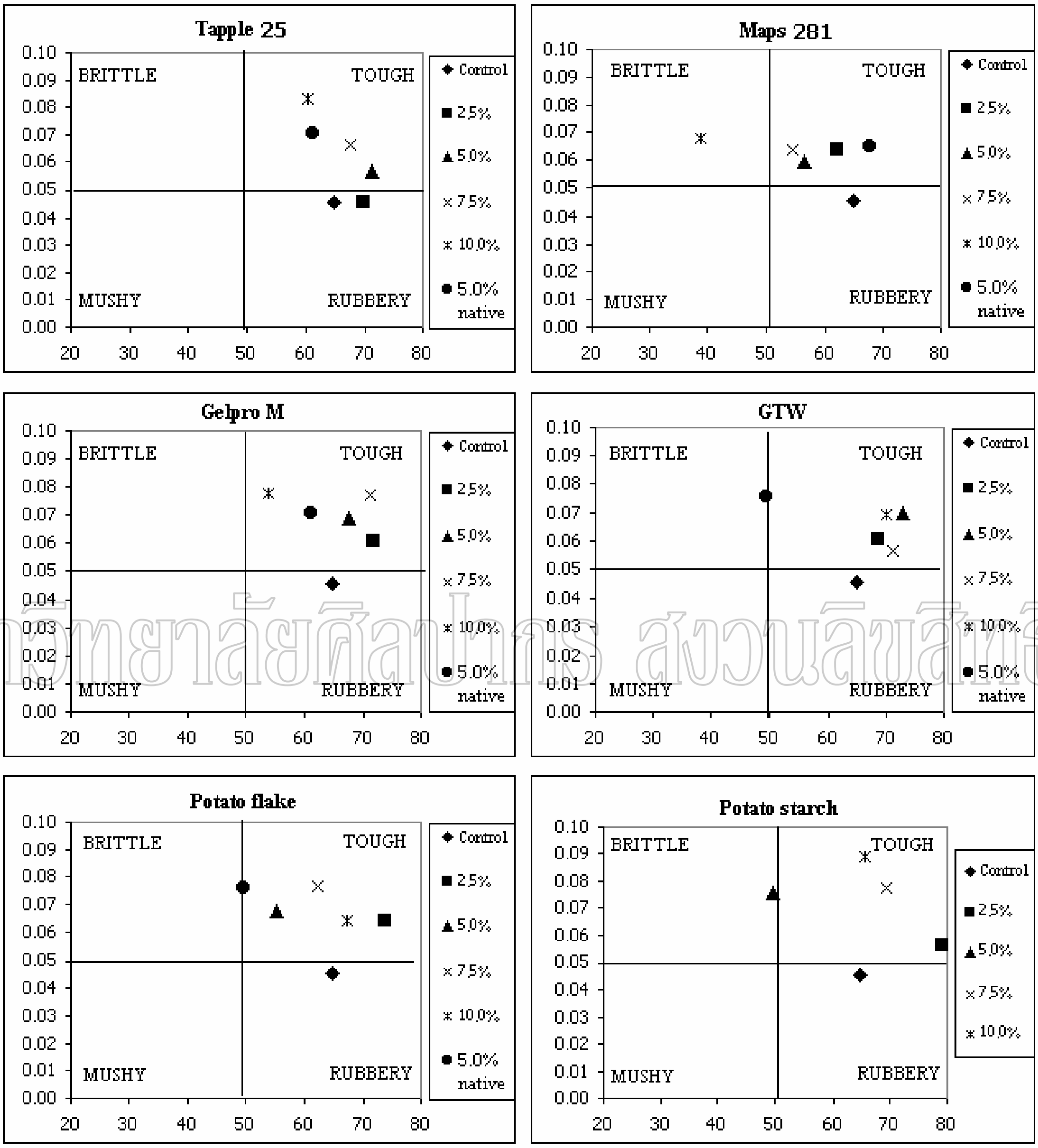


Fig. 3.4 Texture maps of shear test of doughs with various concentrations

CHAPTER 4

CHANGES IN TEXTURAL PROPERTIES OF GLUTINOUS RICE CRACKER ADDED WITH VARIOUS MODIFIED STARCHES AND FLOURS

ABSTRACT

The partially additional modified and native starches in the formulation achieved to potentially reduce the hardness of Arare snack, glutinous-based rice cracker. In this experiment, the glutinous rice flour was mixed with either modified starches or native starch at 4 different amounts of usage (2.5, 5.0, 7.5, and 10%) to investigate the changes in the textural characteristics of Arare snack. Arare products with GTW and potato flake contributed the most ability to decrease the normal stress, shear stress, and firmness ($p<0.05$). The texture map profiles plotted between the stress and strain also confirmed the same results. The further experiments found that the use of 5% native potato starch in Arare exhibited more puffy in appearance and lower intensively all textural parameters than those of Arare added with either 5% GTW or 5% potato flake.

Keywords: glutinous rice cracker, Arare, modified starch, texture analysis

INTRODUCTION

Rice cracker is one of the most numerous Japanese snack foods. Both Arare and Senbei are the major and traditional rice crackers in Japan. Normally, Senbei is made from nonglutinous rice; in contrast, Arare is produced from glutinous rice. As usually, rice is an important raw material commonly used in the preparation of baked or popped snacks because it is capable to expand quickly and finally produce more porous and unique texture of the finished products. The problems of Japanese rice cracker presently relate to the technique of manufacturing with respect to continue keeping in the confidential patent, and Japanese government attempts to control rice distribution and also increase price of rice (Luh, 1991). Thus, the rice cracker industries have gradually evacuated to the suitable locations like in Thailand because of more advantages in the availability of raw materials and the cheap labor cost. In Thailand, the production of rice crackers employs the processing technology transferred from Japan and RD6 or RD8 rice cultivars are currently used as main raw material. However, the problem of rice cracker from rice properties caused from the effect of aging rice tending to decrease the volume expansion and subsequently increased the hardness of Arare. Some manufacturers attempted to solve this problem by mixing the aged rice with the new coming one (Noomhorm et al., 1997). Moreover, the food agency of rice cracker required to elevate the softness of products for the advantageous competition in the global market with fried snacks.

The quality of expanded snacks depends on many factors, such as the quality of raw ingredients, the formulation, and the process conditions. Starch plays a very important role in controlling the texture and appearance of final products (Wang, 1997). The utilization of native starches in foods was definitely limited by its physical and chemical functionalities, so the extra-addition of modified starches and flours in rice cracker was introduced and performed in several works. Senthil et al. (2002) reported the blending of wheat flour and soya flour dramatically increased water absorption, protein content, and the hardness of fried snacks. In addition, the blending of tapioca, corn, and commercial modified starches with partially defatted peanut flour subsequently incremented expansion ratio and reduced shear strength of the puffy products (Suknark et al., 1997).

In general, characterization of food texture commonly can be measured and classified into two main categories consisting of the sensory evaluation and the instrumental testing. Sensory evaluation normally causes great variation, high cost, and long time consuming whileas the instrumental methods can be carried out under more strictly defined and easily controlled the conditions during testing (Peleg, 1983). To measure the instrumental texture using texture analyzer, the response force must be monitored and accurately recorded to investigate the fluctuation of force with an increase of time or deformation distance. Thus, a high frequency response capability was definitely major requirement. To achieve rapidly obtained data processing and reproducible deformation, the application of texture analyzer usually was recommended. A great variety of works have been reported and supported this useful equipments, for distance, the application in fried snack (Kadan et al.,1997; Senthil et al., 2002) and extruded snack (Liu et al., 2000) and occasionally it could be used to analyze texture of baked snack.

The objectives of this experiment were conducted to observe the changes in textural properties of glutinous rice cracker added with various modified starches or flours and also to figure out the best formulation of glutinous rice cracker added with various modified starches or flours that was able to improve the softness of rice crackers.

MATERIALS AND METHODS

Raw materials

Milled RD6 glutinous rice from Udornthani located in the northeastern part of Thailand were used as raw material in this experiment. The rice samples were well tighted seam and stored at room temperature (25^{o}C).

Commercial 8 different starches and flours obtained from the suppliers were used in the research including waxy corn starch “Mazaca”, cross-linked waxy corn starch “Maps 281” (Nutrition Limited Partnership, BKK, Thailand), tapioca starch and esterified tapioca starch “Tapple 25” (Tapioca Development Corp, BKK, Thailand), cross-linked tapioca starch “Gelpro M” (Potential Marketing Co., Ltd., BKK, Thailand), potato starch, potato granules “GTW”, and potato flake (Winner Group Enterprise Ltd., BKK, Thailand). Moisture contents of all starches and flours samples were measured using moisture analyzer (model MX-50, AND, Japan) and then rehydrated to confirm the final moisture content about 40% before further use in the production of dough.

Preparation of Glutinous Rice Cracker

Milled glutinous rice was weighed 500 g, washed, and then soaked in 700 ml of water at 15^{o}C for overnight (approximately 16 hr). After soaking, the moisture content of drained rice was about 38-40%. The drained rice was crushed using blender (model MX-T1PN, National, Taiwan) into fine powder and then sieved through 200 mesh stainless-sieve (Endecotts Ltd., England). Glutinous rice flour was steamed using a steam cooker (model PFC-20BM, Toshiba, Japan) for 45 min and kneaded for 5 min. The dough was placed in squared plastic box and allowed to harden for overnight at 5-7^{o}C. The chilled dough was cut into 28 X 30 X 3 mm individual chip and randomly collected to further analyze. The moistened starch and flour were replaced glutinous rice four and mixed through sieving before steaming at 2.5, 5.0, 7.5, and 10% by weight.

Textural Determination

Texture was determined using a Texture Analyzer (model TA-XT2i, Stable Micro System Co., Ltd., UK) in combination with a 5 kg load cell. The instrument was set as follows:

Puncture Test

Sample was placed on a spring-loaded clamp plate with a 16 mm dia. hole. 5 mm dia. cylindrical flat-end punch was mounted and programmed to punch pass through sample completely. The pre-test speed, test speed and post-test speed were set at 5 mm/s. The punch traveled 15 mm into sample to measure peak force and area under force-deformation curves. 7 tested samples were randomly selected to measure textural characteristics. All experiments were run in triplicates.

