EFFECT OF MODIFIED STARCHES ON QUALITY ATTRIBUTES OF RICE CRACKERS

By

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สาขาวิชาเทคโนโลยีอาหาร

ภาควิชาเทคโนโลยีอาหาร

บัณฑิตวิทยาลัย มหาวิทยาลัยศิลปากร

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การศึกษาผลของการแทนที่แป้งข้าวเจ้าพันธุ์ข้าวขาวดอกมะลิเพียงบางส่วนด้วยสตาร์ชธรรมชาติ และสตาร์ชดัดแปรในอัตราส่วน 1.5%, 2.5% และ 5.0% ต่อลักษณะทางกายภาพ (ความหนาแน่น และอัตราการขยายตัว) และการทดสอบเนื้อสัมผัสของข้าวแผ่นกรอบด้วยเครื่องวิเคราะห์เนื้อสัมผัส (ความแข็ง ความเค้นปกติ และความเครียดปกติ) พบว่าที่ระดับการผสม 2.5% ของการเติม NATIONAL 5730, NATIONAL 687 และ ULTRA-CRISP CS และที่ระดับการผสม 5.0% ของ NATIONAL 5730 และ ULTRA-CRISP CS ทำให้ค่าความแข็ง ความเค้นปกติ และความเครียดปกติของข้าวแผ่นกรอบมีค่าลดลงอย่างมีนัยสำคัญทางสถิติ เป็นผลให้ข้าวแผ่นกรอบมีเนื้อสัมผัสที่นุ่มขึ้นกว่าตัวอย่างควบคุม (ข้าวแผ่นกรอบที่ทำจากแป้งข้าวเจ้า 100%) ในขณะที่ข้าวแผ่นกรอบที่ทำจากการผสมสตาร์ชมันสำปะหลังดิบ 5.0% กลับทำให้ผลิตภัณฑ์เปราะขึ้นเมื่อสังเกตจากแผนภาพเนื้อสัมผัส

อย่างไรก็ตามเมื่อนำข้าวแผ่นกรอบที่ผสม NATIONAL 5730, NATIONAL 687 และ ULTRA-CRISP CSในอัตราส่วน 2.5% มาทดสอบทางประสาทสัมผัสด้วยวิธีการจัดอันดับความชอบ พบว่าไม่มีความแตกต่างกันอย่างมีนัยสำคัญกับตัวอย่างควบคุม และระหว่างชนิดของสตาร์ชดัดแปร ดังนั้นจึงเพิ่มอัตราส่วนการผสมเป็น 3.0%, 4.0% และ 5.0% และทำการศึกษาต่อไปทางด้านคุณลักษณะเนื้อสัมผัสทางประสาทสัมผัส (ความแข็ง ความแน่นเนื้อ และความเหนียวเหนอะ) ด้วยวิธีการทดสอบเชิงพรรณนา (QDA) และทางเครื่องมือ (ความแข็ง และความเค้นเฉือน) ผลปรากฏว่าการเพิ่มอัตราส่วนการผสม NATIONAL 5730 และ ULTRA-CRISP CS ทำให้ค่าความแข็งที่วัดได้จากทางประสาทสัมผัสและทางเครื่องมือ ค่าความเค้นเฉือน และความหนาแน่นของผลิตภัณฑ์ลดลง แต่มีอัตราการขยายตัวเพิ่มขึ้น นอกจากนี้ยังพบว่าความแข็งเป็นคุณลักษณะที่สำคัญที่สุดในการปรับปรุงคุณสมบัติของผลิตภัณฑ์ เนื่องจากค่าความแข็งที่วัดได้จากประสาทสัมผัสมีความสัมพันธ์ไปในทิศทางเดียวกันกับค่าความแข็งจากการวัดด้วยเครื่องมือ และการใช้ NATIONAL 5730 บ่งบอกความแข็งของข้าวแผ่นกรอบได้ดีเมื่อใช้วิธีการวิเคราะห์ความสัมพันธ์ด้วย Partial Least Squares (PLS) ดังนั้นข้าวแผ่นกรอบที่ผสม NATIONAL 5730 ในอัตราส่วน 5.0% สามารถลดความแข็งของข้าวแผ่นกรอบได้ดีที่สุด

ภาควิชาเทคโนโลยีอาหาร บัณฑิตวิทยาลัย มหาวิทยาลัยศิลปากร ปีการศึกษา 2547

ลายมือชื่อนักศึกษา..

ลายมือชื่ออาจารย์ผู้ควบคุมวิทยานิพนธ์ 1.................. 2..................... 3.....................

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KEY WORD : RICE CRACKER / MODIFIED STARCH / NATIVE STARCH / TEXTURE MAP

THIPKANA PICHETNAWIN : EFFECT OF MODIFIED STARCHES ON QUALITY ATTRIBUTES OF RICE CRACKERS. THESIS ADVISORS : BHUNDIT INNAWONG, Ph.D., EAKAPHAN KEOWMANEECHAI, Ph.D., AND PRASONG SIRIWONGWILAICHAT, Ph.D. 77 pp. ISBN 974-464-531-8.

The effects of partially substituted rice flour with various modified and native starches (at 1.5%, 2.5%, and 5.0%) on physical properties (bulk density and expansion ratio) and instrumental parameters (hardness, normal stress and normal strain) of nonglutinous rice (jasmine rice) cracker were investigated. As compared to the control (rice cracker with 100% rice flour), the additional NATIONAL 5730, NATIONAL 687, and ULTRA-CRISP CS at 2.5%, and also NATIONAL 5730 and ULTRA-CRISP CS at 5.0% significantly decreased hardness, normal stress and normal strain of rice crackers ($p<0.05$). These starches also provided more mushy rice crackers. On the other hand, the rice cracker mixed with 5.0% native tapioca starch exhibited brittle texture as illustrated by the texture map.

However, sensory evaluation via preference ranking method simplify revealed the rice crackers hardness containing each 2.5% of NATIONAL 5730, NATIONAL 687, and ULTRA-CRISP CS had no significant difference eventhough compared with the control and among starch types ($p>0.05$). For this reason, the use of higher additional levels such as 3.0%, 4.0%, and 5.0% of NATIONAL 5730 and ULTRA-CRISP CS was essential to investigate for further sensory evaluation (hardness, firmness and stickiness) using both quantitative descriptive analysis (QDA) and instrumental parameters (hardness and shear stress). As a result, when additional level increased, sensory hardness, instrumental hardness, shear stress and bulk density remarkably decreased while the product expansion ratio elevated. According to partial least squares (PLS) analysis, the sensory hardness and the instrumental hardness also showed the same response. The hardness, therefore, was the main attribute for rice cracker quality improvement and NATIONAL 5730 directly affected hardness. Conclusively, the addition of 5.0% NATIONAL 5730 in rice crackers expressed the best ability to reduce the hardness of products.

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

Student's signature……………………………………………………………………

Thesis Advisors' signature 1………………….. 2………………….. 3………....………..

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CHAPTER 1
Introduction

Rice is one of the world's most important cereals for human consumption and is also consumed in variety forms of noodles, puffed rice, fermented sweet rice and snack foods. Many types of rice snack foods are popular in the Orient markets (Luh, 1991). Moreover, rice also contributes several unique properties such as ease of digestibility, bland flavor and hypoallergenicity. It served as well in many available cultivars, therefore, rice flour has become an attractive ingredient in the snack foods (Kadan et al., 2001). Some of the rice snack foods are made from either glutinous rice or nonglutinous rice, while others are made from both types. Thailand, one of countries in Asia, produces a lot of rices and still maintains in the top rice-exporting country in the world (Luh, 1991). Consequently, rice based expanded snack food production enhances the price of rice and was the value-added products for the exportation.

This research was studies the changes in physical characteristics of the rice cracker made from pure rice flour with the additional of modified starch. The method of processing rice crackers varies among the species of rice used, whereas the quality of the products obtained from each processing is not the same. Rice crackers made from glutinous rice mostly are generally called Arare or Okaki. Each contains an unique textural characteristic and can be easily dissolved in the mouth. Regarding to the baked or popped snacks, glutinous rice expands readily and produces more porous texture. Whereas rice crackers made from nonglutinous rice are called Senbei, which exhibits a hard and rough texture (Hsieh and Luh, 1991). Therefore, nonglutinous rice cracker manufacturer need to improve product characteristic to soften in texture. Nevertheless, numerous factors influence the physicochemical properties and sensory characteristics of rice based expanded snacks including raw materials, ingredients, and types of process such as extrusion, baking, or frying. However, starch is an important component ultimately affecting the quality of the expanded snacks (Moore, 1994). The modification of starches by advanced physical and chemical processing techniques have made the possible improvements in existing products and the development of a complete new family of snacks. Utilizing the proper blends of some potentially modified starches, it is presently feasible procedure to produce a wide variety of product textures. Products based on these starches may range in texture from light, fragile, highly puffed items to dense product. In addition, the amylose to amylopectin ratio apparently influences the textural properties of the finished product. The waxy type starches commonly promote puffing and retain an extremely light, fragile product. For this reason, most snacks containing different amounts of amylose starches potentially attempt the desirable texture (Feldberg, 1969).

Texture is of dominating importance for certain categories of foods, particularly those with a bland flavor such as rice and pasta (Wilkinson et al., 2000). Food texture is a group of physical properties derived from the structure of food that can be determined by both sensory and instrumental analyse. Instrumental measurements are easy to perform, simple to reproduce, less time consuming, and more accurate to record output data (Kayacier and Singh, 2003). Using texture analyzer for measurement of expanded rice snacks was widely applied in several researches (Ilo et al., 1999; Kadan et al., 2001; Ding et al., 2004). In contrast sensory evaluation is generally time consuming, expensive, and not subject to absolute standards. Sensory measurement of texture, however, is a very important aspect of food quality that cannot be ignored because people will not purchase or consume food unless it contains high acceptability with respect to their perception of quality (Bourne, 1982). Therefore, the correlation between the data from sensory evaluation to those from instrumental measurement still has been played an important role to indicate the quality attributes and identifications of food textures (Lee et al., 1999).

The first objective of these studies was to investigate the effects of various modified and native starches on the textural properties of nonglutinous rice cracker.

The second objective was to determine the appropriate type and concentration of added starch to improve the textural characteristic of product. The others, was to investigate the effect of selected modified starches on physical attributes of rice cracker using both sensory and instrumental methods. The last also attempted to match the sensory and instrumental data for discover the instrumental parameters that are the best fitted to the critical sensory variables.

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CHAPTER 2
Literature Review

Rice Cracker

Rice cracker is a Japanese baked snack food made from rice. Rice crackers made from glutinous rice are generally called arare or okaki, soft in texture. Rice crackers made from nonglutinous rice are called senbei which has a hard and rough texture (Hsieh and Luh, 1991; Maga, 1991). In choosing between glutinous or nonglutinous rice, one has to pay attention to uniformity in quality, rate of water absorption, extent of refinement and absence of objectionable odors and tastes (Luh, 2000). The classification of Japanese rice crackers relative to rice type is summarized in Fig. 2.1 (Maga, 1991).

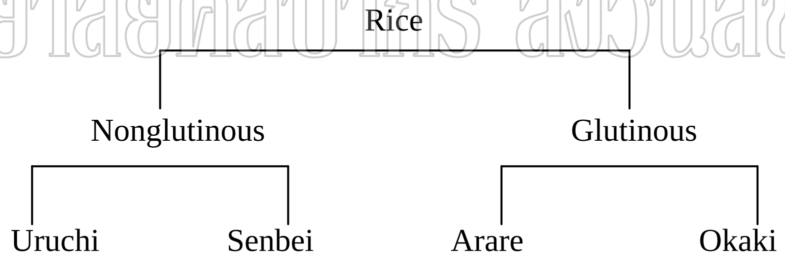


Fig. 2.1 Classification of Japanese rice crackers.

Source: Maga (1991)

Processing Method

Nonglutinous rice crackers. After milling, the rice is washed, soaked in water to moisture content of 20-30%, and ground into powder. After some water is added, the rice is placed in a kneading machine, where it will be steamed for 5-10 min. After cooling to 60-65^{o}C, the rice is rolled and pressed into thin layers and cut into desired shapes. It is dried by hot air at 70-75^{o}C to 20% moisture and tempered at room temperature for 10-20 hr. Then a second drying is applied until moisture content of

10-12% is reached. Finally, it is baked at 200-260^{o}C in a baking machine or band oven. After baking, it is seasoned by coating with soy sauce, spice and other seasoning materials (Hsieh and Luh, 1991).

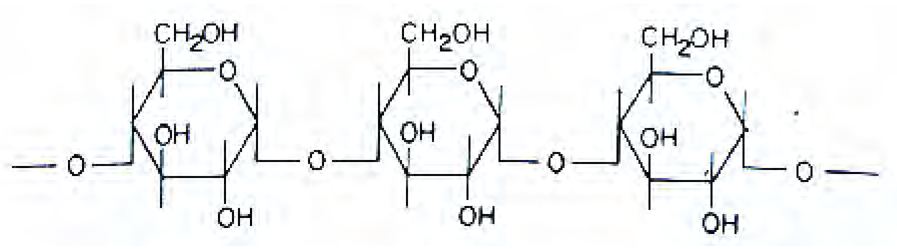
Structure of Starch

Starch is a polymeric carbohydrate consisting of anhydroglucose units linked together primarily through glucosidic linkages. It has been established that starch is a heterogeneous material consisting at the extremes of two major types of polymers such as amylose and amylopectin (Wurzburg, 1986).

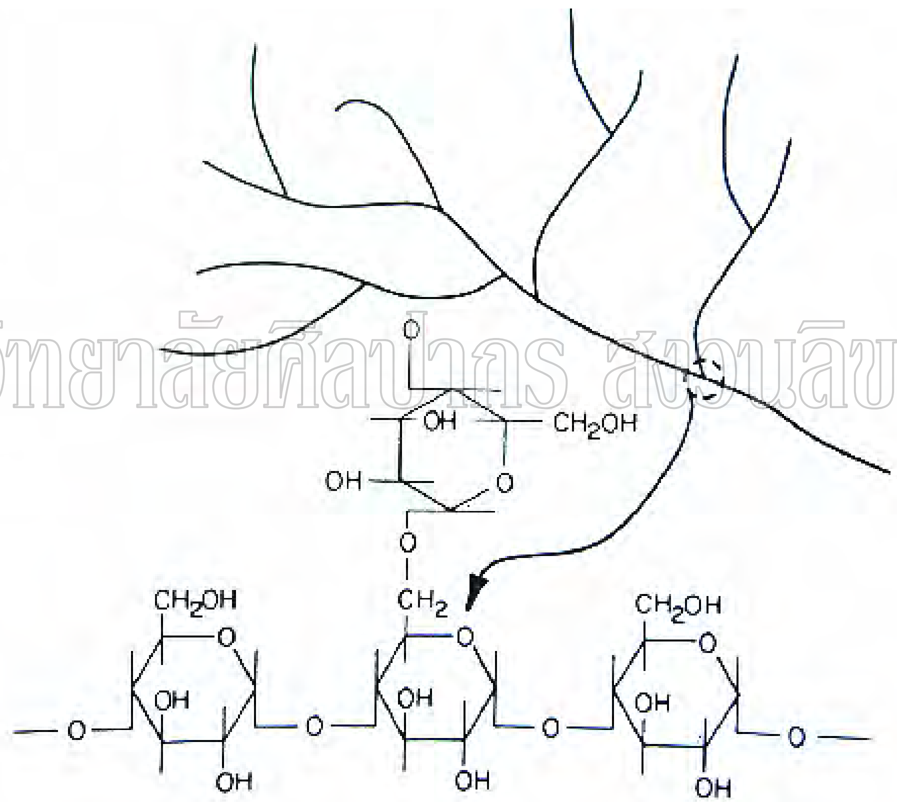
Amylose is essentially a linear polymer in which the anhydroglucose units are predominantly linked through α-D-(1,4) glucosidic bonds (Fig. 2.2 a). Its molecular size varies depending upon the plant source and processing conditions employed in extracting the starch. It may contain anywhere from about 200 to 2000 anhydroglucose units (Whistler and Bemiller, 1984).

On the other hand, amylopectin is a branched polymer containing, in addition to anhydroglucose units linked together as in amylose through α-D-(1,4) glucosidic bonds, periodic branches at the carbon 6 position. These branches are linked to the 6 carbon by α-D-(1,6) glucosidic bonds. Each branch contains about 20 to 30 anhydroglucose units. A schematic of the amylopectin molecule is shown in Fig. 2.2 b (Wurzburg, 1986).

Starches of different origins have different amylose-amylopectin ratios and average degree of polymerizations (DP) of both fractions, as shown in Table 2.1.



(a)



(b)

Fig. 2.2 Two major types of starch polymers: amylose molecule (a), amylopectin molecule (b).

Source: Wurzburg (1986)

Table 2.1 Amylose and amylopectin contents and degree of polymerization of various starches.

Starch	Amylose (%w/w)	Amylopectin (%w/w)	Average DP, amylose	Average DP, amylopectin
Corn	28	72	800	2,000,000
Potato	21	79	3,000	2,000,000
Wheat	28	72	800	2,000,000
Tapioca	17	83	3,000	2,000,000
Waxy maize	0	100	-	2,000,000
Amylomaize	50-80	20-50	715	-
Rice	17	83	-	-
Sorghum	28	72	-	-
Sago	27	73	-	-
Arrowroot	20	80	-	-

DP: Degree of polymerization

Source: Beynum and Roels (1985)

Physical Properties of Starch

Gelatinization : Starch molecules associate through hydrogen bond, when starch granules are insoluble in cold water but absorb water to a limited extent and slightly swell. However, the swelling is reversible when starch is dried (Kerr, 1950). When the starch granule is heat in water, the weaker hydrogen bonds in the amorphous areas are ruptured and the granule swells with progressive hydration. As the granule continues to expand, more water is imbibed, clarity is improved and viscosity increased. Birefringence is lost which is measured with a microscope equipped with a Kofler hot stage. This phenomenon is called gelatinization and initial gelatinization temperature varies with the type of starch (Wurzburg, 1986). In addition, the best method for following the viscosity changes during cooking of a starch paste is with the Brabender viscoamylograph. This apparatus measures the viscosity of starch water dispersions that are stirred and heated at a uniform rate, held at any desired temperature for a specific time and then cooled at uniform rate. The temperature at which the viscosity begins to rise is termed the Brabender pasting temperature. This pasting temperature is usually higher than the gelatinization temperature measured by the loss in birefringence. As shown in Table 2.2 (Beynum and Roels, 1985).

Table 2.2 Gelatinization characteristics of native starches.

Starch	Kofler gelatinization temperature range (°C)	Brabender pasting temperature (8%; °C)[a]	Brabender peak viscosity (8%;BU)[a,b]	Swelling power at 95 °C
Corn	62-67-72	75-80	700	24
Potato	58-63-68	60-65	3,000	1,153
Wheat	58-61-64	80-85	200	21
Tapioca	59-64-69	65-70	1,200	71
Waxy maize	63-68-72	65-70	1,100	64
Amylomaize	67-80-92	90-95	-	6
Rice	68-74-78	70-75	500	19
Sorghum	68-74-78	75-80	700	22
Sago	60-66-72	65-70	1,100	97
Arrowroot	62-66-70	-	-	54

[a] Starch concentration, 8% w/v

[b] BU = Brabender units

Source: Beynum and Roels (1985)

Retrogradation : After gelatinization, the viscosity of starch paste rises and continues to rise until it approaches a peak where the granules have approached their maximum hydration. As heating is continued, the granules tend to rupture, releasing the amylose and amylopectin molecules resulted in the viscosity drop. The amylose molecules are solubilized and leach out into solution, these molecules will then reassociate into aggregates and precipitate at low concentrations or set to a gel at higher starch concentrations due to the steric hindrance may interfere so only partial orientation between the segments of the polymers. This phenomenon of intermolecular association between amylose molecules is commonly called "set back" or retrogradation (Beynum and Roels, 1985). It is schematically illustrated in Fig. 2.3.

As a general rule, sols of common cereal starches such as corn, wheat, rice, etc., having relatively high levels of moderately sized amylose molecules, become opaque and form gels on cooling. Those of potato and tapioca, however, usually maintain their clarity much better and while they thicken on cooling, they do not form opaque gels. Waxy corn starch, unlike regular corn starch, behaves like tapioca or potato. Its sols show even less tendency to thicken on cooling than tapioca or potato. Subsequently, the congealed paste will become cloudy and opaque with time and will eventually release water to shrink into a rubbery consistency, this is referred to as syneresis (Wurzburg, 1986; Beynum and Roels, 1985). The factors influence setback are concentrations of starch, pH, temperatures, times, sizes of amylose and amylopectin molecules, heating and cooling process, including chemical components (Sriroth and Piyachomkwan, 2000).

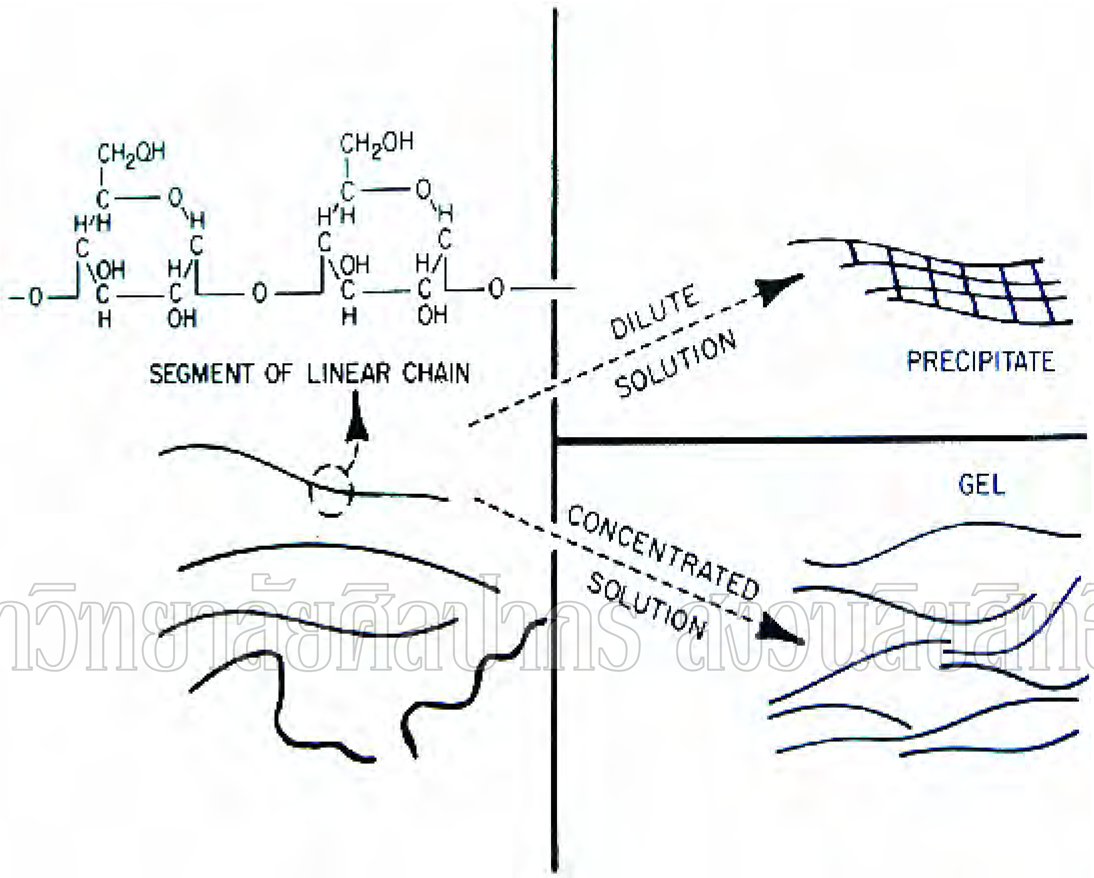


Fig. 2.3 Amylose schematic.

Source: Wurzburg (1986)

Modified Starches

Native starches have some usage limitation in the food industry owing to their properties such as poor stability, easily lost viscosity, texture limitation, susceptibility to severe process, for example, high temperature, high shear, and high acidity. Thus, there exists the need to modify some starches to enhance or repress its inherent properties as appropriate for a specific application. Principal types of modified food starches such as hybridization, physical modification and chemical modification (Light, 1990).

Hybridization: Normally, the common starches contain 20-30% amylose contents. Hybridization is a process to yield products with different percentages of amylose and amylopectin contents since both polymer ratios affect starch properties (Light, 1990). Thus, modified starch is used in a snack process to achieve various textural attributes (Huang, 1995). Starches are modified from hybridization. They consist of waxy starch and high amylose starch. Waxy starch is starch which contains essentially no linear amylose molecules as well as waxy maize so its paste will remain flowable and clear, it will not gel or weep. To follow the viscosity behavior of starch while cooking, the Brabender Viscoamylograph is normally used. Waxy maize will increase in viscosity at a more rapid rate the than regular corn. The peak viscosity for waxy maize will be greater and will be obtained sooner. However, it will also breakdown in viscosity faster and to a greater extension. On cooling, waxy maize shows little increase in viscosity because it does not gel (Mason, 1996). With their fine starch granule size, waxy based starches are the most suitable for the baked snack products because the tests show they perform easy sheeting and good binding, which results in minimal breakage (Huang, 2002). An effective way to elevate the expansion of snack is to add waxy corn starch, which is essentially 100% amylopectin. However, one problem with high amylopectin starch is the breakdown of amylopectin molecules by the high temperature and high shear processing conditions experienced during cooker extrusion and frying. Anyway, a crosslinked waxy corn starch normally improved resistance of amylopectin to breakdown (Huang, 1995). In rice crackers, waxy rice helps impart a light texture, while amylose rice types are better for heavier snack (Huang, 2002). For high amylose starch, it contains more than 50% amylose content. Granules of high amylose corn starch hardly swell resulting in higher gelatinization temperature than regular corn starch and retrogradation occurs very well (Radley, 1976). In addition, high amylose starches have unique properties for gelling and film forming and have been used to provide quick gels in confectionary and reduced oil absorption in fried snacks (Mason, 2002). Besides, high amylose corn starch and modified high amylose starches can be used to reduce cracking and breakage that result in excessive losses in baked snack products (Huang, 2002).