Shear Test

Sample was placed across the bottom of Warner Bratzer Blade Set (‘v’ slot blade). The blade was driven downward at pretest and test speed of 5 mm/s. The post-test speed was set at 10 mm and the blade traveled 30 mm through sample completely to measured peak force and area under force-deformation curves. 7 tested samples were randomly selected to measure textural characteristics. All experiments were run in triplicates.

Data collection and analysis were accomplished using software of TA-XT2i analyzer (Texture Expert Ver.1.22) in N and mm. The instrumental parameters of puncture test were calculated as hardness, normal stress, normal strain, firmness, stickiness, and modulus of elasticity and the instrumental parameters of shear test were determined to evaluate hardness, shear stress, shear strain, firmness, stickiness, and shear modulus.

Expansion Volume Determination

The length and width of rice crackers after baking was measured using a Vernia caliper (Mitutoyo, Japan) while the thickness was determined using a micrometer (Mitutoyo, Japan). Volume expansion was calculated from these measurements and compared with the control (Noomhorm et al., 1997).

Statistical Analysis

All data were performed using the General Linear Model of the Statistical Analysis System software (Ver.8.1, SAS Inst., Cary, NC, USA). Significant calculated means were compared by least significant difference (LSD) at 95% confidence level.

RESULTS AND DISCUSSIONS

The addition of modified starches and flours in Arare could alter the deformable forces applied to deform the glutinous rice cracker treatment (Table 4.1). Arares supplemented with GTW, potato flake, and potato starch exhibited to reduce normal force, firmness, stickiness, modulus of elasticity, and also reduce shear force upto 25.3%, 23.2%, and 20.2%, respectively as compared with the control. Whileas rice crackers with Tapple 25 and Maps 281 significantly increased ($p<0.05$) normal force, firmness, stickiness, modulus of elasticity, shear modulus, and finally normal force. Potato starch and flour presented the ability to diminish modulus of elasticity, and dramatically resist the deformation. However, the rice crackers with native potato starch provided the lowest hardness and firmness among the use of native waxy corn starch and tapioca starch.

Starch expansion usually caused by both amylose and amylopectin since amylose had film-forming property and amylopectin considerably formed a network and generated a porous structure. These contributed an increase in the expansion ability of snack (Wang, 1997). Thus, the optimum of amylose and amylopectin contents absolutely affected the expansion rate, subsequently increased the puffiness and reduced the hardness of snack. Liyan et al. (2001) had used to blend glutinous rice starch with corn starch to adjust the content of amylopectin and reported that the complex texture of the gel network formed by amylopectin had higher strength and could endure higher pressure. In this studies, glutinous rice flour, containing low amylose content, when mixed with potato starch, containing high amylose and in the presence of phosphoric acid in amylopectin, dramatically decreased the force required to deform the rice crackers.

Potato starch and flour exhibited the beneficial changes in morphological, thermal rheology, and chemical properties and excessively affected the final textural characteristics. These properties would be different and depended on the cultivars (Lisinska and Leszczynski, 1989; Li and Yeh, 2001; Kita, 2002; Singh et al., 2003). Potato starch granules were larger size than other cereal starches, because it contained

20-75 nm spaces and small pores at the order of 0.5-20 nm. Large granules contained a loosen structure and a more expanded systems of pores, while the structure of small granules usually considerably compacted. Moreover, amylopectin in potato starch had the properties of a weak acid anion, called amylophosphoric acid, and approached the anode and the free valences of phosphate group bind cations e.g. calcium, magnesium (Lisinska and Leszczynski, 1989) probably made a strong network in the puffing process. Similar observations were reported by Park et al. (2001), who mixed wheat flour with various starches in rolling snacks and found the inner aspects of puffing, showed the air space in the pellet of potato starch, was the largest and provided the highest puffing ratio. The formation of air cells and cracks during baking played an important role to obtain the desirable texture attributes (Kayacier and Singh, 2003).

Regarding to the hardness of crackers added with tapioca starch addition, Kusunose et al. (2001) reported that the procedure to control the dough expansion was to do not disrupt the starch granules and let them fuse together during gelatinization as same as tapioca starch did. The disruption of cell membrane would not prevent shrinkage of gas impermeable membrane during cooling after baking. Thus, it had the impacted structure and resulted in high hardness of rice crackers.

In general, BeMiller and Whistler (1996) found that the waxy corn starch contained higher lipid and protein than potato and tapioca starch. Higher protein content in starch resulted in a significant increase in hardness when using the blend between wheat and soybean in fried snacks (Senthil et al., 2002). Furthermore, lipid content could form amylose-lipid complexes that were insoluble in water and inhibited gelatinization (Singh et al., 2003). These may cause to inhibit the expansion of cracker added with waxy corn starch as compared to potato starch.

Texture maps of glutinous rice cracker were generated as shown in Fig. 4.1. Both normal and shear stress-strain curves similarly showed the changes of texture to brittleness area when adding of Maps 281, Gelpro M, and Tapple 25 in glutinous rice crackers and exhibited the mushy structure with the addition of potato starch, GTW, and potato flake. These results were also described by the expansion rate of crackers.

High expansion rate of cracker was observed with added with potato starch and flour and then resulted in lower values of texture properties and the opposite results were notified in glutinous rice crackers with the remaining starches.

The hardness of crackers varied with an increase in concentration of starch and flour and was measured by shear test (Fig. 4.2). Tapple 25 provided greater hardness as higher concentration ($p<0.05$). In contrast, Maps 281, Gelpro M, and potato flake were not different hardness with the changes of concentration usage ($p>0.05$). The addition of 2.5% GTW in rice crackers could obtain softer texture but the products with higher concentration were not ($p>0.05$). The rice crackers with 2.5, 5.0, and 7.5% potato starch provided softer textural characteristics but at 10%, the hardness of rice crackers with potato starch was higher than the control.

According to the texture map (Fig. 4.3), higher concentration of Tapple 25, Maps 281, and Gelpro M contributed than the control. The product with 7.5% GTW, or 5.0% of potato flake and 2.5, 5.0, and 7.5% of potato starch exhibited provided mushier characteristic than the control. These results also described by the expansion rate of crackers due to the limitation of by amylose content in starch. Liyan et al. (2001) and Wang (1997) reported that the expansion rate of products expansion elevated with an increase of amylopectin content and decreased with an increase of amylose content in material. These results evidenced about the limit of amylose content in starch expansion and showed the limit of starch addition in glutinous rice cracker.

The comparison between native and modified starch addition at the same concentration had been observed. The addition of cross-linked starch (Maps 281 and Gelpro M) in the glutinous rice cracker provided higher hardness, firmness, stickiness, modulus of elasticity, and shear modulus than the use of native starch. The changes in textural properties may cause via the restriction of swelling of granule during gelatinization and resistance to shear (Eliasson and Gudmundsson 1996). Moreover, cross-linked starch resulted in the reduction capability to provide puffy, uniform and light texture products (Wang, 1997). These were reasons of high hardness from lessen expansion of cross-linked starch.

Esterified starch (Tapple 25) was designed for preventing or minimizing the association of the outer branches of amylopectin molecules. It probably inhibited a forming of network in the dough matrix that became porous texture after baking, and showed in lessen expansion. For example, the product with GTW and potato flake also provided the same textural properties with potato starch. The results informed that in this concentration (5.0%) the other component as lipid and protein in potato flour hardly affected expansion rate of cracker.

The expansion volume (EV) of rice crackers with starches and flours addition compared to the control was shown in Table 4.2. Similar to previous reports, (Noomhorm et al., 1997), the crackers with high hardness gave the low EV while the low hardness contained the high one. For example, the glutinous rice cracker with 5.0% potato starch had more 8.6% EV than the control and was significantly different ($p<0.05$) from the glutinous rice cracker with 10.0% Tapple 25 and also the glutinous rice cracker with 7.5% Maps 281 had less 1.5% EV than the control. The EV tended to lessen value as higher concentration applied and the results of EV from starches and flours addition were described by the previous reasons.

CONCLUSIONS

The addition of starch and flour in the formulation of glutinous rice cracker substantially changed the textural characteristics of crackers. Rice cracker with the additional potato starch provided lower hardness and higher stickiness than the control (100% glutinous rice flour). As higher concentration of potato starch applied, the textural parameters were lower until 10% of addition. Chemical modified starches resulted in higher hardness, stickiness, and modulus of elasticity than the native starches. Texture maps also confirmed that the rice crackers were more brittle as compared with the control. Regarding to the softness improvement, Arares with 2.5% GTW, 5.0% and 7.5% potato starch were able to decrease shear force upto 39.0%, 35.2%, and 33.9%, respectively. Furthermore, the addition of potato starch did not affect the product color and taste. This study provided the valuable information to modify the textural characteristics of glutinous rice cracker with the addition of some potential starches and flours, and then was very useful for the rice cracker manufacturers.