Table 2.3 Properties of amylose and amylopectin

Characteristic	Amylose	Amylopectin
Solubility	Variable	Soluble
Paste clarity	Cloudy	Clear
Film formation	Tough, resistant, coherent films	Weak films
Gel formation	Soft, reversible, flowable gels that become irreversibly firmer with time	No or weak gels
Solution/dispersion stability	Rapid retrogradation, proportional to concentration	Stable
Syneresis of paste/gel	High	Little
Shear resistance	High	Relatively low
Acid resistance	High	Relatively low
Complex formation	Complexes with iodine, lipids and various slightly polar organic molecules	Does not complex

Source: BeMiller (1993)

Physical modification: Pregelatinized starch or pregeled starch is the most popular physical modification, also referred to as instant starch slurries, are those that have been simply precooked and drum dried to give products that readily disperse in cold water to form moderately stable suspensions (Anastasiades et al., 2002). Such pregeled starches are used mainly as thickeners in foods such as instant pudding, cake mixes, sauce and gravies (Radley, 1976). For expanded snacks by baking, where internal temperatures of snacks increase more slowly than in extrusion or frying, pregelatinized waxy corn starches are normally recommended. Pregelatinized starches have been precooked in water and then dried, they require no further cooking before baking to contribute to texture development (Huang, 1995). In addition, Yu and Low (1992) used to pregelatinized tapioca starch in the manufacture of a snack food, fish cracker or keropok which are popular snack foods in Malaysia. Before consumption the slices are fried in hot oil, where upon the cracker expands into a porous low density product. Results show that only cracker made from a slurry with a water:starch ratio of 70:30 pregelatinized at 133.5^{o}C, 143.6^{o}C, and 151.8^{o}C had linear expansion greater than the minimum acceptable value of 77%. Furthermore, the cracker produced from 70:30 slurry at 133.5^{o}C had a better flavor and overall acceptability than the control made from native starch. On the other hand, the manufacture of a shelf-stable snack food produced from fruit or vegetable juices or juice concentrates. Juice or juice concentrate is mixed with a starch hydrolysis product and pregelatinized starch to form a dough. Vacuum drying of the dough produces a shelf-stable product with a cellular or crumb-like structure. Heating the dough causes expansion owing to evaporation of water and produces a substance with a cracker or cookie-like appearance and texture (Gimmlera et al., 1997). Moreover, the snacks are prepared from a pregelatinized waxy starch, which enables cohesive, continuously machinable doughs to be produced from starchy materials or ingredients that contain starches with either no gluten or a low gluten content. The dough sheets are heated in a gas oven to obtain chip-like snacks with a low oil content, a blistered appearance and a crispy texture (Addessoa et al., 1996)

Chemical modification: This method can be classified 2 types that are conversion and derivatization. Conversion is a process that is used to reduce the viscosity of raw starches. Its main objectives are to allow the use of starches at higher percentages, increase the water solubility, control gel strength or modify the stability of starch. Methods of conversion include acid hydrolysis, oxidation, dextrinization, and enzyme conversion. Each method of conversion provides starch products with distinctive functionality (Zobel, 1992). Other chemical modifications fall in the area of derivatization, including stabilization and crosslinking. Stabilization, a process whereby monofunctional group substitutes hydroxyl group of starch molecules results in the reduction of gelatinization temperature, an increases the clarity of sols with an increase the degree of swelling and dispersion of the starch granule as well as the reduction of retrogradation (Whistler et al., 1984). Inhibiting retrogradation imparts textural and freeze-thaw stability, thus prolonging the shelf life of the food product. This modification is most important in frozen foods since retrogradation of starch polymers is accelerated at cold temperatures (Light, 1990). Although, these starches have sensitivity to high shear, high temperature, and low pH which make them unsuitable for some specific uses, but Bhattacharyya et al. (1996) used carboxymethyl starch (CMS) prepared from corn and waxy small sized amaranth starch and tested as an extrusion aid in the ready-to-eat extruded snack. The CMS was used at 0.25-1.0% and had a degree of substitution (DS) ranging from 0.1-0.2. The extruded products were analyzed for bulk density, moisture, expansion ratio, and texture analysis. Waxy amaranth starch was found to be slightly better than corn starch, when samples containing CMS with identical DS used at the same level were compared. Cross-linking, this is a treatment whereby small amounts of compounds that can react with more than one hydroxyl group are added to the starch polymers. Cross-linking of starch can be occurred at random locations which are covalent bond, reinforcing hydrogen bonding and inhibiting granule swell (Mason, 1996). Cross-linking yields starch granules with increased resistance to overcooking and other variations in processing conditions such as high temperature, acid and shear (Light, 1990). Cross-linked starches are suitable for fried and extruded snack because they prevent the disruption of starch granules that can lead to poor texture and toothpacking in the mouth. With proper modification, specialty starches made from waxy maize, corn and tapioca may be used to prevent these problems (Huang,2002). According to this experiment, cross-linked tapioca starch can be utilized in the extruded snack by partial substitution of rice flour. As a result, the final product containrd more fine and consistent pore size than the native tapioca based snack (Duangchai, 1993).

In addition, 3 different modification methods are referred to above statement and then the resistant starch and combination modifying are mentions in some researches. The combination of modifying techniques considerably improve starch properties and extend their usefulness. So, from study of O'Dell (1976) about the fried snack item which had an even honeycomb texture, a complete melt-away in the mouth and some resistance to staling or softening in the packet. The equipment being used was a cooker extruder, crosslinked and esterified waxy maize starch gave a very high expansion when the product was finally fried. Introduction of a crosslinked starch in conjunction with the modified waxy maize retarded the bursting of the starch giving only partially swollen granules in the final product matrix, this is turn preserving the melt-away texture required and a much longer period of time before staling took place. However, the honeycomb texture proved to be extremely fragile and losses due to breakage of the snack since the packing operation were too high. It was decided that in order to impart rigidity to the snack after frying it was necessary to include amylose in some form or other. While, resistant starch is not digested in the small intestine but can be fermented in the large intestine. As an insoluble product, resistant starch is especially appropriate for grain based, low and moderate moisture foods. Its physical properties, particularly its low water holding capacity, allow it to be a functional ingredient that provides good handling in processing and crispness, expansion, and improved texture in the final product (Waring, 2002). Thus, Gallagher et al. (2001) used the resistant starch which has traditional name that NOVELOSE 330 by National starch and chemical company for produce short dough biscuit and found that NOVELOSE 330 greatly affected the thickness of the final product. Food applications of resistant starch are of interest to product developers and nutritionists for two reasons. First, fiber fortification and the potential physiological benefits of resistant starch which may be similar to fiber and the another reason is unique functional properties, yielding high quality products not attainable otherwise with traditional insoluble fibers (Waring, 1998).

Cookie and Cracker Texture

Food texture is a group of physical properties that derives from the structure of food, is related to deformation, disintegration, and flow under force, and that is subjectively sensed by the feelings of touch, hearing, and sight. Food textures are objectively measured as functions of mass, distance, pressure and time. Since texture refers to a group of properties, any one or a combination of which may be measurable at a time, it is the most accurate to refer as textural properties.

Instruments for measuring textural properties of cookies and crackers can be classified relatively to the principle of measurement utilized. Such classification emphasizes the importance of understanding the theories of engineering materials testing, precisely which rheological measurement is accomplished by an instrument, and the resulting units of measurement.

Several schemes have been used to categorize instrumental texture methods. They include the nature of the test, the motion and geometry of the instrument, the variables underlying the measurement, the product being analyzed, and the type of force being employed. Principles of mechanical operation by which food texture is often evaluated (Gaines, 1994):

1. Resistance to puncture by a probe.
2. Extrusion force or time of foods that can attain flow characteristics.
3. Resistance to cutting shear of solid foods.
4. Gentle compression to measure the force of resistance or distance of deformation.
5. Resistance to crushing to a point of destruction of the structure.
6. Tensile strength.
7. Resistance to bending and snapping.
8. Resistance to torsional force or torque of rotational force of part of the material.
9. Distance (length, area, or volume).
10. Time of various measurements.
11. Measurements based on multiple principles, often force/distance/time.

Sensory Methods for Food Texture Evaluation

Consumer would not purchase or consume food unless it contains high acceptability according to their perception of product quality. Sensory method, therefore, is the ultimate tool for calibrating instrumental methods of texture measurement, even though it is generally time consuming, expensive and not subject to absolute standard.

Sensory evaluation offers the opportunity to obtain a complete analysis of the textural properties of foods as perceived by the human senses. A number of processes occur while food is being masticated, including deformation, flow, comminution, mixing and hydration with saliva, and sometimes changes in temperature, size, shape, and surface roughness of the food particles. All of these changes are recorded with great sensitivity by human senses, but many of them are difficult to measure by objective methods. The entire complex of events that occurs during mastication cannot be measured completely by instruments. Consequently, sensory evaluation is an important measurement in the product development. It is the best methods for evaluating texture of new types of foods in the early stages of the product development and for providing a basis on which instrumental methods might later be designed for use as a quality measurement and production control (Bourne, 1982).

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CHAPTER 3

Textural Properties of Rice Crackers Obtained from Partially Substituted Rice Flour with Various Modified and Native Starches

Abstract

Jasmine rice as a major raw material for rice cracker processing normally exhibited hard and rough in texture, so the processor attempted to diminish the hardness while still retain the crispness by mean of partial substitution of rice flour with some modified and native starches at three different levels (1.5%, 2.5%, and 5.0%, respectively). Instrumental hardness of rice crackers mixed with 2.5% of each NATIONAL 5730, ULTRA-CRISP CS, and NATIONAL 687 significantly decreased up to 22.63%, 16.53%, and 16.11%, respectively. The additional 5.0% each of NATIONAL 5730 and ULTRA-CRISP CS intensively reduced the hardness up to 27.89%, and 21.89%, respectively, as compared to the control (rice cracker with 100% rice flour). According to contain lower normal stress, normal strain, and bulk density, the rice crackers provided more mushy texture as illustrated by the texture map profiles that was plotted between normal stress and normal strain. Whereas the rice crackers added with native tapioca starch exhibited brittle texture in texture map.

Keywords: rice cracker, modified starch, native starch, texture map

Introduction

Snack foods are the most enjoyable food products consumed all over the world. Early snack products such as cookies, crackers, and biscuits are made from wheat flour. As the new products evolved, other base ingredients like rice, corn, potato, and tapioca were continuously added to the list of the upcoming and important raw materials. Special interest are various rice-based oriental snacks whose popularity is still increasing in the United States. Both glutinous and nonglutinous rice are used and their starch expansion abilities significantly differentiate. Rice crackers made from glutinous rice contain soft in texture, whereas nonglutinous rice produces rice crackers inversely exhibiting a hard and rough texture (Maga, 1991).

Numerous factors directly influence the quality attributes of expanded snacks including raw materials, ingredients, and processing methods such as extrusion, baking, and deep-fat frying. However, starch is the most essential and major contributor to the textural product characteristics. One procedure to alter or improve the texture is to add a small amount of a special starch. The combination usage of mixed starches consisting of raw starches, chemical modified starch, pregelatinized starch, and some special starches with either high amylose or amylopectin content have been reported to express how to obtain better improvement of textural attributes (Moore, 1994). Gimmlera et al. (1997) reported that a shelf-stable snack from juice or juice concentrate mixed with maltodextrin and gelatinized corn starch provided well expanded product whereas gelatinized wheat starch exhibited moderate puffing. In the extrusion cooking of rice flour and amaranth blends, an increasing of amaranth content caused the enormous reduction in the sectional expansion index and also increased in the breaking strength of extrudates (Ilo et al., 1999). Moreover, a mixture of waxy and high amylose rice flour incorporated with extruding temperature and insert size significantly related to fat content, moisture, hardness, and fracturability of rice fries (Kadan et al., 2001).

The objectives of this study were (a) to study the effects of various modified and native starches on the textural properties of nonglutinous rice crackers and (b) to formulate the appropriate of nonglutinous rice cracker added with various modified and native starches to successfully improve product texture and retain the desirable softness.

Materials and Methods

Raw materials

Jasmine rice flour was obtained from Namchow (Thailand) Ltd. and 11 commercial starches were used as the supplemented raw material in this experiment. Commercial starches consisting of native tapioca starch, GELPRO M, GELPRO 40M, GELPRO AC50, GELPRO HC30, and GELPRO HC48 were supplied by Potential Marketing Co., Ltd. The remaining of 5 commercial starches were native waxy corn starch, NATIONAL 5730, NATIONAL 687, ULTRA-CRISP CS, and NOVELOSE 240 obtained from National Starch and Chemical (Thailand) Co., Ltd.

Regarding to the source of starch, the modified starches used in this research were classified into 3 groups.

1. Tapioca starch
    - GELPRO M (cross-linked starch)
    - GELPRO 40M (low acetylated cross-linked starch)
    - GELPRO AC50 (medium acetylated cross-linked starch)
    - GELPRO HC30 (low hydroxypropylated cross-linked starch)
    - GELPRO HC48 (medium hydroxypropylated cross-linked starch)
    - NATIONAL 687 (pregelatinized starch)
2. Waxy corn starch
    - NATIONAL 5730 (pregelatinized starch)

- ULTRA-CRISP CS (pregelatinized starch)

3. High amylose corn starch
    - NOVELOSE 240 (resistant starch)

Thin rice cracker production

A 2.5 kg of milled rice flour containing moisture content about 28-30% was hydrated and steamed for 1.5 hr. The final moisture content of rice dough was controlled approximately 45%. The dough was consequently kneaded using the two arms mixer for 10 min, and then shaped into thin sheet like paper with approximately 1-2 mm of thickness using the roller machine. The sheeted dough was cut into circle pellets by the stainless mould with 48-mm in diameter. The fresh-cut pellets were continuously oven-dried for 60-90 min at 75-80^{o}C until 10-12% of moisture content was obtained. Once, the pellets had over-specified moisture contents, they must be rejusted to retain the desirable moisture at 40-50^{o}C. The dried pellets were continuously baked at 200-250^{o}C for 1-2 min. Rice cracker was kept in aluminum foil bag for 2 days before randomly selected for further analysis. Modified and native starches were utilized as partial substitution of rice flour at 3 different levels (1.5%, 2.5%, and 5.0%) by blending with other dry ingredients before steaming step.

Textural measurement

Texture of rice cracker was measured using the texture analyzer (Model:TA-XT 2i, Stable Micro System Co. Ltd.,UK) with a cylindrical flat ended probe of 5-mm in diameter. The compression test at a speed of 5 mms^{-1} to a distance of 15 mm, pre-test speed of 5 mms^{-1} and post-test speed of 10 mms^{-1} was examined. Each texture parameter was calculated based upon an average of ten replications. Data collection and analysis were accomplished by software of TA.XT2i analyzer (Texture Expert Version 1.22). The instrumental parameters of the puncture test were calculated as hardness, normal stress, and normal strain.

Bulk density determination

The bulk volume was measured using the sand replacement technique in which the sand was used as the substitution of ten pieces of rice cracker and measured the volume of sand via the use of 100 ml cylinder. Bulk density, ρ_b (g/ml), was then calculated by dividing the weight of the crackers by their bulk volume. The test was performed in triplicate.

Expansion ratio

The bulk volume was measured using the sand replacement technique as described earlier. Expansion ratio was calculated by dividing the bulk volume of cracker by the bulk volume of pellet.