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Table 4.1 Textural properties of glutinous rice crackers with starch and flour addition[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	31.6 ± 3.4^{c}	12.2 ± 4.9^{abc}	27.3 ± 11.8^{bc}	182.8 ± 84.9^{ab}	36.7 ± 7.0^{a}	1.7 ± 0.6^{c}
Tapple25	37.8 ± 8.6^{a}	14.9 ± 7.6^{a}	33.4 ± 8.2^{ab}	198.5 ± 105.1^{a}	35.7 ± 6.6^{a}	2.0 ± 0.9^{bc}
Gelpro M	34.5 ± 4.9^{b}	15.1 ± 8.5^{a}	27.8 ± 10.2^{c}	158.0 ± 75.0^{b}	34.4 ± 4.2^{b}	1.8 ± 0.7^{c}
Maps281	37.7 ± 3.9^{a}	15.0 ± 8.8^{a}	33.5 ± 16.9^{ab}	194.6 ± 87.8^{a}	35.9 ± 3.9^{a}	2.3 ± 1.2^{a}
GTW	29.4 ± 3.5^{d}	11.5 ± 5.3^{bc}	26.4 ± 14.7^{c}	129.2 ± 63.3^{c}	27.4 ± 4.4^{d}	1.9 ± 0.7^{c}
Potato flake	31.1 ± 3.5^{c}	11.6 ± 6.3^{bc}	25.7 ± 10.9^{c}	147.0 ± 80.4^{bc}	28.2 ± 3.2^{d}	2.2 ± 1.3^{ab}
Potato starch	30.2 ± 8.0^{cd}	12.4 ± 7.8^{b}	35.9 ± 14.5^{a}	155.9 ± 95.1^{b}	29.3 ± 7.1^{c}	1.6 ± 0.8^{c}

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

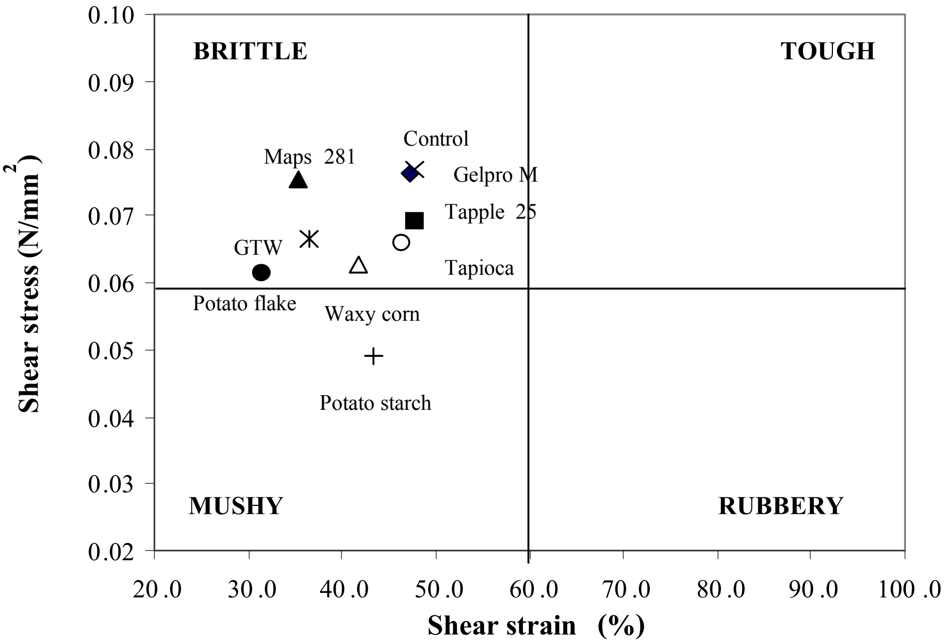
Table 4.2 Expansion volume (%) of glutinous rice crackers with starch and flour addition[1]

	Expansion Volume (%)				
Starch[2] / Conc. (%)	0.0	2.5	5.0	7.5	10.0
Control	100.0^{dc}	-	-	-	-
Tapple25	-	104.6 ± 0.4^{abcd}	102.9 ± 5.1^{abcd}	102.3 ± 3.7^{abcd}	98.5 ± 5.2^{d}
Gelpro M	-	103.8 ± 4.1^{abcd}	102.3 ± 0.6^{abcd}	101.4 ± 8.3^{abcd}	100.7 ± 7.4^{cd}
Maps281	-	101.7 ± 6.5^{abcd}	102.4 ± 4.0^{abcd}	98.5 ± 3.0^{d}	100.9 ± 9.8^{bcd}
GTW	-	105.9 ± 1.5^{abcd}	104.5 ± 3.5^{abcd}	103.5 ± 1.2^{abcd}	103.7 ± 2.4^{abcd}
Potato flake	-	106.3 ± 1.7^{abc}	106.2 ± 2.2^{abc}	106.8 ± 1.6^{abc}	106.6 ± 2.7^{abc}
Potato starch	-	107.0 ± 2.5^{abc}	108.6 ± 6.7^{a}	108.5 ± 1.5^{ab}	99.4 ± 3.6^{dc}
Tapioca starch	-	-	103.7 ± 6.9^{abcd}	-	-
Waxy corn starch	-	-	104.1 ± 7.5^{abcd}	-	-

n=30

[1] Means with difference letters differ significantly ($p<0.05$).

[2] Commercial name



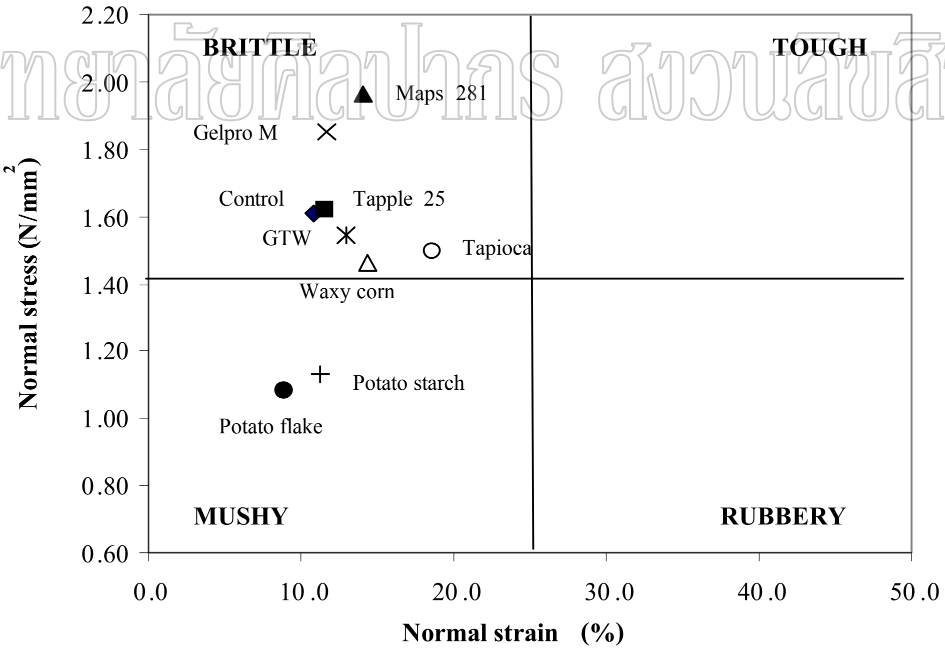


Fig. 4.1 Texture maps of glutinous rice crackers with 5% starch and flour addition

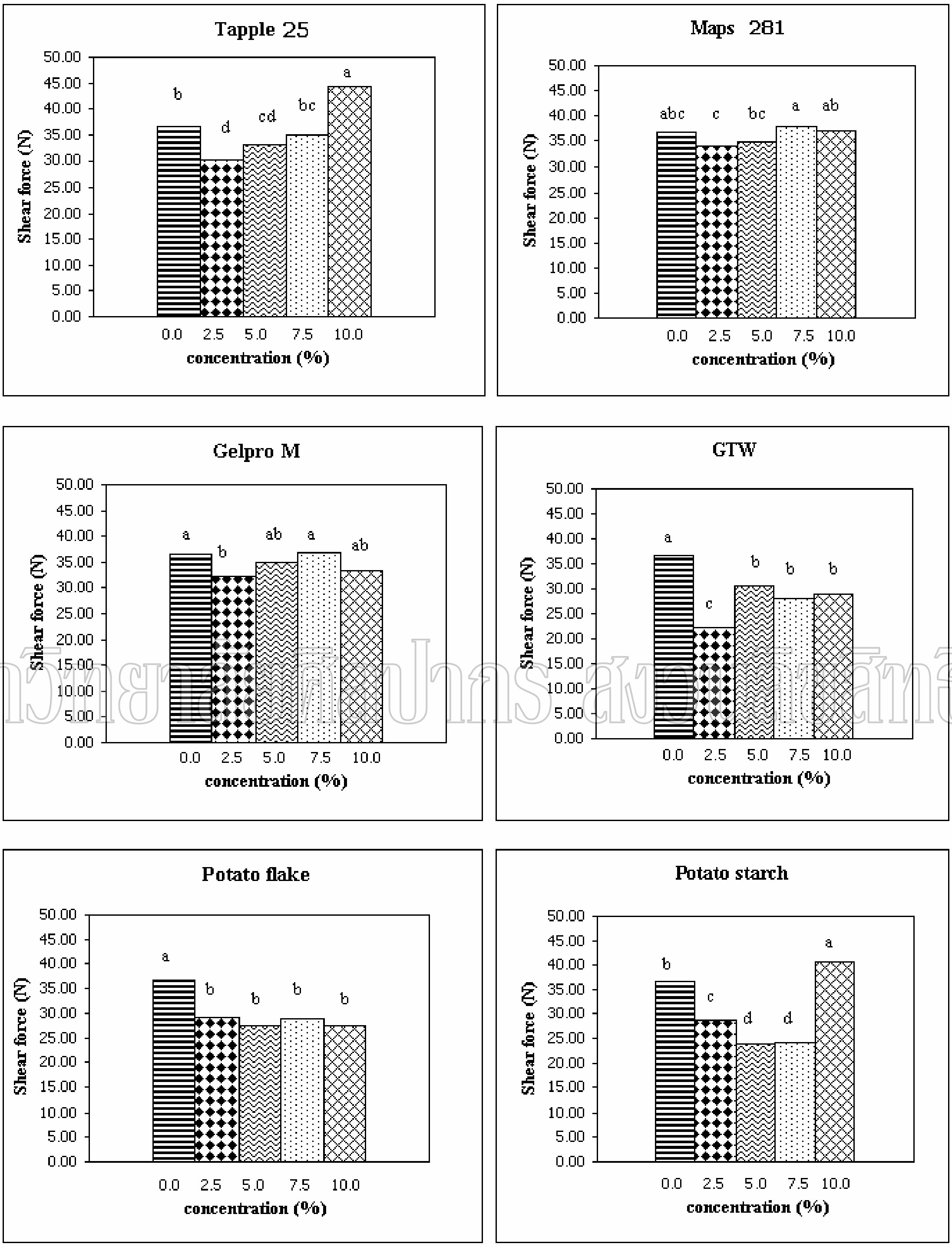


Fig. 4.2 Shear forces of crackers with various concentrations

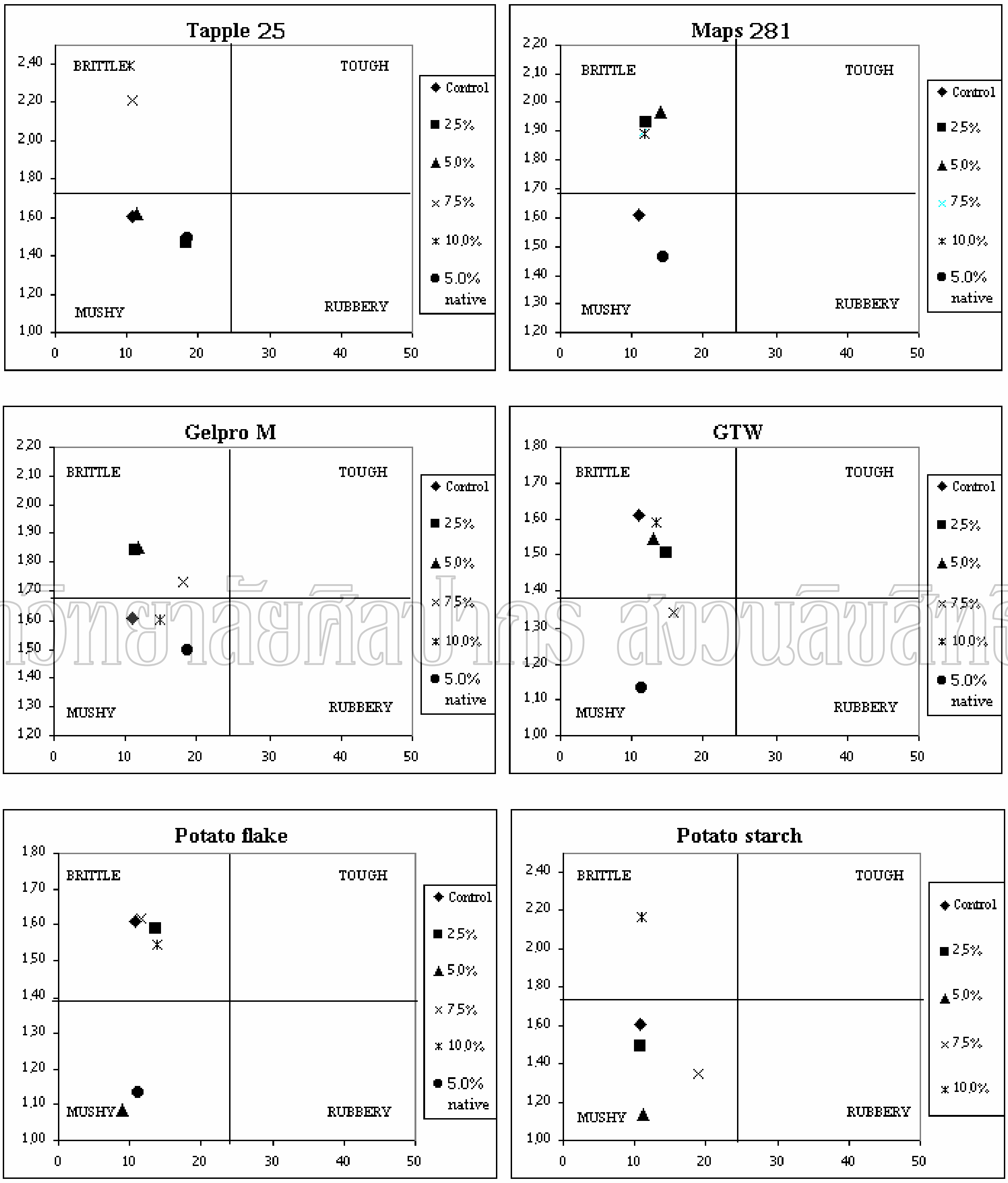


Fig. 4.3 Texture maps of puncture test of rice crackers with various concentrations

CHAPTER 5

RELATING DESCRIPTIVE ANALYSIS AND INSTRUMENT TEXTURE DATA OF GLUTINOUS RICE CRACKER

ABSTRACT

Principal component analysis with PLS regression was performed to discriminate and classify the relationships between the instrumental and the sensory textural parameters with regard to the different formulations of glutinous rice crackers. Rice crackers added with 10% Tapple 25 and 10% Maps 281 intensively correlated very well to the hardness attributed, whileas the rice crackers with each 2.5% Gelpro M, 7.5% potato flake, and 5.0% potato starch exhibited the negative responses to the hardness attributed. Sensory hardness was explained clearly via the instrumental hardness measurements calculated from the peak force of force-deformation curves. In contrast, firmness and stickiness attributes were the complex sensory evaluation, thus, it could not be described well by the human senses. However, the results obtained from sensory evaluation were excellently mapped with the instrumental measurement in the separating groups of various formulations of rice crackers.

Keywords: PLS, texture analysis, sensory analysis, rice cracker.

INTRODUCTION

Texture is an important quality attribute of food material and dominates an importance for the certain categories of food, particularly those with a bland flavor as rice, or which have the characteristics of crispiness as snacks (Wilkinson et al., 2002; Lewis, 1996; Xiong et al., 2002). The most reliable method to evaluate the textural attributes is the application of use sensory evaluation techniques. Texture perception is a synthesis of information combined from several senses, such as visual, tactile, or auditory, in the oral processes while the food is masticated (Wilkinson et al., 2000). It is a dynamic process, with the changes of food structure and a discrete perceptual channel for an aspect of texture senses during chewing. Thus, the reliability of sensory evaluation typically relies on the statistical analyses and the trained panels (Booth et al., 2003).

For mass production, quantitative descriptive analysis (QDA) is often applied in food industries. This method involves the detection and the description of sensory aspects of a product by the trained panels about 5-100 judges. Panelists must be able to detect and describe the perceived attributes; in addition, must learn to differentiate and rate intensity of a sample in scaling for statistical analysis (Meilgaard et al., 1999). Therefore, it is very time consuming and expenses for selection and training of panel members. In contrast, the instrumental measurements, especially textural properties, become commonly easier to use and provide the reliable and meaningful data. They could carry out under more strictly defined and controlled conditions. Therefore, a main goal of many texture studies is to devise one or more mechanical tests with the capacity to replace human sensory evaluation as a potential tool to evaluate food texture (Lewis, 1996; Peleg, 1983).

Sensory and instrumental measurements have been conducted and attempted to relate together for indicating the texture of many foods products. In such case, it is crucial to extract and identify instrumental measurements that correlated best to the sensory attributes of interest products. Partial least square regression (PLS) serves this purpose very well. PLS by Win-DAS is a modeling technique using for data compression and structure the specifically of data sets into group. It requires to supply a matrix of information utilized in the calculation of the PLS score and loading. The aim of the PLS regression is to find series of coefficients of data and better capable to compress the information required to distinguish the groups into just the first score. It is a potentially preferable technique for examining data classified its structure individual group (Kemsley, 1998). Few studies had been devoted to correlate sensory and instrumental parameters of rice crackers. The objective of this study was to investigate the sensory evaluation of glutinous rice cracker prepared by varying raw material formulations and using PLS to correlate and compare between textural properties from sensory evaluation and instrumental measurement to identify instrument parameters that correlated best to sensory variables.

MATERIALS AND METHODS

Raw materials

Milled RD6 glutinous rice from Udornthani located in the northeastern part of Thailand were used as raw material in this experiment. The rice samples were well tighted seam and stored at room temperature (25^{o}C).

Commercial 8 different starches and flours obtained from the suppliers were used in the research including waxy corn starch “Mazaca”, cross-linked waxy corn starch “Maps 281” (Nutrition Limited Partnership, BKK, Thailand), tapioca starch and esterified tapioca starch “Tapple 25” (Tapioca Development Corp, BKK, Thailand), cross-linked tapioca starch “Gelpro M” (Potential Marketing Co., Ltd., BKK, Thailand), potato starch, potato granules “GTW”, and potato flake (Winner Group Enterprise Ltd., BKK, Thailand). Moisture contents of all starches and flours samples were measured using moisture analyzer (model MX-50, AND, Japan) and then rehydrated to confirm the final moisture content being 40% before further use in the production of dough.

Preparation of Glutinous Rice Cracker

Milled glutinous rice was weighed 500 g, washed, and then soaked in 700 ml of water at 15^{o}C for overnight (approximately 16 hr). After soaking, the moisture content of drained rice was about 38-40%. The drained rice was crushed using blender (model MX-T1PN, National, Taiwan) into fine powder and then sieved through 200 mesh stainless-sieve (Endecotts Ltd., England). Glutinous rice flour was steamed using a steam cooker (model PFC-20BM, Toshiba, Japan) for 45 min and kneaded for 5 min. The dough was placed in squared plastic box and allowed to harden for overnight at 5-7^{o}C. The chilled dough was cut into 28 X 30 X 3 mm individual chip and randomly collected to further analyze. The moistened starch and flour were replaced glutinous rice four and mixed through sieving before steaming at 2.5, 5.0, 7.5, and 10% by weight.

Textural Determination

Texture was determined using a Texture Analyzer (model TA-XT2i, Stable Micro System Co., Ltd., UK) in combination with a 5 kg load cell. The instrument was set as follows:

Puncture Test

Sample was placed on a spring-loaded clamp plate with a 16 mm dia. hole. 5 mm dia. cylindrical flat-end punch was mounted and programmed to punch pass through sample completely. The pre-test speed, test speed and post-test speed were set at 5 mm/s. The punch traveled 15 mm into sample to measure peak force and area under force-deformation curves. 7 tested samples were randomly selected to measure textural characteristics. All experiments were run in triplicates.

Shear Test

Sample was placed across the bottom of Warner Bratzer Blade Set (‘v’ slot blade). The blade was driven downward at pre-test and test speed of 5 mm/s. The post-test speed was set at 10 mm and the blade traveled 30 mm through sample completely to measure peak force and area under force-deformation curves. 7 tested samples were randomly selected to measure textural characteristics. All experiments were run in triplicates.

Data collection and analysis were accomplished using software of TA-XT2i analyzer (Texture Expert Ver.1.22) in Newton and mm. The instrumental parameters of puncture test were calculated as hardness, normal stress, normal strain, firmness, stickiness, and modulus of elasticity and the instrumental parameters of shear test were determined to evaluate as hardness, shear stress, shear strain, firmness, stickiness, and shear modulus.