Statistical analysis

All data were performed using the General Linear Model of the Statistical Analysis System software version 8.1, SAS Institute, Inc., Cary, NC, USA (SAS, 2001). All experimental means were compared by least significant difference (LSD) at 95% confidence level.

Results and Discussion

In a rice cracker production, the process needed to sheet dough as a thin piece about 1-2 mm. Some of dough added with 5.0% modified tapioca starch, could not be sheeted such as GELPRO M, GELPRO 40M, GELPRO AC50, GELPRO HC30, GELPRO HC48, and NATIONAL 687 because tapioca starch granule contained loose crystalline region and less hydrogen bond and resulted in its internal bond structure that holds the granules together was weak and absorbed water very well. So, the dough was sticky and difficult to handle.

Supplemental starches affected the required force to deform the rice crackers

(Table 3.1). The same amounts of hardness in both the control (rice cracker with 100% rice flour) and several types of 1.5% modified or native starches added products were observed. Bigner and Berry (1997) reported that the use of modified pregelatinized potato starch at 2.0% to reduce fat content of pork crumbles whereas Troutt et al. (1992) reported the use of 0.5% potato starch insignificantly affected the fat content of cooked patties because probably very little level usage of starches were not enough capability to alter or improve the textural product characteristics. Thus, the rice crackers still exhibited tough in texture as same as the control (Fig. 3.1). In contrast, an increase the substituted modified starch level at 2.5%, both GELPRO M and GELPRO 40M intensively contributed high hardness products and contained tough texture as shown in Fig. 3.2 because they were modified by mean of the cross-linking. In general, the cross-linking reinforced the hydrogen bonds in the granule with chemical bonds acting as bridges between the starch molecules, thus, granular swelling power was restricted during gelatinization. As a result, the cross-linked starches more effectively resisted to high temperature, low pH, and high shear, therefore, it considerably reduced ability to provide puffy, uniform, and light texture products (Nabeshima and Grossmann, 2001). However, higher additional levels of GELPRO HC30 and GELPRO HC48 tended to more decrease the hardness than GELPRO AC50. As a result of both GELPRO HC30 and GELPRO HC48 were hydroxypropylated cross-linked starch, hydroxypropylation renders a hydrophilic character and hydroxypropyl group had more molecular weight than acetyl group. When introduced each of them into the starch granule, it substantially retarded the reassociation of starch molecules and it was known to weaken the internal bond structure holding all the granules together, thereby increase the acceptability of the starch granules to water and swelling power. While the resistance to high temperatures potentially increased and textural stability improved with respect to the cross-linking method (Pal et al., 2002). As the consequence, the rice crackers mixed with each GELPRO HC30 and GELPRO HC48 exhibited the rubbery texture (Fig. 3.2). As compared to the rice crackers mixed with native tapioca starch at the same concentration, its provided less hardness but at the additional level of 5.0%, the crackers produced high hardness as well as exhibited brittle texture (Fig. 3.3). In general, the native tapioca starch capably offered very great swelling power but unstable for some specific processes, for instance, it sensitive to shear, high temperature, and low pH. Kusunose et al. (2001) described some procedures how to control expansion of dough and finally found that the starch granule should not be disrupted and easily fuse together during gelatinization as tapioca starch did because the disruption of cell membrane would not prevent shrinkage of gas impermeable membrane during cooling after baking. Thus, it exhibited the impact structure and resulted in an increase in hardness of rice crackers.

While native waxy corn starch addition had a tendency to decrease hardness since it contained high amylopectin content which easily formed the network and became the porous texture, increased the expansion ability of snack (Feldberg, 1969). Previous works proposed that the degree of hardness was positively correlated to the amylose content (Kadan et al., 1997). However, pregelatinized waxy corn starch contributed to improve better the product texture. Pregelatinized starches have been precooked in water and then dried, so they require no further cooking before baking to contribute to the textural development. This is an important ability because the conditions during the baking of expanded snacks did not allow adequate gelatinization of regular waxy starch whereas pregelatinized waxy corn starch allowed the expansion process to begin earlier due to the loss of granular integrity, and higher water absorbability, subsequently increased expansion rate of products and affected to softness texture (Huang,1995). Thus, the addition of each NATIONAL 5730, NATIONAL 687, and ULTRA-CRISP CS provided more ability to decrease the hardness of rice crackers ($p<0.05$), therefore, product exhibited more mushy texture with an increase in substitution level (Fig. 3.2-3.3). Conclusively the different types and concentrations of pregelatinized starch intimately influenced the product expansion (Gimmlera et al., 1997). In addition, Case et al. (1992) report that wheat flour, wheat starch, corn meal, and corn starch were gelatinized from 20 to 100% by mean of the extrusion and partial cooking to obtain half-product so the extruded could be shortly fried before consumption. They also reported that, the volume of puffed products increased and bulk density decreased with an increase in gelatinization duration, and temperature. This work ultimately confirms the results of Kawas and Moreira (2001) as well. They reported that steamed-baked tortilla (87% of starch gelatinized before frying) produced chips with high degree of puffiness and lower crunchiness as compared to the control chips (45% of starch gelatinized before frying) and the freeze-dried chips (5% of starch gelatinized before frying).

The substitution of NOVELOSE 240 imparted a tough texture (Fig. 3.3) and produced more hardness product with an increase in the additional levels. Normally, NOVELOSE 240 was classified to be the resistant starch modified by high amylose corn starch, and amylose had better film forming property and it contained 40% of total dietary fiber with low water holding capacity. Rice crackers formulated from NOVELOSE 240 exhibited the limitation of puffing and the lower expansion, and consequently, contributed a very hard texture (Feldberg, 1969). These results also described by the amylose content influencing the expansion rate of crackers. Accordingly, Gallagher et al. (2001) also reported that the resistant starch (NOVELOSE 330) greatly affected the thickness of the short dough biscuit. From Table 3.2, it indicated the addition of NOVELOSE 240 at level 1.5%, 2.5%, and 5.0% tremendously reduced the expansion rate of rice crackers as compared to the control samples up to 3.43%, 9.64%, and 16.73%, respectively.

The expansion ratio and bulk density of rice crackers with various starch additions were shown in Table 3.2. According to above report, the degree of hardness negatively correlated to the expansion ratio and positively related to the bulk density. Particularly, at 5.0% each of NATIONAL 5730 and ULTRA-CRISP CS substitution contributed the rice crackers with more expansion ratio than the control up to 17.46% and 15.19% as well as the bulk density decreased up to 10.25% and 7.76%, respectively.

Conclusions

The starch types and concentrations intensively influenced the textural characteristics of rice crackers. Pregelatinized starch was capable to improve better texture in case of the reduction of hardness and bulk density but an increase in the expansion ratio, as well. While some chemical modified starches showed the potential ability to receive higher tough texture than native starch as noticed by texture map profile. In addition, at highest level of additional native starch exhibited brittle in texture of rice crackers. These results were significantly useful for the manufacturers to select the appropriate modified starches used in the rice cracker production.

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Table 3.1 Textural properties of rice crackers with various starch additions[1]

Level	Starch[2]	Hardness (N/g)	Normal Stress ($x10^{-2}$ N/g.mm^2)	Normal Strain (%)
	Control	9.50 ± 2.04^{abcde}	48.41 ± 10.38^{abcde}	41.20 ± 5.76^{bcd}
1.5%	Native waxy corn	9.59 ± 1.28^{abcde}	48.87 ± 6.51^{abcde}	32.24 ± 11.57^{ef}
	Native tapioca	9.36 ± 1.96^{abcdef}	47.68 ± 9.99^{abcdef}	28.74 ± 9.43^{fg}
	GELPRO M	9.88 ± 1.46^{abcd}	50.35 ± 7.43^{abcd}	42.65 ± 10.79^{bc}
	GELPRO 40M	9.27 ± 2.17^{abcdef}	47.25 ± 11.05^{abcdef}	43.41 ± 7.51^{bc}
	GELPRO AC50	9.37 ± 1.70^{abcdef}	47.73 ± 8.68^{abcdef}	40.16 ± 5.66^{bcd}
	GELPRO HC30	9.73 ± 1.44^{abcde}	49.58 ± 7.32^{abcde}	43.54 ± 7.41^{bc}
	GELPRO HC48	9.07 ± 1.59^{bcdef}	46.22 ± 8.12^{bcdef}	39.97 ± 8.99^{bcd}
	NATIONAL 5730	8.93 ± 0.93^{cdef}	45.51 ± 4.74^{cdef}	52.27 ± 9.86^{a}
	ULTRA-CRISP CS	8.62 ± 1.87^{defgh}	43.93 ± 9.52^{defgh}	42.09 ± 6.69^{bcd}
	NATIONAL 687	9.76 ± 1.75^{abcd}	49.73 ± 8.91^{abcd}	38.81 ± 4.26^{cde}
	NOVELOSE 240	9.36 ± 2.15^{abcdef}	47.68 ± 10.93^{abcdef}	42.14 ± 4.69^{bcd}
2.5%	Native waxy corn	8.89 ± 1.37^{cdefg}	45.29 ± 7.00^{cdefg}	31.94 ± 12.44^{ef}
	Native tapioca	8.25 ± 1.38^{fghi}	42.04 ± 7.04^{fghi}	22.34 ± 10.64^{gh}
	GELPRO M	10.23 ± 2.47^{abc}	52.12 ± 12.59^{abc}	45.65 ± 9.79^{abc}
	GELPRO 40M	10.01 ± 1.62^{abcd}	51.01 ± 8.26^{abcd}	41.20 ± 7.80^{bcd}
	GELPRO AC50	9.28 ± 1.63^{abcdef}	47.26 ± 8.32^{abcdef}	46.59 ± 9.93^{ab}
	GELPRO HC30	8.80 ± 1.82^{cdefgh}	44.82 ± 9.25^{cdefgh}	44.83 ± 8.60^{abc}
	GELPRO HC48	8.55 ± 1.11^{defgh}	43.55 ± 5.65^{defgh}	44.86 ± 15.29^{abc}
	NATIONAL 5730	7.35 ± 1.36^{hi}	37.46 ± 6.91^{hi}	16.93 ± 5.64^{h}
	ULTRA-CRISP CS	7.93 ± 0.89^{fghi}	40.40 ± 4.53^{fghi}	18.41 ± 7.68^{h}
	NATIONAL 687	7.97 ± 1.98^{fghi}	40.58 ± 10.06^{fghi}	17.13 ± 7.37^{h}
	NOVELOSE 240	10.61 ± 1.77^{a}	54.07 ± 9.01^{a}	20.40 ± 10.70^{h}
5.0%	Native waxy corn	9.06 ± 1.83^{bcdef}	46.14 ± 9.32^{bcdef}	17.72 ± 3.06^{h}
	Native tapioca	9.26 ± 1.76^{abcdef}	47.17 ± 8.97^{abcdef}	15.49 ± 6.90^{h}
	NATIONAL 5730	6.85 ± 0.96^{i}	34.88 ± 4.90^{i}	15.97 ± 4.10^{h}
	ULTRA-CRISP CS	7.42 ± 1.55^{ghi}	37.81 ± 7.89^{ghi}	16.72 ± 6.30^{h}
	NOVELOSE 240	10.54 ± 2.37^{ab}	53.69 ± 12.05^{ab}	35.17 ± 4.24^{def}

1 = Means in the same column with different letters were significantly different ($p<0.05$)

2 = Commercial name

Table 3.2 Physical attributes of rice crackers with various starch additions[1]

Level	Starch[2]	Expansion Ratio	Bulk Density (g/ml)
	Control	2.59 ± 0.17^{b}	0.36 ± 0.01^{bcd}
1.5%	Native waxy corn	2.60 ± 0.12^{b}	0.37 ± 0.01^{abc}
	Native tapioca	2.60 ± 0.13^{b}	0.36 ± 0.02^{bcd}
	GELPRO M	2.61 ± 0.12^{b}	0.37 ± 0.01^{abc}
	GELPRO 40M	2.60 ± 0.13^{b}	0.36 ± 0.02^{bcd}
	GELPRO AC50	2.60 ± 0.13^{b}	0.36 ± 0.02^{bcd}
	GELPRO HC30	2.61 ± 0.09^{b}	0.36 ± 0.01^{bcd}
	GELPRO HC48	2.58 ± 0.10^{b}	0.36 ± 0.02^{bcd}
	NATIONAL 5730	2.58 ± 0.09^{b}	0.36 ± 0.01^{abcd}
	ULTRA-CRISP CS	2.59 ± 0.08^{b}	0.36 ± 0.01^{bcd}
	NATIONAL 687	2.62 ± 0.09^{b}	0.37 ± 0.01^{abc}
	NOVELOSE 240	2.51 ± 0.12^{bc}	0.36 ± 0.01^{abcd}
2.5%	Native waxy corn	2.58 ± 0.07^{b}	0.36 ± 0.01^{bcd}
	Native tapioca	2.64 ± 0.11^{b}	0.36 ± 0.02^{bcd}
	GELPRO M	2.54 ± 0.07^{b}	0.37 ± 0.01^{abc}
	GELPRO 40M	2.50 ± 0.12^{bc}	0.37 ± 0.02^{abcd}
	GELPRO AC50	2.61 ± 0.12^{b}	0.37 ± 0.01^{abc}
	GELPRO HC30	2.58 ± 0.05^{b}	0.36 ± 0.01^{bcd}
	GELPRO HC48	2.64 ± 0.13^{b}	0.36 ± 0.02^{bcd}
	NATIONAL 5730	2.67 ± 0.12^{b}	0.34 ± 0.01^{def}
	ULTRA-CRISP CS	2.61 ± 0.14^{b}	0.35 ± 0.02^{cde}
	NATIONAL 687	2.64 ± 0.11^{b}	0.36 ± 0.01^{bcd}
	NOVELOSE 240	2.34 ± 0.16^{c}	0.38 ± 0.01^{ab}
5.0%	Native waxy corn	2.63 ± 0.11^{b}	0.35 ± 0.01^{cde}
	Native tapioca	2.55 ± 0.14^{b}	0.37 ± 0.01^{abc}
	NATIONAL 5730	3.05 ± 0.09^{a}	0.32 ± 0.01^{f}
	ULTRA-CRISP CS	2.99 ± 0.14^{a}	0.33 ± 0.01^{ef}
	NOVELOSE 240	2.16 ± 0.06^{d}	0.38 ± 0.01^{a}