Sensory Evaluation

Descriptive analysis was conduced using 10 rice cracker manufacturing staffs who experienced over 2 years and so familiar to rice cracker testing. Panel training and evaluation adapted from Meilgaard et al. (1999), Elmore et al. (1999), and Martinez et al. (2002). The first session, samples were presented and a list of terms describing the textural sensory characteristics of products was generated. Secondly, and thirdly session, the various textural characteristic crackers and a tentative score sheet were introduced to each panelist for testing the protocol. After tested, the results were discussed and each panelist would learn to adjust the degree of sensory and consensus on texture definition and technique (Table 5.1). In the fourth sessions, the products were informally evaluated with the prepared score sheet. The discretion of panelist performance relatively to other members was conducted to select the potential members.

Textural attributes were scored on a 0-100 mm line scale having verbal anchors at the both ends. Evaluations were completed in the separated room and all five samples were served in the plastic cup coded with three-digit random number. Water and toothpicks were used to rinse between samples. All samples and water were expectorated. Samples were evaluated in triplicate.

Statistical Analysis

All data were performed using the General Linear Model of the Statistical Analysis System software (Ver.8.1, SAS Inst., Cary, NC, USA). Significant calculated means were compared by least significant difference (LSD) at 95% confidence level.

The relationships between the specific attributes and the formulations were statistically modeled using Partial Least Squares (PLS) performed via Win-DAS software (John Wiley and Sons Ltd., Chichester, UK). The generated matrices of attributes and formulations were combined and analyzed to assess the mapping process (Lee et al., 1999).

RESULTS AND DISCUSSIONS

Instrumental and sensory analyses

The results of three different textural attributes comprising hardness, firmness, and stickiness of 24 treatments from the instrument measurement were summarized in Table 5.2. The differences in the results caused from the addition of various modified starches and flours. The starches or flours providing the weak network molecules would affect the expansion rate of rice crackers during baking and consequently caused to be high hardness and firmness of products. In contrast, the mixed starches containing the optimum amylose and amylopectin contents could create the strong network molecule, and subsequently, increase the expansion rate and finally affect the softness texture. The representative group of rice crackers with modified starch was selected for sensory evaluation. Rice crackers consisting of 10% Tapple 25, 10% Maps 281, 2.5% Gelpro M, 7.5% potato flake, and 5.0% potato starch were tested via both instrumental and sensory analyses and correlated each other to reveal the graphically textural characteristics.

The Comparison between the instrumental and descriptive analyses of the selected glutinous rice crackers was shown in Table 5.3. The sensory hardness showed the same trend between the sensory and the instrumental measurements. According to the instrumental analysis, the addition of starches and flours significantly distinguished in hardness and firmness but did not discriminate in stickiness. Rice cracker with 10% Tapple 25 exhibited the highest hardness and firmness whileas rice cracker with 7.5% potato flake contributed the lowest firmness and stickiness. For descriptive analysis, the trained panels could easily differentiate the hardness score in the same order of the instrumental measurements but were unable to distinguish the firmness among the samples. The instrumental stickiness was not significant difference but the panels' scores were.

The firmness and stickiness via the instrumental measurement were the parameters calculated from the area under force-deformation curved, it represented the work or energy to masticate so these parameters were difficult and usually confused when performing the sensory evaluation. Also, the few differences of firmness and stickiness of products might be not easily detectable. In addition, firmness and stickiness were usually the sensual complexity to measure. Human sensory evaluation occurred at about 35°C in the presence of saliva (Gaines, 1994), so the low moisture cracker tended to absorb the saliva during mastication. As a result, the environment was considerable different from the dry room temperature of most instrumental testing. Thus, the firmness and stickiness sensory was quite different patterns from the instrumental testing. Anyway, for the low moisture content of crackers the compression and shear force, hardness, is the most useful evaluated parameters because it could easily interpret the resistance to deformation of crackers (Gaines, 1994).

Relationship between sensory attributes and instrumental parameters

PLS plots of the instrumental measurements between the textural attributes and starch formulation were shown in Fig. 5.1. Arares with 10% Tapple 25 and 10% Maps 281 provided the best correlation to the hardness while Arare with 5.0% potato starch provided the best correlation to the stickiness and Gelpro M showed the negatively correlation to the stickiness. PLS plots of the sensory test between the textural attributes and the starch formulations were shown in Fig. 5.2. Like the instrumental results, Arares with 10% Tapple 25 and 10% Maps 281 had the best correlation to the hardness but contrastingly resulted as compared with the instrumental measurements. Arare with 5.0% potato starch exhibited the best correlation to firmness. However, Arare with 2.5% Gelpro M was found positively correlation to the stickiness. The contradiction results obtained from the sensory and the instrumental mapping with respect to the sensory complex perception since the panels tended to score the stickiness following to the hardness while the contrast results were found in the instrumental measurement.

These results showed only Arares with 10% Tapple 25 and 10% Maps 281 could map with the hardness attributes. Arares with 2.5% Gelpro M and 7.5% potato flake decreased in hardness but nearly the same stickiness and firmness as Arares with 10% Tapple 25 and 10% Map 281, so they could not provide clearly correlation. Tapple 25 was the esterified starch that designed to prevent the association of amylopectin molecules. That would inhibit the network causing the porous texture. As result of the addition of Maps 281, higher protein and lipid content from waxy corn starch could increased the hardness of the puff snacks and lipid would form the amylose-lipid complex that inhibited the expansion of cracker (Senthil et al., 2002). On the other hand, potato starch was a high amylose content starch and the presence of phosphoric acid in amylopectin could bind cations (Lisinska and Leszczynski, 1989) probably generating the strong network of porous texture, so it contributed more puff snacks.

PLS plots of the sensory attributes and the instrumental parameters were shown in Fig. 5.3. Sensory hardness best correlated to the instrumental hardness. It existed that the sensory hardness was mostly explained by instrumental hardness, being a curve peak force obtained from the textural analysis. In contrast, sensory firmness and stickiness had somewhat factors during mastication such as the saliva effects on the sensory evaluation, so the instrumental parameters could be not explained a few differences between firmness and stickiness obtained from the sensory evaluation.

The graphical mapping of the formulation between the sensory and the instrumental measurements was shown in Fig. 5.4. The results well fitted between the sensory and the instrumental measurements and clearly separated between each formulation. Eventhough, Arares with 10% Tapple 25 and 10% Maps 281 hardly deviated but Arares with 2.5% Gelpro M, 7.5% potato flake, and 5.0% potato starch were served well. The instrumental measurement disposed to follow to the hardness attributes as similarly to the panels that scored the sensory evaluation to the hardness and firmness. In addition, it may cause the standard deviation of the hardness that was lower than the standard deviation of the firmness and stickiness. PLS regression was performed on the variance-covariance matrix (Chabanet, 2000; Borgognone, 2001), so it could describe the best to less standard deviation and resulted in the best correlation of the mapping.

CONCLUSIONS

PLS implementation technique for all instrumental and sensory data of rice crackers showed the major differences in hardness attributes and quantitative descriptive analysis clearly separated only hardness attributes. The rice crackers with 10% Tapple 25 and 10% Maps 281 were plotted in the same location of hardness whileas the rice cracker with 5.0% potato starch was in the opposite. The hardness texture of Arares measured by the instrumental measurements and the sensory evaluation expressed the same location plot of mapping. The trained panels could not distinguish the firmness and stickiness attributes due to its sensual complexity during the mastication. In addition, the firmness and stickiness highly varied due to be calculated from the area under curves obtained from the instrumental analysis, so it could not map together.

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Table 5.1 Definition of sensory texture attribute for rice cracker

Texture attributes	Definition	Technique
Hardness	The force necessary to attain a given deformation	Compress or bite sample 1 time with molars until fracture
Firmness	The work required to cut sample	Compress or bite sample 1 time until cutting
Stickiness	Degree to which sample sticks to mouth surface of teeth	Chew sample 3 to 5 times, expectorate and feel the surface of the crowns of the teeth to evaluate

Source: Liu et al (2000); Xiong (2002), and Stable Micro Systems Ltd Glossary

Table 5.2 Texture properties of glutinous rice crackers with starch and flour addition

Starch*	Level	Instrumental texture attributes		
		Hardness (N)	Firmness (N.mm)	Stickiness (N.mm)
Tapple 25	2.5	30.3	154.7	76.2
	5.0	33.0	103.1	68.5
	7.5	35.0	104.5	101.5
	10.0	44.4	190.4	111.7
Maps 281	2.5	34.0	157.3	114.5
	5.0	34.7	151.3	96.2
	7.5	37.8	178.0	76.6
	10.0	37.0	152.4	111.7
Gelpro M	2.5	32.4	147.7	88.9
	5.0	35.0	156.1	80.2
	7.5	36.9	181.0	113.9
	10.0	33.5	128.4	97.5
GTW	2.5	22.3	60.8	64.7
	5.0	30.5	119.4	126.1
	7.5	28.1	95.3	86.7
	10.0	28.9	103.2	66.8
Potato flake	2.5	29.2	153.3	95.8
	5.0	27.5	117.9	106.5
	7.5	28.8	98.1	73.4
	10.0	27.4	91.0	67.5
Potato starch	2.5	28.6	118.4	187.2
	5.0	23.8	111.0	108.8
	7.5	24.2	114.1	167.5
	10.0	40.7	178.1	155.4

n=21

* Commercial name

Table 5.3 Comparison between instrumental and sensory measurements[1]

Starch[2]	Hardness		Firmness		Stickiness	
	Instrument (N)	Sensory	Instrument (N.mm)	Sensory	Instrument (N.mm)	Sensory
10% Tapple 25	44.4±3.2[a]	6.8±1.0[a]	190.4± 60.3[a]	6.7±0.8[a]	111.7±57.4[a]	7.0±1.0[a]
10% Maps 281	37.1±3.1[b]	6.3±1.2[ab]	152.4±82.0[ab]	6.4±1.1[a]	111.7±52.4[a]	6.5±0.9[ab]
2.5% Gelpro M	32.4±4.2[c]	6.2±0.8[b]	147.7±72.4[bc]	6.2±1.2[a]	88.9±46.0[ab]	6.3±1.0[b]
7.5% potato flake	28.8±3.1[d]	5.5±0.8[c]	98.1±50.4[d]	4.8±0.5[c]	73.4±38.0[b]	5.6±1.1[c]
5.0% potato starch	23.8±1.7[e]	4.9±0.4[c]	111.0±57.1[cd]	5.5±1.2[b]	108.8±34.9[a]	6.4±0.9[b]