1 = Means in the same column with different letters were significantly different ($p<0.05$)

2 = Commercial name

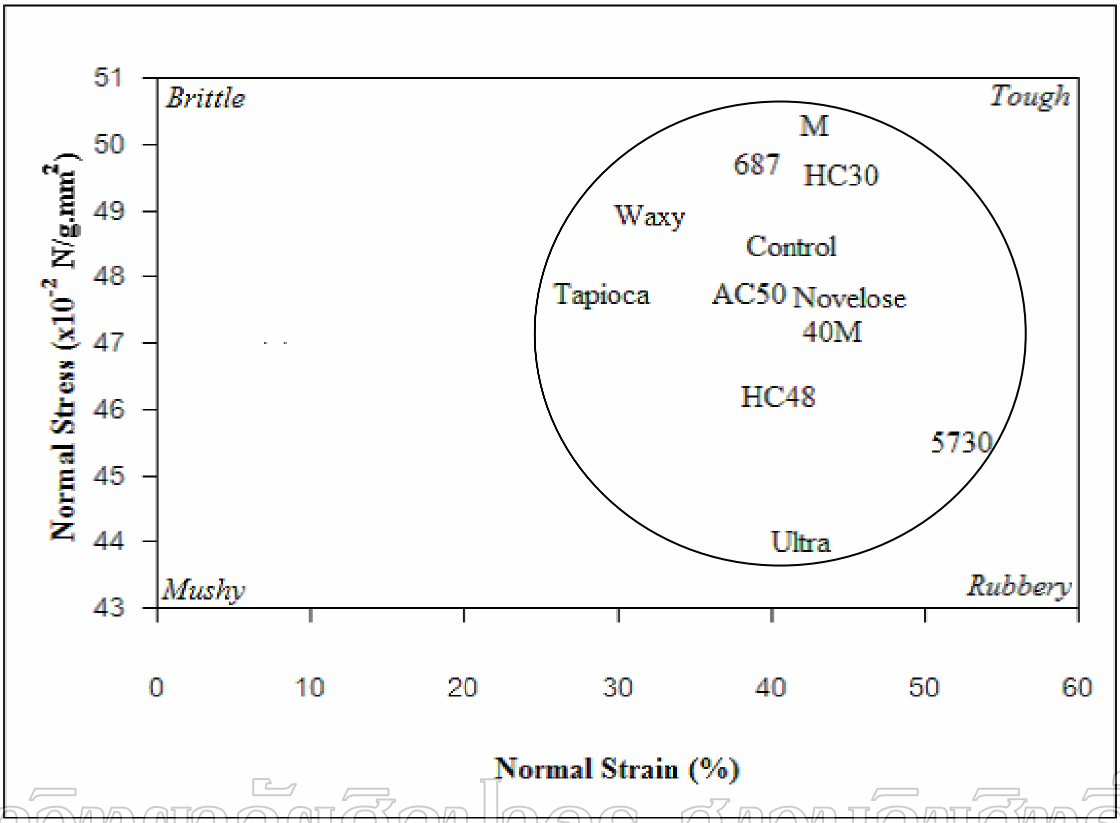

Fig. 3.1 Texture map of the rice crackers mixed with various starches at 1.5%

Waxy: native waxy corn starch

Tapioca: native tapioca starch

M: GELPRO M (cross-linked tapioca starch)

40M: GELPRO 40M (low acetylated cross-linked tapioca starch)

AC50: GELPRO AC50 (medium acetylated cross-linked tapioca starch)

HC30: GELPRO HC30 (low hydroxypropylated cross-linked tapioca starch)

HC48: GELPRO HC48 (medium hydroxypropylated cross-linked tapioca starch)

687: NATIONAL 687 (pregelatinized tapioca starch)

5730: NATIONAL 5730 (pregelatinized waxy corn starch)

Ultra: ULTRA-CRISP CS (pregelatinized waxy corn starch)

Novelose: NOVELOSE 240 (resistant starch)

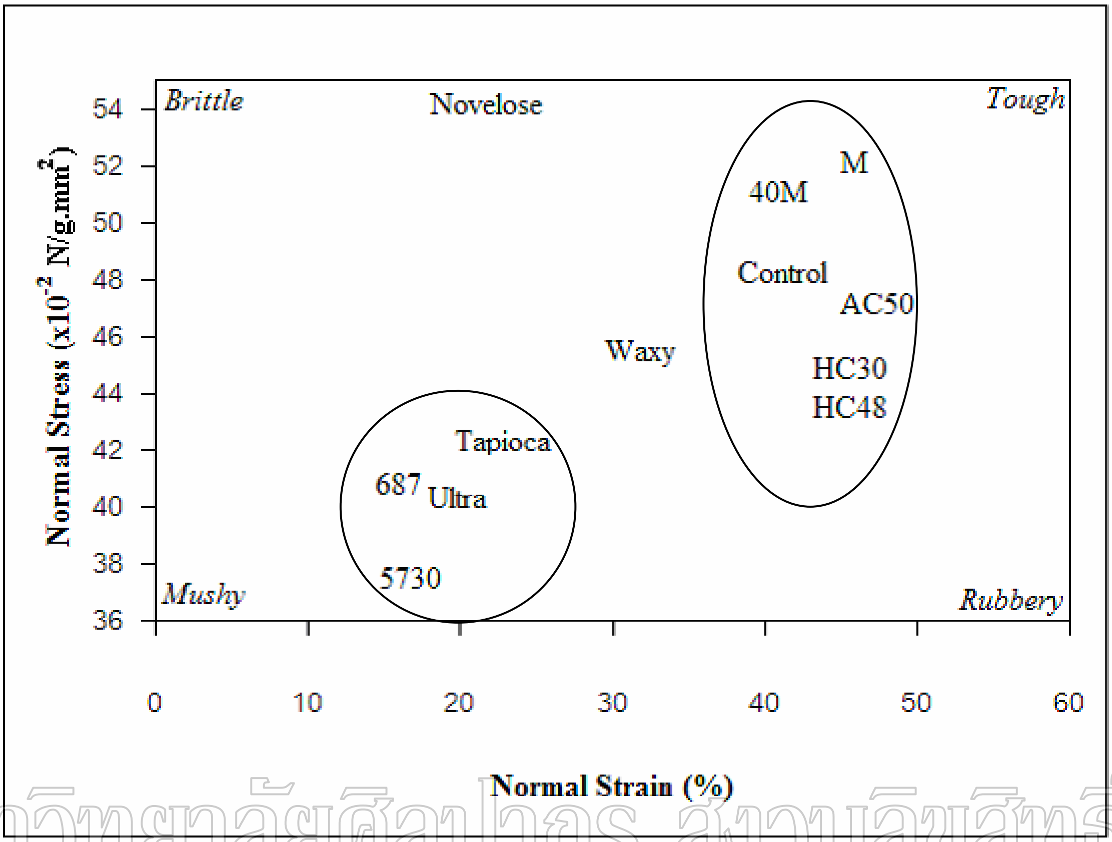

Fig. 3.2 Texture map of the rice crackers mixed with various starches at 2.5%

Waxy: native waxy corn starch

Tapioca: native tapioca starch

M: GELPRO M (cross-linked tapioca starch)

40M: GELPRO 40M (low acetylated cross-linked tapioca starch)

AC50: GELPRO AC50 (medium acetylated cross-linked tapioca starch)

HC30: GELPRO HC30 (low hydroxypropylated cross-linked tapioca starch)

HC48: GELPRO HC48 (medium hydroxypropylated cross-linked tapioca starch)

687: NATIONAL 687 (pregelatinized tapioca starch)

5730: NATIONAL 5730 (pregelatinized waxy corn starch)

Ultra: ULTRA-CRISP CS (pregelatinized waxy corn starch)

Novelose: NOVELOSE 240 (resistant starch)

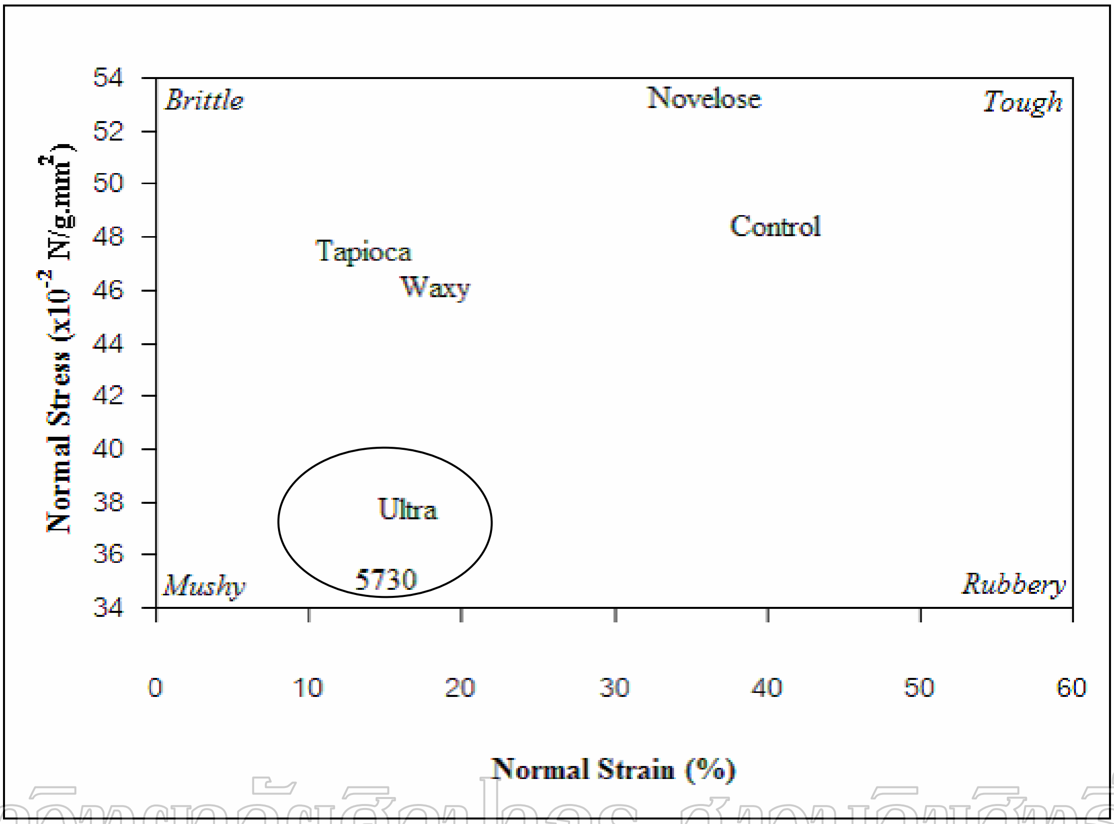

Fig. 3.3 Texture map of the rice crackers mixed with various starches at 5.0%

Waxy: native waxy corn starch

Tapioca: native tapioca starch

5730: NATIONAL 5730 (pregelatinized waxy corn starch)

Ultra: ULTRA-CRISP CS (pregelatinized waxy corn starch)

Novelose: NOVELOSE 240 (resistant starch)

CHAPTER 4
Instrumental Characteristics of Rice Crackers and Their Correlations with Sensory Assessment

Abstract

The textural properties of seven different formulations of the rice crackers including the control made from 100% rice flour, 3.0%, 4.0%, and 5.0% of each NATIONAL 5730 and ULTRA-CRISP CS addition were evaluated by both quantitative descriptive analysis (QDA) and the texture instrument with Warner bratzer shear press. Sensory and instrumental data were then compared and correlated using partial least squares (PLS) technique. Sensory hardness was the best successfully described by the instrumental hardness. NATIONAL 5730 was the most appropriate starch to display an important role to decrease hardness of rice crackers. The control, rice crackers mixed with 3.0% and 4.0% of NATIONAL 5730 clustered together in the same region of hardness variables (sensory and instrumental). The rice crackers mixed with 4.0% National 5730 was significant difference ($p<0.05$) from the control as indicated by both instrumental and sensory hardness. Moreover, the more additional modified starches, the more reduction of hardness obtained. Finally, the rice crackers mixed with 5.0% NATIONAL 5730 exhibited the best potential starch to diminish the hardness of rice crackers.

Keywords: rice cracker, quantitative descriptive analysis, instrumental measurement, partial least squares, modified starch

Introduction

The texture is one of the most significant quality characteristics of the rice crackers since texture contribute a dominant overall quality and acceptability. The texture of rice crackers depends on several factors including raw material and baking conditions. Packaging, storage conditions, and time are also important factors directly affecting the textural characteristics. The freshness and shelf life of rice crackers intimately related to its texture and properties, that normally are evaluated using textural measurements (Kayacier and Singh, 2003).

Texture of food products can be measured by two different procedures, normally including first instrumental analysis and secondly sensory evaluation. The use of instrumental analysis is more convenient than that of sensory evaluation due to easy to perform, simple to reproduce, and less time consuming (Kayacier and Singh, 2003). In contrast, the sensory evaluation is not only time-consuming but also costly, therefore, most researches tend to use the instrumental measurements and attempt to relate those measurement parameters to the real sensory. In such a case, it is crucial to extract and identify instrumental measurements that correlate best to the sensory attributes of interest. Partial least squares regression (PLS) technique presently serves for that statistical purpose well. PLS is a soft modeling technique used to compare two sets of data by seeking out the latent variables common to both data sets (Lee et al., 1999).

In this study, the effects of various modified starches on the textural properties of rice crackers were conducted to perform using both sensory methodology and instrumental measurements. For sensory evaluation, a quantitative descriptive analysis method was selected (Stone and Sidel, 1993). This methodology provides quantitative descriptions of products based on the perceptions of a group of qualified subjects. On the other hand, the instrumental measurements using texture analyzer connected with Warner blatzer blade set was used to measure some interested texture parameters.