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

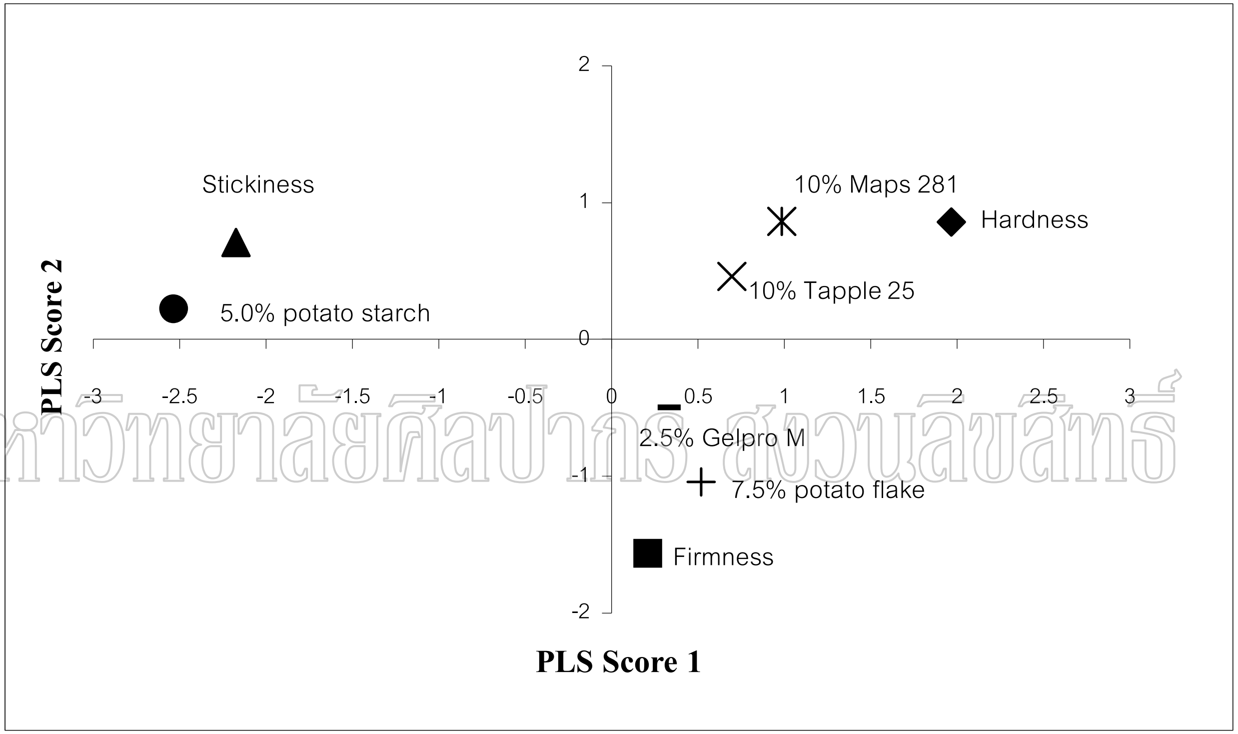


Fig. 5.1 PLS plots of instrumental measurement between attributes and formulations

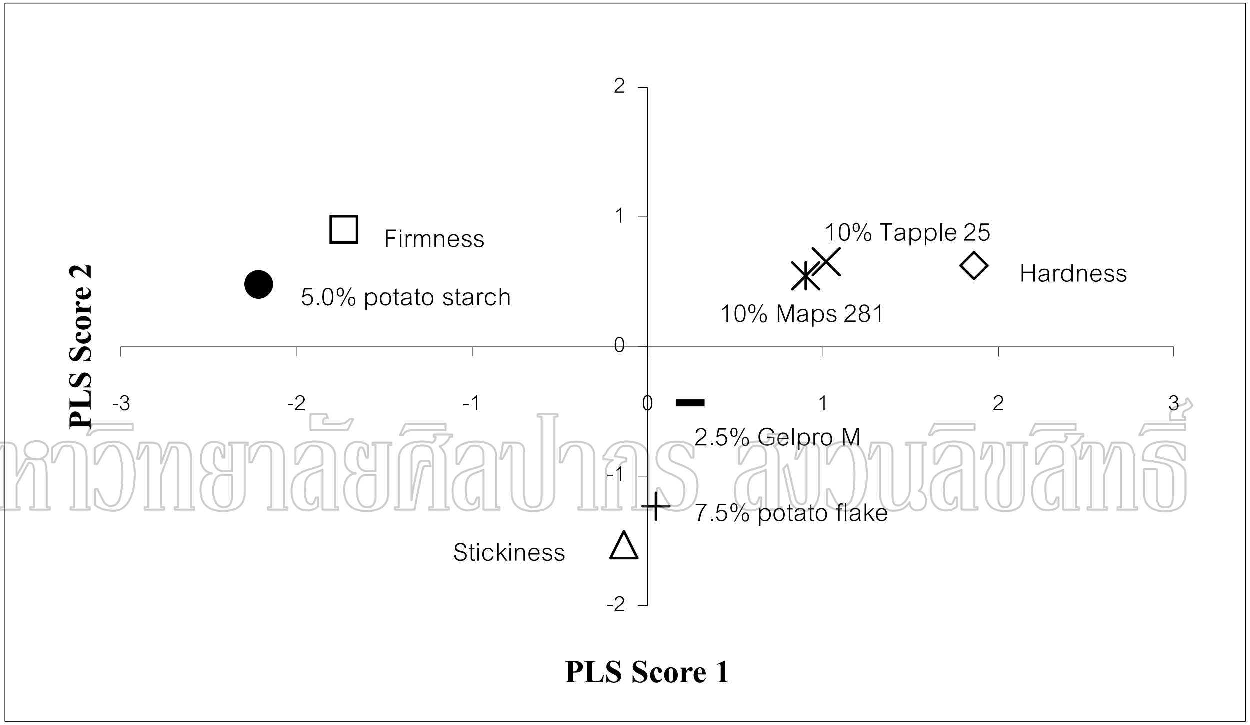
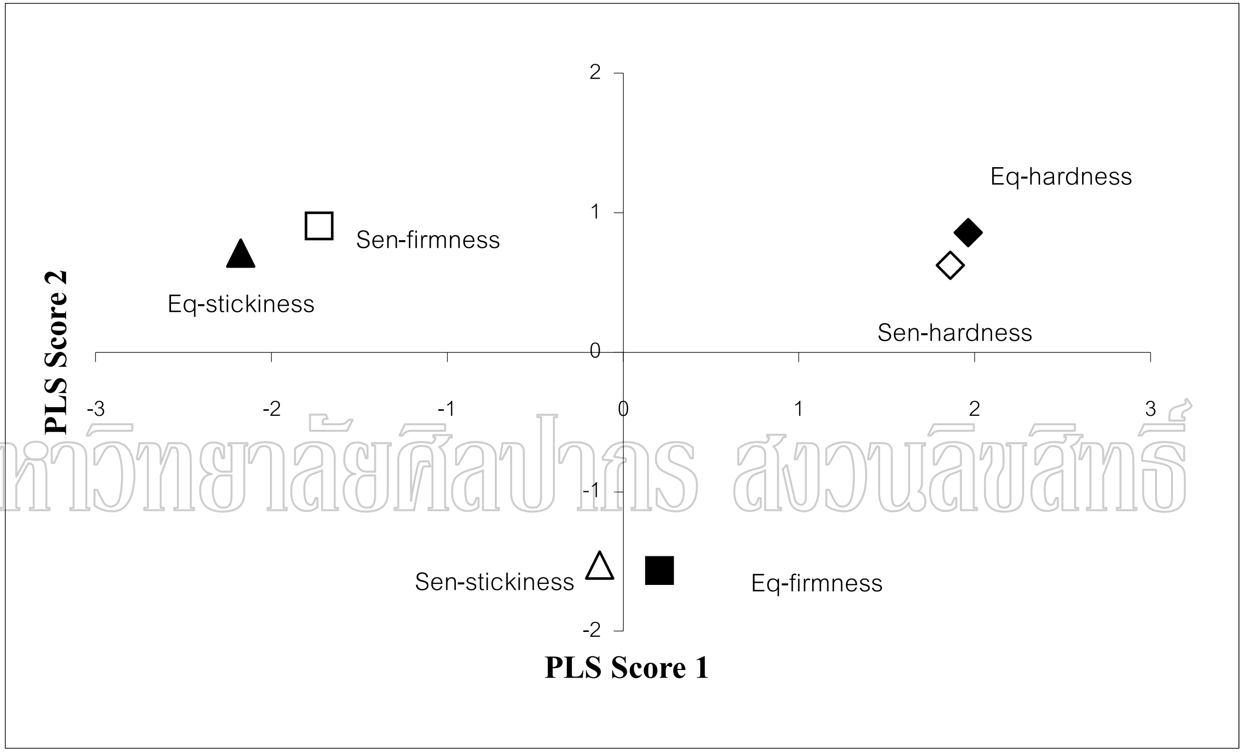