The objectives of this study were to investigate the effects of various modified starches on physical attributes of rice crackers using both sensory and instrumental methods. The second, attempt to correlate and compare the sensory and instrumental measurements to identify the instrumental parameters that potentially best correlated to the critical sensory variables.

Materials and Methods

After that, rice crackers mixed with NATIONAL 5730, NATIONAL 687 and ULTRA-CRISP CS at 2.5% including the control were sensory evaluated via preference ranking method for selecting the optimal modified starch in rice cracker production, exhibited no significant difference among treatments ($p>0.05$), this might be due to sensory panelists were not able to distinguish a little different between each rice cracker sample while the texture analyzer was able to detect it. Therefore, we needed to select all three modified starches but NATIONAL 687 rendered the dough sticky and difficult to handle, so removed it out. Finally, the remaining modified starches were NATIONAL 5730 and ULTRA-CRISP CS, the use of higher additional levels such as 3.0%, 4.0%, and 5.0% were essential to investigate for further determine suitable formula in rice cracker production.

Raw materials

Jasmine rice flour was obtained from Namchow (Thailand) Ltd. and 2 commercial starches were used as the supplemented raw material in this experiment. Commercial starches consisting of NATIONAL 5730 and ULTRA-CRISP CS (pregelatinized waxy corn starch) obtained from National Starch and Chemical (Thailand) Co., Ltd.

Thin rice cracker production

A 2.5 kg of milled rice flour containing moisture content about 28-30% was hydrated and steamed for 1.5 hr. The final moisture content of rice dough was controlled approximately 45%. The dough was consequently kneaded using the two arms mixer for 10 min, and then shaped into thin sheet like paper with approximately 1-2 mm of thickness using the roller machine. The sheeted dough was cut into circle pellets by the stainless mould with 48-mm in diameter. The fresh-cut pellets were continuously oven-dried for 60-90 min at 75-80^{o}C until 10-12% of moisture content was obtained. Once, the pellets had over-specified moisture contents, they must be rejusted to retain the desirable moisture at 40-50^{o}C. The dried pellets were continuously baked at 200-250^{o}C for 1-2 min. Rice cracker was kept in aluminum foil bag for 2 days before randomly selected for further analysis. Modified starches were utilized as partial substitution of rice flour at 3 different levels (3.0%, 4.0%, and 5.0%) by blending with other dry ingredients before steaming step.

Sensory evaluation

Sample preparation

Baked samples were kept for 3 days and then randomly selected for sensory evaluation. Two pieces of each sample were served in plastic cups at room temperature (30^{o}C) and 2.00 pm. The plastic serving cups were labeled with 3 digit random codes.

Sensory method

Quantitative descriptive analysis. A total 10 trained panels consisting of 7 females and 3 males were recruited for this study. Panelists were selected on the following criteria:ages between 22 to 30, interest in participating, able to verbally communicate about the products and good dentition. They were advised not to eat, drink (except for water) or smoke for at least 1 h prior to a session. Definitions and techniques of textural attributes used by the trained panel to describe rice crackers were presented in Table 4.1. All samples were evaluated in partitioned booths for individual test and the use of normal light. Panelists evaluated 7 samples at once with 3 replications. Between each sample evaluation, the panels needed to rinse their mouth with pure water.

Textural measurement

Texture of rice crackers was measured using the texture analyzer (Model:TA-XT 2i, Stable Micro System Co. Ltd.,UK) with a warner bratzer blade set. The probe traveled at pre-test speed of 5 mms^{-1}, test speed of 5 mms^{-1} to a distance of 30 mm and post-test speed of 10 mms^{-1}. Each texture parameter was calculated based upon an average of ten replications. Data collection and analysis were accomplished by software of TA.XT2i analyzer (Texture Expert Version 1.22). The instrumental parameters of the shear test were calculated as hardness and shear stress.

Bulk density determination

The bulk volume was measured using the sand replacement technique in which the sand was used as the substitution of ten pieces of rice cracker and measured the volume of sand via the use of 100 ml cylinder. Bulk density, ρ_b (g/ml), was then calculated by dividing the weight of the crackers by their bulk volume. The test was performed in triplicate.

Expansion ratio

The bulk volume was measured using the sand replacement technique as previously described. Expansion ratio was calculated by dividing the bulk volume of cracker by the bulk volume of pellet.

Statistical analysis

All data were performed using the General Linear Model of the Statistical Analysis System software version 8.1, SAS Institute, Inc., Cary, NC, USA (SAS, 2001). Significant calculated means were compared by least significant difference (LSD) at 95% confidence level.

Specific attributes and formulation samples relationships were statistically modeled using partial least squares (PLS) by Win-DAS software. The matrices of attributes and formulation samples were combined to perform the mapping (Lee et al., 1999).

Results and Discussion

1. Instrumental and Sensory Evaluation

According to the textural test by sensory evaluation for all seven different formulations of rice crackers consisting of 3 major attributes including hardness, firmness, and stickiness whereas an instrumental analysis identified only hardness and shear stress due to the standard deviation was so high in the texture data profile. It might be resulted in the fluctuation of firmness and stickiness with respect to the high variation of the calculated area under curves.

The mean values for the sensory attribute ratings from the quantitative descriptive analysis were presented in Table 4.2. The control sample (rice cracker with 100% rice flour) had the most hardness while the additional NATIONAL 5730 imparted lower hardness with an increase in amount of addition, the use of additional 3.0%, 4.0%, and 5.0% NATIONAL 5730 effectively reduced the hardness of the rice crackers up to 1.86%, 10.04%, and 20.07%, respectively. The use of ULTRA-CRISP CS at 3.0%, 4.0%, and 5.0% also potentially decreased the hardness up to 3.72%, 7.06%, and 18.96%, respectively, as compared with the control. According to the firmness, an increment of NATIONAL 5730 and ULTRA-CRISP CS (3.0-5.0%) levels dramatically decreased the firmness of products about 5.62-11.61%. Regarding to the stickiness, the sensory panelists were not able to distinguish a little difference between each formulation due probably to the presence of saliva. The low moisture cracker tending to absorb the saliva during mastication resulted in the confusion of sensory evaluation (Gaines, 1994).

In addition, amylose to amylopectin ratio apparently influenced the textural properties of the finished product, so the optimum of amylose and amylopectin contents would increase the expansion rate and reduce the hardness of products. The waxy type starches promoted puffing and retain an extremely light, and fragile products (Feldberg, 1969), whereas jasmine rice flour containing amylose content about 14-20% exhibited hard and rough in texture of the rice crackers (Pongsawatmanit, 2000). Therefore, both of NATIONAL 5730 and ULTRA-CRISP CS modified from waxy corn starch with high amylopectin could improve the expansion ability and intimately reduced the hardness of the rice crackers. This also confirmed the researches of Kadan et al. (1997, 2001). They also reported that the degree of hardness was positively correlated to the amylose content. Rice-based fries from waxy rice had very low hardness compared to non-waxy rice. Moreover, NATIONAL 5730 and ULTRA-CRISP CS as pregelatinized starches which the loss of granular integrity and high water absorbability, consequently, it allowed the expansion process to begin earlier and an increase in the expansion rate affected to soften the rice cracker textural characteristics (Huang, 1995). Accordingly, the expanded chips expressed an increase in volume with high degree of extent of gelatinization (Case et al., 2001; Kawas and Moreira, 2001).

Results from the instrumental measurements were summarized in Table 4.3.

The control being the hardest (13.64 N/g) , followed by rice crackers mixed with each 3.0%, 4.0%, and 5.0% of modified starch, respectively. The additional NATIONAL 5730 at 3.0%, 4.0%, and 5.0% provided to decrease the hardness about 10.92%, 15.32%, and 21.55%, respectively while the use of ULTAR-CRISP CS at the same levels also diminished the hardness up to 9.16%, 18.18%, and 24.93%, respectively, as compared to the control. Besides, the shear stress decreased with higher NATIONAL 5730 and ULTRA-CRISP CS usage.

The hardness showed the same tendency between the instrumental and the sensory measurements. However, the instrumental hardness of rice crackers mixed with each NATIONAL 5730 and ULTRA-CRISP CS at 3.0%, 4.0%, and 5.0% significantly differed from the control. But the significantly sensory hardness was observed from the additional at 4.0% and 5.0% as compared to the control. This might be due to undetectable the sensory of each panelist to notify the differentiation among test samples, whereas the instrumental texture analyzer more potentially be useful to detect these different.

2. Expansion Ratio and Bulk Density of Rice Crackers

The expansion ratio and the density of rice cracker with various starch additions was presented in Table 4.4. As the additional levels of both modified starches increased, the expansion ratio elevated and the bulk density inversely decreased. Particularly, the expansion ratio of the rice crackers mixed with 4.0% of each NATIONAL 5730 and ULTRA-CRISP CS significantly incremented 14.68% and 10.71%, respectively. The additional 5.0% of NATIONAL 5730 and ULTRA-CRISP CS also increased the expansion ratio up to 23.02% and 16.67%, respectively, as compared to the control. Furthermore, the rice crackers mixed 4.0% NATIONAL 5730 significantly decreased the bulk density 5.59%. The additional NATIONAL 5730 and ULTRA-CRISP CS at 5.0% also reduced the bulk density 8.94% and 7.54%, respectively, as compared to the control.

3. Relationship Between Sensory Attributes and Instrumental Parameters

Partial least squares (PLS) analysis was performed in order to relate the 2 different data sets. First, the biplot of PLS factor 1 versus PLS factor 2 from the PLS of the matrix of sensory attributes across the starch formulations was shown in Fig. 4.1. In total, this biplot explained 49.26% of the sensory attributes and 49.07% of the formulations. It can be observed that the additional NATIONAL 5730 in the rice cracker exhibit the most potential starch source to decrease the hardness while the other formulations exhibited negatively correlated with the hardness. However, the rice crackers mixing with 3.0% ULTRA-CRISP CS were firmer, 4.0% and 5.0% of the use of ULTRA-CRISP CS showed potentially to retain the stickiness of finish product. For the biplot of instrumental parameters across the formulations was presented in Fig. 4.2. About 89.87% of the variance of the formulations and 59.59% of the variance of the instrumental parameters were explained by first two PLS factors. The correlation of formulations with the hardness attribute was similar to sensory results. That was the use of NATIONAL 5730 provided the best correlation to the instrumental hardness whereas the rice crackers mixed with ULTRA-CRISP CS contributed the best correlation to the shear stress.

PLS correlation with all the sensory and instrumental variables was carried out (Fig. 4.3). In total, this biplot explained 49.26% of the sensory attributes and 59.59% of the instrumental variables. It seemed that the sensory hardness was highly correlated with an instrumental hardness. Consequently, the hardness texture map of all formulations between sensory and instrumental measurements was conducted in Fig. 4.4. It was clearly noticed that this biplot that the rice crackers with the same additional levels and types of modified starches from two measuring methods clustered together. About 97.43% of the variance of the formulations from instrumental measurement and 73.60% of the variance of the formulations from sensory evaluation were explained by the first two PLS factors. Finally, the use of

5.0% NATIONAL 5730 the most effectively reduced the hardness of the rice crackers.

Conclusions

The seven different formulations of rice crackers were investigated in this study by means of the sensory and the instrumental measurements. Both sensory and instrumental results exhibited that the hardness decreased with higher additional levels of modified starches and correlated also negatively with the expansion ratio, positively with the bulk density. However, as compared to the control in the hardness attribute, the instrument was sensitively able to detect significant difference from 3.0% additional level and up while sensory panels were occasionally able to distinguish from 4.0% additional level and up. A combination of the instrumental parameters and the sensory attributes in PLS exhibited sensory hardness was directly related to the instrumental hardness. Therefore, the hardness was the major and important attribute for the rice cracker quality improvement. PLS technique was an excellent tool to select the appropriate sensory and instrumental variables that were highly correlated (Hough, 1997; Lee et al., 1999).

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Table 4.1 Definitions and techniques for sensory textural attributes of rice crackers

Textural attributes	Definition	Technique
Hardness	The force required to compress the sample.	Compress or bite sample one time with molars until fracture.
Firmness	The work required to cut sample.	Compress or bite sample one time with molars until cutting.
Stickiness or Toothpack	The amount of product packed into the crowns of your teeth after mastication.	Chew sample 10-15 times, expectorate and feel the surface of the crowns of the teeth to evaluate.

Source: adapted from Grosso and Resurreccion (2002); Lenjo and Meullenet (2000)

Table 4.2 The mean sensory attributes rating from the quantitative descriptive analysis[1]

Treatment[2]	Hardness	Firmness	Stickiness
Control	2.69 ± 0.17[a]	2.67 ± 0.32[a]	2.61 ± 0.21[a]
3% NATIONAL 5730	2.64 ± 0.19[a]	2.52 ± 0.31[ab]	2.60 ± 0.16[a]
4% NATIONAL 5730	2.42 ± 0.23[c]	2.37 ± 0.40[bc]	2.57 ± 0.11[a]
5% NATIONAL 5730	2.15 ± 0.32[d]	2.42 ± 0.28[bc]	2.65 ± 0.14[a]
3% ULTRA-CRISP CS	2.59 ± 0.29[ab]	2.49 ± 0.23[bc]	2.58 ± 0.17[a]
4% ULTRA-CRISP CS	2.50 ± 0.21[bc]	2.40 ± 0.28[bc]	2.63 ± 0.17[a]
5% ULTRA-CRISP CS	2.18 ± 0.22[d]	2.36 ± 0.29[c]	2.61 ± 0.20[a]

1 = Means in the same column with different letters were significantly different ($p<0.05$)

2 = Commercial name

Table 4.3 Instrumental evaluation of rice crackers with various starch additions[1]

Treatment[2]	Hardness (N/g)	Shear stress ($x10^{-2}$ N/g.mm^2)
Control	13.64 ± 1.77[a]	5.49 ± 0.72[a]
3% NATIONAL 5730	12.15 ± 1.53[bc]	4.81 ± 0.64[bc]
4% NATIONAL 5730	11.55 ± 1.49[cd]	4.60 ± 0.59[cd]
5% NATIONAL 5730	10.70 ± 1.47[ef]	4.24 ± 0.57[e]
3% ULTRA-CRISP CS	12.39 ± 2.08[b]	4.90 ± 0.81[b]
4% ULTRA-CRISP CS	11.16 ± 1.32[de]	4.42 ± 0.53[de]
5% ULTRA-CRISP CS	10.24 ± 1.28[f]	4.15 ± 0.51[e]

1 = Means in the same column with different letters were significantly different ($p<0.05$)

2 = Commercial name

Table 4.4 Physical attributes of rice crackers with various starch additions[1]

Treatment[2]	Expansion Ratio	Bulk Density (g/ml)
Control	2.52 ± 0.09^{d}	0.36 ± 0.01^{a}
3% NATIONAL 5730	2.62 ± 0.05^{cd}	0.34 ± 0.01^{abcd}
4% NATIONAL 5730	2.89 ± 0.05^{b}	0.34 ± 0.02^{bcd}
5% NATIONAL 5730	3.10 ± 0.12^{a}	0.33 ± 0.01^{d}
3% ULTRA-CRISP CS	2.63 ± 0.13^{cd}	0.35 ± 0.01^{ab}
4% ULTRA-CRISP CS	2.79 ± 0.08^{bc}	0.35 ± 0.01^{abc}
5% ULTRA-CRISP CS	2.94 ± 0.12^{ab}	0.33 ± 0.01^{cd}

1 = Means in the same column with different letters were significantly different ($p<0.05$)

2 = Commercial name

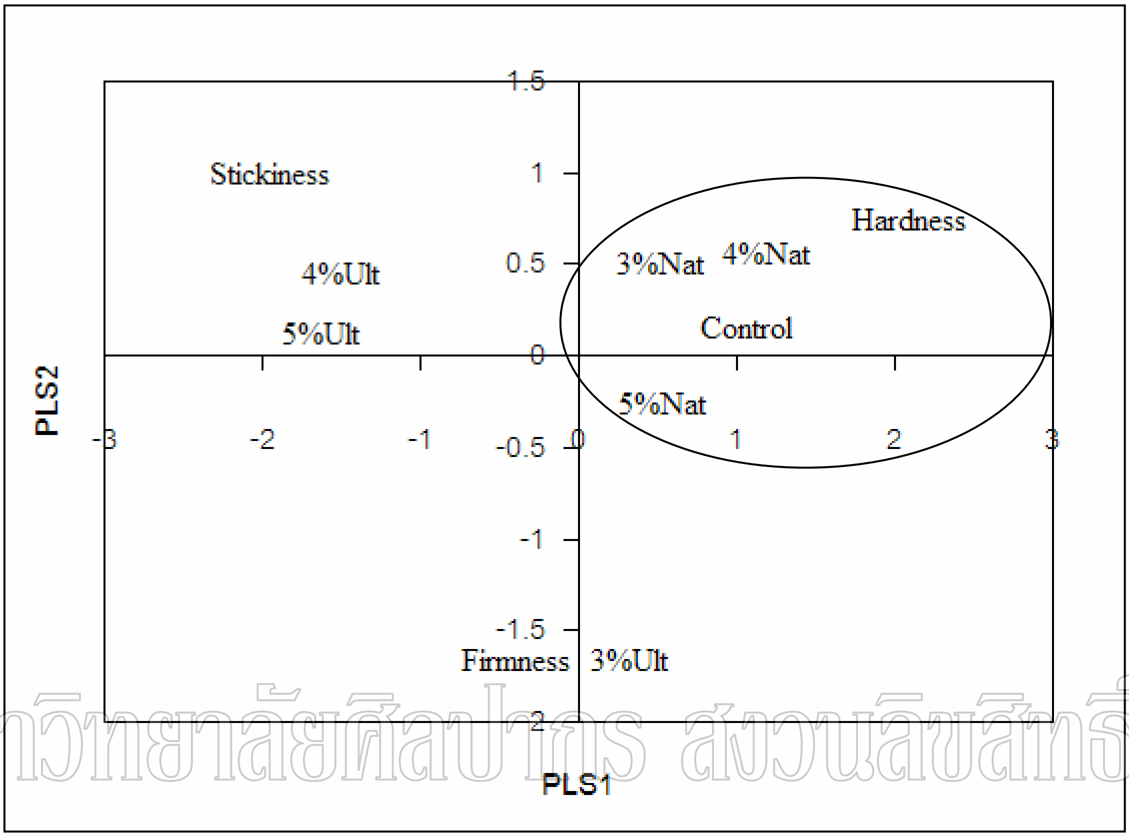


Fig. 4.1 Correlation coefficients expressed the PLS X-scores of the sensory attributes, and the formulations. Sensory attributes explained: 31.94%, 17.32% and formulations explained: 29.76%, 19.31%.

Nat: NATIONAL 5730 (pregelatinized waxy corn starch)

Ult: ULTRA-CRISP CS (pregelatinized waxy corn starch)

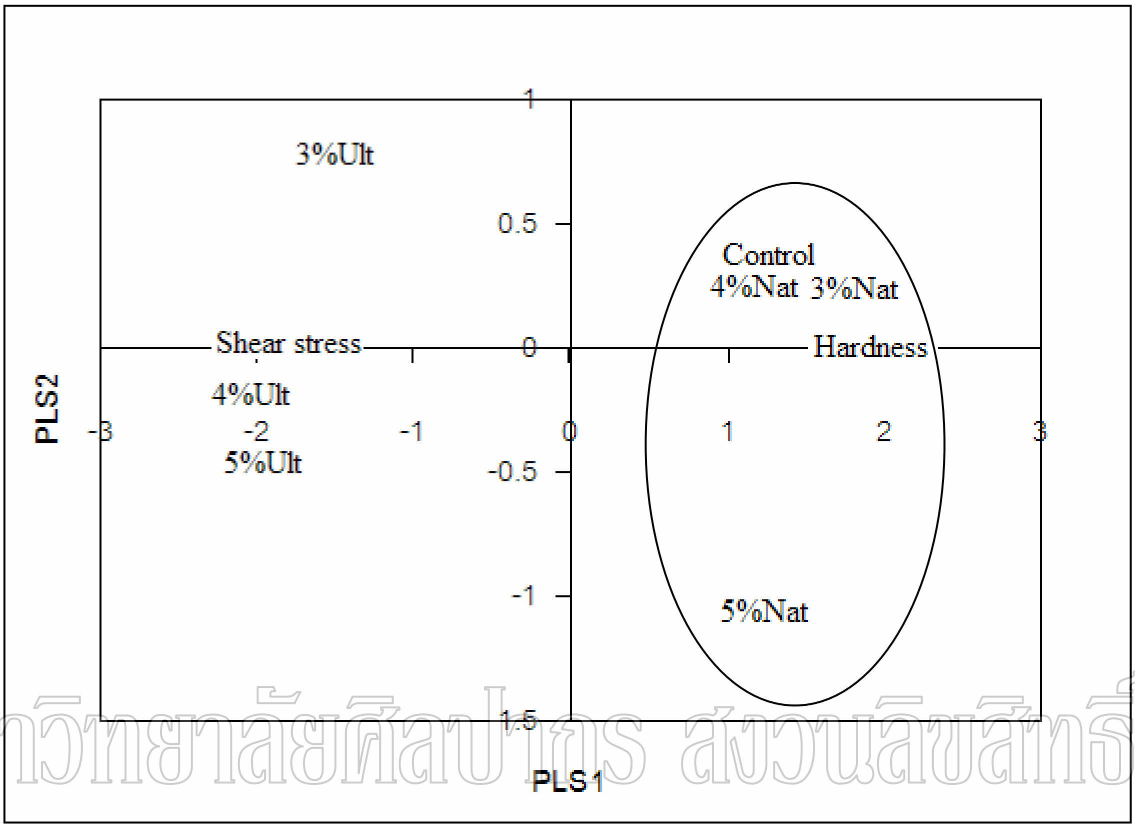


Fig. 4.2 Correlation coefficients expressed the PLS X-scores of the instrumental parameters, and the formulations. Instrumental parameters explained: 49.20%, 10.39% and formulations explained: 68.30%, 21.57%.

Nat: NATIONAL 5730 (pregelatinized waxy corn starch)

Ult: ULTRA-CRISP CS (pregelatinized waxy corn starch)

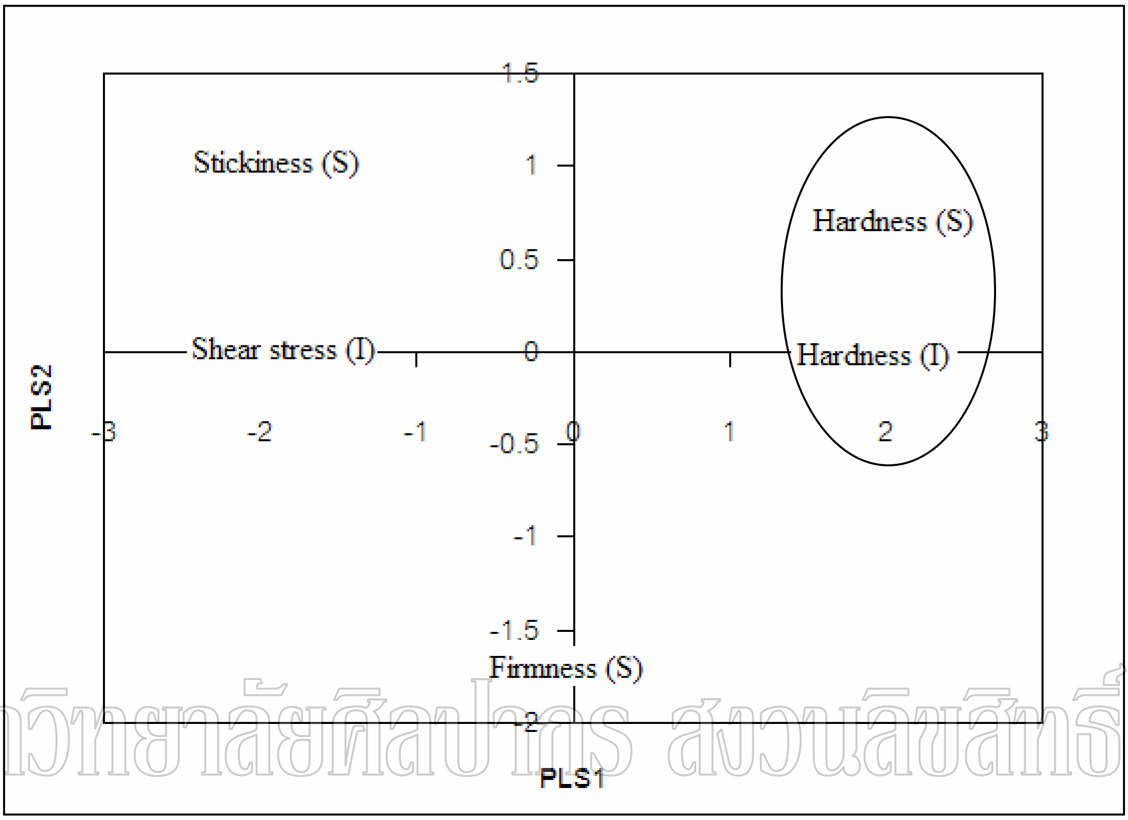


Fig. 4.3 Correlation coefficients expressed as the PLS X-scores of the sensory attributes, and the instrumental parameters. Sensory attributes explained: 31.94%, 17.32% and instrumental parameters explained: 49.20%, 10.39%.

S: Sensory evaluation

I: Instrumental measurement

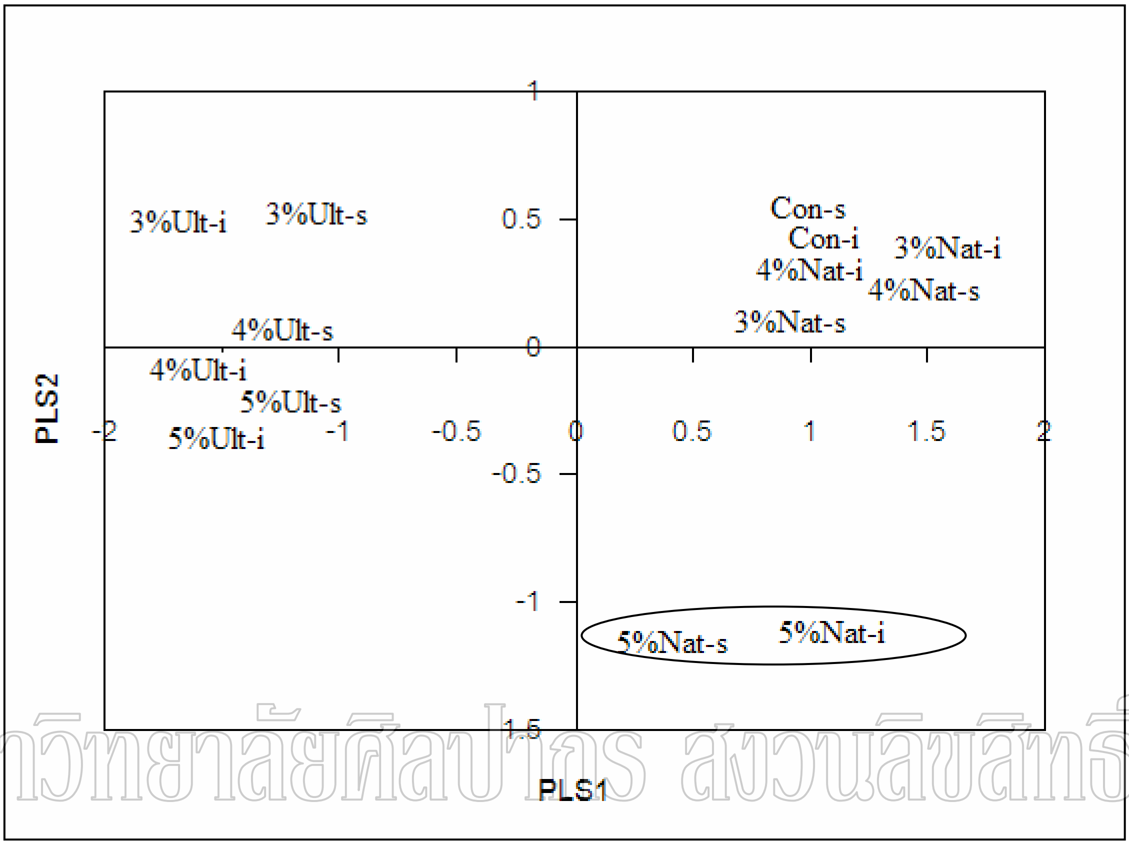


Fig. 4.4 Correlation coefficients of hardness attribute expressed as the PLS X-scores of the sensory, and the instrumental formulations. Sensory formulations explained: 47.57%, 26.03% and instrumental formulations explained: 66.28%, 31.15%.