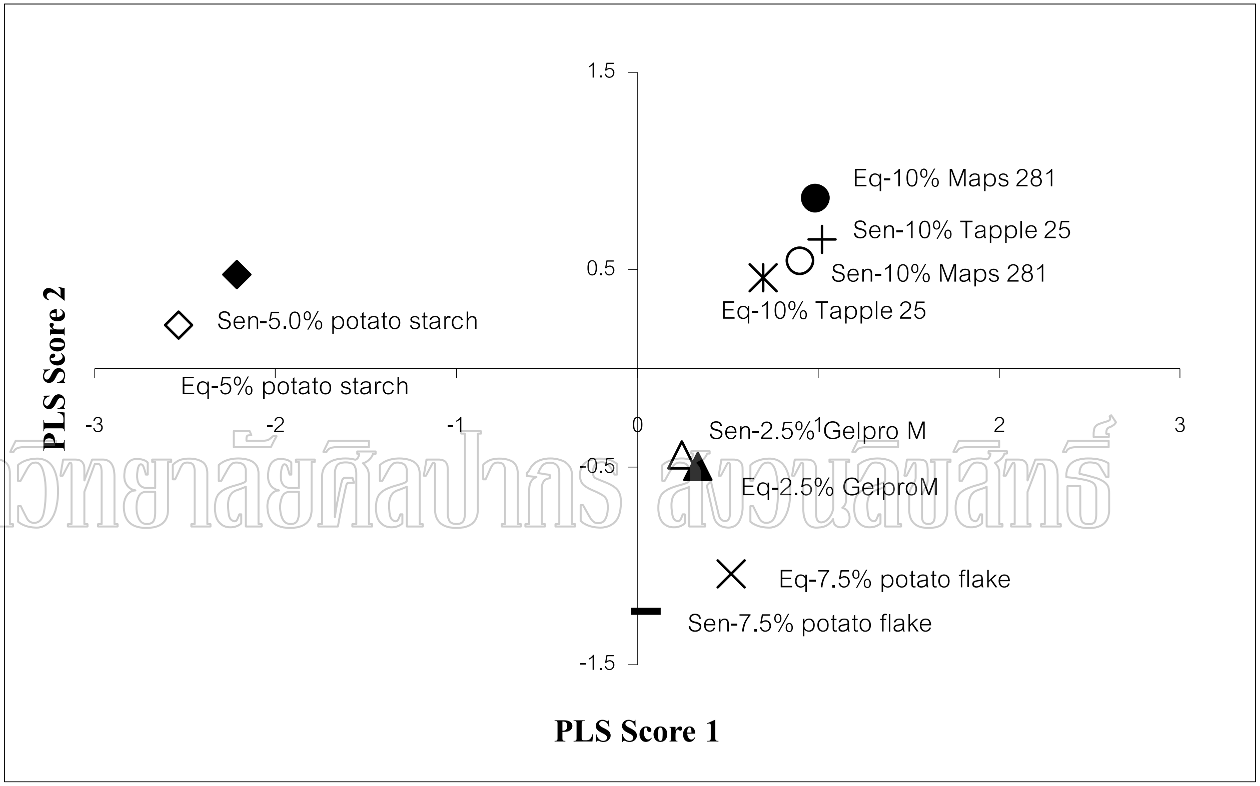
Fig. 5.2 PLS plots of sensory evaluation between attributes and formulations



Sen Sensory attributes

Eq Equipment attributes

Fig. 5.3 PLS plots of sensory attributes and instrumental parameters



Sen Sensory attributes

Eq Equipment attributes

Fig. 5.4 PLS plots of different formulations measured by sensory and instrument

CHAPTER 6

CONCLUSIONS

The supplementation of various modified starches and flours directly affected the textural attributes of glutinous rice dough (Mochi) and cracker (Arare). The partial substitution of each modified starch and flour remarkable provided more hardness, firmness, and modulus of elasticity dough with higher concentration utilized with respect to greater degrees of retrogradation. Modified and native tapioca starches exhibited the stickiness dough as observed via its cohesive characteristic. Anyway, in overview of the starch and flour addition did not exhibit the negative results of glutinous rice dough.

According to Arare products, the hardness of Arares tended to reduce via the addition of modified potato starch, GTW, potato flake, and native potato starch but the native potato starch would not change in color and taste of rice cracker in opposite to modified potato did. Potato starch exhibited a loosen structure and more expansion systems of pores. Moreover, it contained weak anions, which could bind cations to build up the strong network during baking, so it provided puffier crackers. The expansion volume had the same trend to the textural measurements. In addition, the texture maps also confirmed the same results to obtain mushy characteristic when potato starch was added in the formulation.

The comparison between the sensory and the instrumental measurements exhibited the good correlation. Sensory hardness of rice cracker was well related to the instrumental measurements, in contradiction with sensory firmness and stickiness. The sensory firmness and stickiness were the complex perception and extremely influenced by the saliva during mastication, so it could not explain well by the instrumental testing.

However, these studies elucidated the valuable information for Arare manufacturers who required improving the textural characteristics of products especially, attempting to soften products and did not disrupt the original processing. In addition, the mapping between the sensory and the instrumental measurements could be a potential tool substituted the sensory evaluation in Arare production.

APPENDIX A

PROCESS FLOW CHART AND TESTING OF RICE CRACKER



Glutinous rice → **Soaking** → **De-watering**



Crushing → **Sieving** → **Streaming**

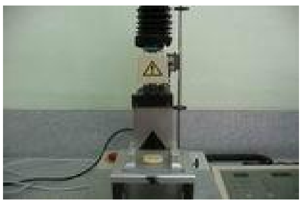


Kneading → **Cooling** → **De-molding**



Cutting → **Pellet** → **Drying**





Baking → **Arare** → **Testing**

APPENDIX B

MOISTURE ADJUSTMENT OF STARCHES AND FLOURS

Initial moisture content of starches and flours

Initial moisture content of experiment starches or flours were measured by Moisture analyzer (model MX-50, AND, Japan).

Starches / Flours	Moisture content (%)
Tapioca starch	13.24
Waxy corn starch	12.64
Potato starch	19.74
Tapple 25	14.04
Maps 281	13.74
Gelpro M	13.36
Extrusamyl GTW	8.83
Potato flake	10.04

Example of moisture adjustment

Supplementation of Tapple25 at 5% in total weight 500 grams

Total weight of glutinous rice = 500 X 0.95 = 475 grams

Total weight of Tapple25 = 500 X 0.05 = 25 grams

Initial %mc. of Tapple25 = 14.04%, required to adjust for 40% mc.

$$\text{Total weight of moisten starch} = \frac{\text{Weight of starch} \times ((100\text{-initial mc.})/100)}{((100\text{-required mc.})/100)}$$

$$= \frac{25.00 \times 0.8596}{0.60}$$

$$= 35.82 \text{ grams}$$

$$\text{Weight of water for adjustment} = 35.82\text{-}25.00 \text{ grams}$$

$$= 10.82 \text{ grams}$$

APPENDIX C

DEFINITION AND CALCULATION OF TEXTURAL PARAMETERS

Hardness

The force necessary to attain a given deformation

Hardness = Maximum force (peak force)

Normal stress

The force per unit area applied perpendicular to the plane in unit of $N/mm.^2$, this experiments used probe P5, the area of probe = 19.63 mm^2

Normal stress = Maximum force/probe area (19.63)

$$\sigma = F/A$$

Normal strain

The change in length per unit of length in the direction of applied normal stress, this experiments punched through the sample so using the maximum force for calculation

$$\text{Normal Strain} = \frac{\text{(Distance at maximum force/Thickness of sample)}}{100}$$

$$\varepsilon = \Delta h/h$$

Shear stress

The force per unit area acting in the direction parallel to the surface of the plane in unit of $N/mm.^2$, This experiment, area acting in the direction parallel to Warner Bratzler's blade was the two surfaces (width X length) of sample

Shear stress = Shear force/(2 X width X thickness of sample)

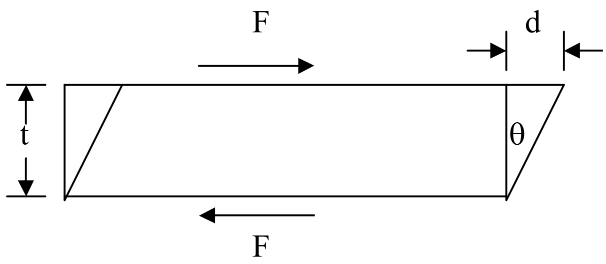
$$\iota = F/A \ ; A=2wl$$

Shear strain

The change in the angle formed between two planes that are orthogonal prior to deformation which results from the application of the shear stress, this experiment cut through the sample so using the maximum shear force for calculation

$$\text{Shear Strain} = \frac{\text{(Distance at maximum force/Thickness of sample)}}{100}$$

$$\gamma = \tan\theta = d/t$$



Firmness

The work while cutting under specified conditions to attain a given deformation in unit of $N.mm^2$

Firmness = Area under the curve from start to maximum force

Stickiness

The work required releasing the probe after to attain a given deformation in unit of $N.mm^2$

Stickiness = Area under the curve from maximum force to finished

Modulus of elasticity (Young modulus)

A measure of rigidity or stiffness of a material in unit of N/mm

Modulus of elasticity = Normal stress/Normal strain

$$E = \sigma / \varepsilon$$

Shear modulus

The resistance to deformation from shear force in unit of N/mm

Shear modulus = Shear stress/Shear strain

$$G = \iota / \gamma$$

APPENDIX D

TEXTURAL PROPERTIES OF GLUTINOUS RICE DOUGH WITH 5% NATIVE STARCHES

Table D.1. Textural properties of glutinous rice doughs with 5% native starches[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	14.5±1.3[d]	16.7±3.2[c]	29.6±4.9[c]	11.3±1.3[d]	8.2±0.5[d]	0.8±0.2[b]
Waxy corn	19.6±1.9[c]	23.0±3.5[b]	34.7±5.5[b]	15.6±1.7[c]	11.7±1.3[c]	1.2±1.0[b]
Tapioca	21.1±2.0[b]	23.2±3.5[b]	37.9±6.8[b]	17.4±2.6[b]	12.7±0.8[b]	1.8±0.9[a]
Potato	23.9±1.5[a]	26.9±2.5[a]	42.7±5.6[a]	19.3±1.3[a]	13.7±1.4[a]	1.8±0.9[a]

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table D.2. Textural properties comparison between glutinous rice doughs with modified and native waxy corn starch[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	14.5±1.3[c]	16.7±3.2[c]	29.6±4.9[c]	11.3±1.3[c]	8.2±0.5[c]	0.8±0.2[b]
Waxy corn	19.6±1.9[b]	23.0±3.5[b]	34.7±5.5[b]	15.6±1.7[b]	11.7±1.3[a]	1.2±1.0[ab]
Maps 281	21.6±0.6[a]	25.3±2.0[a]	43.3±5.8[a]	16.9±1.6[a]	10.7±1.0[b]	1.3±0.7[a]

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table D.3. Textural properties comparison between glutinous rice doughs with modified and native tapioca starch[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	14.5 ± 1.3^{d}	16.7 ± 3.2^{c}	29.6 ± 4.9^{c}	11.3 ± 1.3^{d}	8.2 ± 0.5^{c}	0.8 ± 0.2^{b}
Tapioca	21.1 ± 2.0^{a}	23.2 ± 3.5^{a}	37.9 ± 6.8^{a}	17.4 ± 2.6^{a}	12.7 ± 0.8^{a}	1.8 ± 0.9^{a}
Tapple 25	19.6 ± 1.9^{b}	23.1 ± 4.7^{a}	36.1 ± 8.1^{ab}	15.8 ± 3.1^{b}	10.2 ± 0.7^{b}	1.1 ± 1.3^{b}
Gelpro M	17.7 ± 1.2^{c}	20.7 ± 2.6^{b}	34.2 ± 5.9^{b}	14.0 ± 2.1^{c}	12.4 ± 1.0^{a}	1.1 ± 0.3^{b}

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table D.4. Textural properties comparison between glutinous rice doughs with modified and native potato starch[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	14.5 ± 1.3^{c}	16.7 ± 3.2^{d}	29.6 ± 4.9^{c}	11.3 ± 1.3^{c}	8.2 ± 0.5^{c}	0.8 ± 0.2^{b}
Potato	23.9 ± 1.5^{a}	26.9 ± 2.5^{a}	42.7 ± 5.6^{a}	19.3 ± 1.3^{a}	13.7 ± 1.4^{a}	1.8 ± 0.9^{a}
GTW	21.4 ± 0.6^{b}	21.9 ± 1.4^{c}	34.7 ± 4.7^{b}	18.8 ± 1.4^{a}	12.2 ± 0.5^{b}	1.6 ± 1.1^{a}
Potato flake	21.5 ± 1.0^{b}	23.8 ± 3.1^{b}	37.3 ± 3.4^{b}	17.2 ± 1.5^{b}	12.6 ± 0.7^{b}	1.0 ± 0.2^{b}

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

APPENDIX E

TEXTURAL PROPERTIES OF GLUTINOUS RICE CRACKER WITH 5% NATIVE STARCHES

Table E.1. Textural properties of glutinous rice crackers with 5% native starches[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	31.6±3.4[a]	12.2±4.9[ab]	27.3±11.8[a]	182.8±84.9[a]	36.7±7.0[a]	1.7±0.6[a]
Waxy corn	28.7±3.2[b]	13.8±8.8[a]	22.3±11.3[a]	119.0±42.7[b]	30.9±5.5[b]	1.6±0.5[ab]
Tapioca	29.4±3.6[b]	16.7±11.4[a]	24.4±16.9[a]	110.6±63.8[b]	31.2±4.4[b]	1.5±0.5[ab]
Potato	22.3±3.6[c]	8.5±3.4[b]	26.7±12.2[a]	118.8±64.5[b]	23.8±1.7[c]	1.3±0.6[b]

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table E.2. Textural properties comparison between glutinous rice crackers with modified and native waxy corn starch[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	31.6±3.4[b]	12.2±4.9[a]	27.3±11.8[ab]	182.8±84.9[a]	36.7±7.0[a]	1.7±0.6[b]
Waxy corn	28.7±3.2[c]	13.8±8.8[a]	22.3±11.3[b]	119.0±42.7[b]	30.9±5.5[b]	1.6±0.5[b]
Maps 281	38.6±3.7[a]	16.7±10.3[a]	31.8±16.2[a]	179.5±90.0[a]	34.7±2.7[a]	2.5±1.4[a]

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table E.3. Textural properties comparison between glutinous rice crackers with modified and native tapioca starch[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	31.6±3.4^{bc}	12.2±4.9^{a}	27.3±11.8^{ab}	182.8±84.9^{a}	36.7±7.0^{a}	1.7±0.6^{a}
Tapioca	29.4±3.6^{c}	16.7±11.4^{a}	24.4±16.9^{b}	110.6±63.8^{b}	31.2±4.4^{c}	1.5±0.5^{a}
Tapple 25	31.8±2.7^{b}	12.4±8.1^{a}	33.8±9.4^{a}	177.0±75.9^{a}	33.0±3.2^{bc}	1.7±0.8^{a}
Gelpro M	36.3±5.0^{a}	15.0±8.7^{a}	33.6±18.3^{a}	184.7±70.3^{a}	35.0±4.2^{ab}	1.7±0.4^{a}

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table E.4. Textural properties comparison between glutinous rice crackers with modified and native potato starch[1]

Starch[2]	Normal force (N)	Firmness (N.mm)	Stickiness (N.mm)	Modulus of elasticity (kPa)	Shear force (N)	Shear modulus (kPa)
Control	31.6±3.4^{a}	12.2±4.9^{a}	27.3±11.8^{a}	182.8±84.9^{a}	36.7±7.0^{a}	1.7±0.6^{bc}
Potato	22.3±3.6^{b}	8.5±3.4^{b}	26.7±12.2^{a}	118.8±64.5^{b}	23.8±1.7^{d}	1.3±0.6^{c}
GTW	30.3±1.8^{a}	11.4±6.6^{ab}	29.1±13.1^{a}	149.7±76.8^{ab}	30.5±1.7^{b}	2.1±0.8^{ab}
Potato flake	31.3±4.3^{a}	12.4±7.4^{a}	22.0±10.0^{a}	114.2±66.7^{b}	27.5±2.8^{c}	2.2±0.7^{a}

n=21

[1] Means in the same column with difference letters differ significantly ($p<0.05$).

[2] Commercial name

APPENDIX F

HARDNESS OF GLUTINOUS RICE DOUGHS WITH MODIFIED STARCH AND FLOUR ADDITION

Table F.1. Shear force of glutinous rice doughs with modified starch and flour addition[1]

Starch[2]	0	2.5	5.0	7.5	10.0	Average
Tapple 25	8.2^{d}	8.3^{d}	10.2^{c}	11.9^{b}	15.0^{a}	11.3
Gelpro M	8.2^{d}	11.0^{c}	12.4^{b}	13.8^{a}	14.0^{a}	12.8
Maps 281	8.2^{d}	11.4^{b}	10.7^{c}	11.5^{b}	12.2^{a}	11.5
GTW	8.2^{d}	11.5^{c}	12.2^{b}	13.8^{a}	11.5^{c}	12.2
Potato flake	8.2^{d}	10.8^{b}	12.6^{a}	10.2^{c}	12.4^{a}	11.5
Potato starch	8.2^{d}	10.1^{c}	13.7^{b}	13.9^{b}	16.0^{a}	13.4
Average	8.2	10.5	11.9	12.5	13.5	

n=21

[1] Means in the same row with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table F.2. Normal force of glutinous rice doughs with modified starch and flour addition[1]

Starch[2]	0	2.5	5.0	7.5	10.0	Average
Tapple 25	14.5^{e}	17.1^{d}	19.6^{c}	21.4^{b}	23.9^{a}	20.5
Gelpro M	14.5^{d}	17.1^{c}	17.7^{c}	19.8^{b}	22.3^{a}	19.2
Maps 281	14.5^{d}	19.7^{c}	21.6^{b}	21.7^{b}	22.4^{a}	21.3
GTW	14.5^{c}	21.4^{b}	21.4^{b}	22.7^{a}	21.7^{b}	21.6
Potato flake	14.5^{e}	19.9^{c}	21.5^{a}	16.9^{d}	20.8^{b}	19.8
Potato starch	14.5^{e}	20.3^{d}	23.9^{c}	24.9^{b}	26.7^{a}	23.9
Average	14.5	19.2	21.0	21.2	22.8	

n=21

[1] Means in the same row with difference letters differ significantly ($p<0.05$).

[2] Commercial name

APPENDIX G

HARDNESS OF GLUTINOUS RICE CRACKERS WITH MODIFIED STARCH AND FLOUR ADDITION

Table G.1. Shear force of glutinous rice crackers with modified starch and flour addition[1]

Starch[2]	0	2.5	5.0	7.5	10.0	Average
Tapple 25	36.6^{b}	30.3^{d}	33.0^{cd}	35.0^{bc}	44.4^{a}	35.7
Gelpro M	36.6^{a}	32.4^{b}	35.0^{ab}	36.9^{a}	33.5^{b}	34.4
Maps 281	36.6^{abc}	34.0^{c}	34.7^{bc}	37.8^{a}	37.0^{ab}	35.9
GTW	36.6^{a}	22.3^{c}	30.5^{b}	28.1^{b}	28.8^{b}	27.4
Potato flake	36.6^{a}	$29. 2^{b}$	27.5^{b}	28.8^{b}	27.4^{b}	28.2
Potato starch	36.6^{b}	28.6^{c}	23.8^{d}	24.2^{d}	40.7^{a}	29.3
Average	36.6	29.5	30.7	31.8	35.3	

n=21

[1] Means in the same row with difference letters differ significantly ($p<0.05$).

[2] Commercial name

Table G.2. Normal force of glutinous rice cracker with modified starch and flour addition[1]

Starch[2]	0	2.5	5.0	7.5	10.0	Average
Tapple 25	31.6^{c}	29.0^{d}	31.8^{c}	43.3^{b}	47.0^{a}	37.8
Gelpro M	31.6^{b}	36.2^{a}	36.3^{a}	34.0^{ab}	31.5^{b}	34.5
Maps 281	31.6^{b}	37.9^{a}	38.6^{a}	37.2^{a}	37.1^{a}	37.7
GTW	31.6^{a}	29.6^{b}	30.3^{ab}	26.4^{c}	31.2^{ab}	29.4
Potato flake	31.6^{a}	31.2^{a}	31.3^{a}	31.7^{a}	30.3^{a}	31.1
Potato starch	31.6^{b}	29.3^{c}	22.3^{e}	26.6^{d}	42.5^{a}	30.2
Average	31.6	32.2	31.8	33.2	36.6	

n=21

[1] Means in the same row with difference letters differ significantly ($p<0.05$).

[2] Commercial name

APPENDIX H

BALLOT

Ballot

Name……………………………….Date………………………………..

Product………Rice cracker……………

Instruction : test the sample and mark on the lines to indicate your feeling

Hardness

None ____ All

Firmness

None ____ All

Stickiness

None ____ All

VITA

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	Majority : Bachelor of Science (Bsc.)
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Professional experience	
	May 1994 to Present
	Company : Krispy Snacks Co., Ltd. (Thai Wah Group)
	Position : Factory Manager
	March 1992 - May 1994
	Company : Better Foods Co., Ltd. (Betagro Group)
	Position : Technical Staff
Rewards and Honors	
	3rd Prize for Project Poster of The 6th Agro-Industry Conference (2004)
	Presented the research in the 4th National Symposium on Graduate Research, Chiang Mai University