Nat: NATIONAL 5730 (pregelatinized waxy corn starch)

Ult: ULTRA-CRISP CS (pregelatinized waxy corn starch)

s: Sensory evaluation

i: Instrumental measurement

CHAPTER 5
Summary

Rice crackers made from nonglutinous rice flours were too hard, so the purposes of this research were to investigate the effects of partial substitution of rice flour with various modified and native starches (1.5%, 2.5%, and 5.0%) on the physical properties of rice crackers. At the additional 2.5% and 5.0% of some pregelatinized starches were able to improve the texture of rice crackers and intensively decrease the instrumental hardness and the bulk density, and increase the expansion ratio. Whereas mixing of chemical modified starches such as cross-linked starch, acetylated cross-linked starch and hydroxypropylated cross-linked starch resulted in more tough texture than native starches. Moreover, at highest mixing level of native tapioca starch exhibited brittle texture of rice crackers. Regarding to the use of resistant starch, it substantially increased both hardness and bulk density. Pregelatinized starches, therefore, were selected for further study in the rice cracker improvement.

Consumer acceptance, however, is so important aspect. Consequently, sensory evaluation by preference ranking method was used to select the appropriate modified starch. Among rice crackers mixed with 2.5% of each selected pregelatinized starches consisting of NATIONAL 5730, NATIONAL 687 and ULTRA-CRISP CS and then compared the results to the control. The experiment indicated that all treatments were not significant difference on consumer acceptance. Higher additional levels (3.0%, 4.0%, and 5.0%) each of NATIONAL 5730 and ULTRA-CRISP CS were used to study sensory characteristics and correlated them with instrumental parameters in the same textural attributes. Regarding to preliminary study, the NATIONAL 687 was finally discard from the list since the dough with NATIONAL 687 provided too sticky, and difficult to form the thin sheet.

Investigation between sensory (QDA) and instrumental (Warner bratzer shear test) textures of rice crackers showed that both sensory and instrumental hardness, and bulk density significantly decreased, and expansion ration increased with an increase in concentration usage. Regarding to PLS technique by the comparison of instrumental parameters and sensory characteristics, the sensory hardness positively related to the instrumental hardness. Therefore, the hardness was an important and major quality attribute for the rice cracker quality improvement. NATIONAL 5730 was the most selected starch with respect to hardness. Conclusively, the use of 5.0% NATIONAL 5730 exhibited the most powerful reduction ability in hardness of the rice crackers.

Recommendations for Further Study

1. NATIONAL 687 potentially tended to decrease the hardness of the rice crackers, so it would be the most interesting one to partially use for textural improvement because it was modified from tapioca starch that domestically be available and cheap. But the highly additional NATIONAL 687 retained the sticky dough and difficult to handle, consequently, we should to improve the dough properties for less stickiness and feasible sheeting, for example,
    - Moisture adjustment of the dough to be less than 45%
    - The addition of plasticizers such as glycerol and sorbitol in the formulation
2. The attemption to use of the other native starches except tapioca and waxy corn starch to improve texture of rice crackers such as potato starch. Since the granules of potato starch are large and shows great swelling power, therefore, it may be well expand and less hardness of rice crackers.
3. Alternative improvement technique is to use the other modified starches, except the used starches in this experiment such as acid-modified starch, oxidized starch, and dextrin.

APPENDIX A

SPECIFICATION OF MODIFIED STARCHES

GELPRO M (cross-linked tapioca starch)

Parameters	**Methods**	**Standard Value**
Appearance	Visual	White powder
Water content	10 g/1 h/130^{o}C	10.00-13.50%
pH Value	20%, 25^{o}C	5.00-6.50
Ash	Incinerated at 575^{o}C	0.20% maximum
Sieve test	Pass through 100 mesh	99.50% minimum
Fiber content	100 g/200 mesh	0.30 cc maximum
SO_2 content	Volumetric	30 ppm maximum
Viscosity	Brabender viscometer	
	27 g/450 ml H_2O at 95^{o}C	560-740 BU
	at 95^{o}C + 20 min	610-790 BU
Microbiology	Total plate count	10,000 cols./g maximum
	Yeast	100 cols./g maximum
	Mold	100 cols./g maximum
	E. coli	Negative/25 g
	Samonella	Negative/100 g
Packaging	Multiply paper bags of 25 kg net weight	
Storage condition	Store under dry conditions in sound, closed bags	
Shelf life	12 months	

GELPRO 40M (**low acetylated cross-linked tapioca starch**)

Parameters	**Methods**	**Standard Value**
Appearance	Visual	White powder
Water content	10 g/1 h/130^{o}C	10.00-13.00%
pH Value	20%, 25^{o}C	5.00-6.50
Ash	Incinerated at 575^{o}C	0.20% maximum
Sieve test	Pass through 80 mesh	99.50% minimum
Fiber content	100 g/230 mesh	0.30 cc maximum
SO_2 content	Volumetric	30 ppm maximum
Viscosity	Brabender viscometer	
	27 g/450 ml H_2O at 95^{o}C	500-700 BU
	at 95^{o}C + 20 min	600-800 BU
Microbiology	Total plate count	10,000 cols./g maximum
	Yeast	100 cols./g maximum
	Mold	100 cols./g maximum
	E. coli	Negative/25 g
	Samonella	Negative/100 g

Packaging	Multiply paper bags of 25 kg net weight
Storage condition	Store under dry conditions in sound, closed bags
Shelf life	12 months

GELPRO AC50 (**medium acetylated cross-linked tapioca starch**)

Parameters	**Methods**	**Standard Value**
Appearance	Visual	White powder
Water content	10 g/1 h/130^oC	10.00-13.50%
pH Value	20%, 25^oC	5.00-7.00
Ash	Incinerated at 575^oC	0.20% maximum
Sieve test	Pass through 100 mesh	99.50% minimum
Fiber content	100 g/200 mesh	0.30 cc maximum
SO_2 content	Volumetric	30 ppm maximum
Viscosity	Brabender viscometer	
	27 g/450 ml H_2O at 80^oC	350-550 BU
	at 95^oC	400-600 BU
	at 95^oC + 20 min	450-650 BU
Microbiology	Total plate count	10,000 cols./g maximum
	Yeast	100 cols./g maximum
	Mold	100 cols./g maximum
	E. coli	Negative/25 g
	Samonella	Negative/100 g

Packaging	Multiply paper bags of 25 kg net weight
Storage condition	Store under dry conditions in sound, closed bags
Shelf life	12 months

GELPRO HC30 (**low hydroxypropylated cross-linked tapioca starch**)

Parameters	**Methods**	**Standard Value**
Appearance	Visual	White powder
Water content	10 g/1 h/130^{o}C	10.00-13.50%
pH Value	20%, 25^{o}C	5.00-7.00
Ash	Incinerated at 575^{o}C	0.20% maximum
Sieve test	Pass through 100 mesh	99.50% minimum
Fiber content	100 g/200 mesh	0.30 cc maximum
SO_2 content	Volumetric	30 ppm maximum
Viscosity	Brabender viscometer	
	30 g/450 ml H_2O at 95^{o}C	300-400 BU
Microbiology	Total plate count	10,000 cols./g maximum
	Yeast	100 cols./g maximum
	Mold	100 cols./g maximum
	E. coli	Negative/25 g
	Samonella	Negative/100 g
Packaging	Multiply paper bags of 25 kg net weight	
Storage condition	Store under dry conditions in sound, closed bags	
Shelf life	12 months	

GELPRO HC48 (**medium hydroxypropylated cross-linked tapioca starch**)

Parameters	**Methods**	**Standard Value**
Appearance	Visual	White powder
Water content	10 g/1 h/130^{o}C	10.00-13.50%
pH Value	20%, 25^{o}C	5.00-7.00
Ash	Incinerated at 575^{o}C	0.20% maximum
Sieve test	Pass through 100 mesh	99.50% minimum
Fiber content	100 g/200 mesh	0.30 cc maximum
SO_2 content	Volumetric	30 ppm maximum
Viscosity	Brabender viscometer	
	30 g/450 ml H_2O at 95^{o}C	300-400 BU
Microbiology	Total plate count	10,000 cols./g maximum
	Yeast	100 cols./g maximum
	Mold	100 cols./g maximum
	E. coli	Negative/25 g
	Samonella	Negative/100 g

Packaging	Multiply paper bags of 25 kg net weight
Storage condition	Store under dry conditions in sound, closed bags
Shelf life	12 months

ULTRA-CRISP CS (pregelatinized waxy corn starch)

Physical and Chemical Characteristics:

Color	White to Off-white
Form	Fine powder
Taste	Bland
Granulation	
Thru USSS #200	> 50% typically
Moisture	14% maximum
pH (10% slurry)	3.0-4.0
Viscosity (CML-B113T)	
at 95^{o}C	600 BU minimum

Microbiological Specifications:

Total plate count	10,000 cols./g maximum
Yeast	200 cols./g maximum
Mold	200 cols./g maximum
E. coli	Negative
Samonella	Negative

Packaging and Storage

ULTRA-CRISP CS is packaged in four-ply, Kraft paper bags with a net weight of 50 lbs. We recommend that ULTRA-CRISP CS be stored in a clean, dry area at ambient temperature and away from heavily aromatic material. The shelf life for ULTRA-CRISP CS is 24 months from the date of manufacture.

NATIONAL 5730 (**pregelatinized waxy corn starch**)

Physical and Chemical Characteristics:

Color	White to Off-white
Form	Slightly coarse powder
Taste	Bland
Granulation	
On USSS #50	< 30% typically
Thru USSS #200	< 30% typically
Moisture	14% maximum
pH (10% slurry)	3.0-4.0
Viscosity (CML-B113T)	
Peak	600 BU minimum

Microbiological Specifications:

Total plate count	10,000 cols./g maximum
Yeast	200 cols./g maximum
Mold	200 cols./g maximum
E. coli	Negative
Samonella	Negative

Packaging and Storage

NATIONAL 5730 is packaged in four-ply, Kraft paper bags with a net weight of 50 lbs. We recommend that NATIONAL 5730 be stored in a clean, dry area at ambient temperature and away from heavily aromatic material. The shelf life for NATIONAL 5730 is 24 months from the date of manufacture.

NATIONAL 687 (pregelatinized tapioca starch)

Physical and Chemical Characteristics:

Color	White to Off-white
Form	Fine powder
Taste	Bland
Granulation	
On USSS #10	Trace
Thru USSS #100	> 95% typically
Thru USSS #200	> 70% typically
Moisture	14% maximum
pH (10% slurry)	3.0-4.0
Viscosity (CML-B113T)	
Peak	1300 BU minimum
Drop from peak	75% minimum

Microbiological Specifications:

Total plate count	10,000 cols./g maximum
Yeast	200 cols./g maximum
Mold	200 cols./g maximum
E. coli	Negative
Samonella	Negative

Packaging and Storage

NATIONAL 687 is packaged in four-ply, Kraft paper bags with a net weight of 55 lbs. We recommend that NATIONAL 687 be stored in a clean, dry area at ambient temperature and away from heavily aromatic material. The shelf life for NATIONAL 687 is 24 months from the date of manufacture.

NOVELOSE 240 (resistance starch)

Physical and Chemical Characteristics:

Color	White to Off-white
Form	Fine powder
Particle shape	Granular
Particle size (wet)	10-15 μm
Taste	Bland
pH (20% slurry)	4.5-7.5

Nutritional Composition

Available carbohydrate (glycemic starch)	59% maximum
Fiber (TDF)	40% minimum
Fat	< 1.0%
Protein	< 1.0%
Ash	< 1.0%
Calories	2.3-2.4 kcal/g

Microbiological Specifications:

Total plate count	10,000 cols./g maximum
Yeast	200 cols./g maximum
Mold	200 cols./g maximum
E. coli	Negative
Samonella	Negative

NOVELOSE 240 resistant starch will have a moisture content of approximately 12%. Analyses for the vitamin and mineral content of our starch products is not routinely run. In general, starches are considered to have little or no nutritional value for calcium, iron, potassium, vitamin A, thiamin, riboflavin, niacin or ascorbic acid. The sodium content of NOVELOSE 240 starch would be equivalent to that of the corn starch from which it is derived, typically 200 mg/100 g.

APPENDIX B
RAW MATERIAL ANALYSIS

Moisture Content (**A.O.A.C., 1995**)

In cooled and weighed aluminum can (provided with cover), previously heated to 130 ± 3^{o}C, accurately weigh ca 2 g well mixed sample. Uncovered sample and cover was oven-dried for 8-10 hr at 130 ± 3^{o}C until constant weight. And then cover sample while still in oven, transfer to desiccator, and weigh soon after reaching room temperature. Report loss in weight as moisture.

$$\text{Moisture content (\%)} = \frac{W_o - W_i}{W_o} \times 100$$

W_o = weight of sample before oven-drying
W_i = weight of sample after oven-drying

Swelling Power and Solubility (**Adapted from Schoch, 1964**)

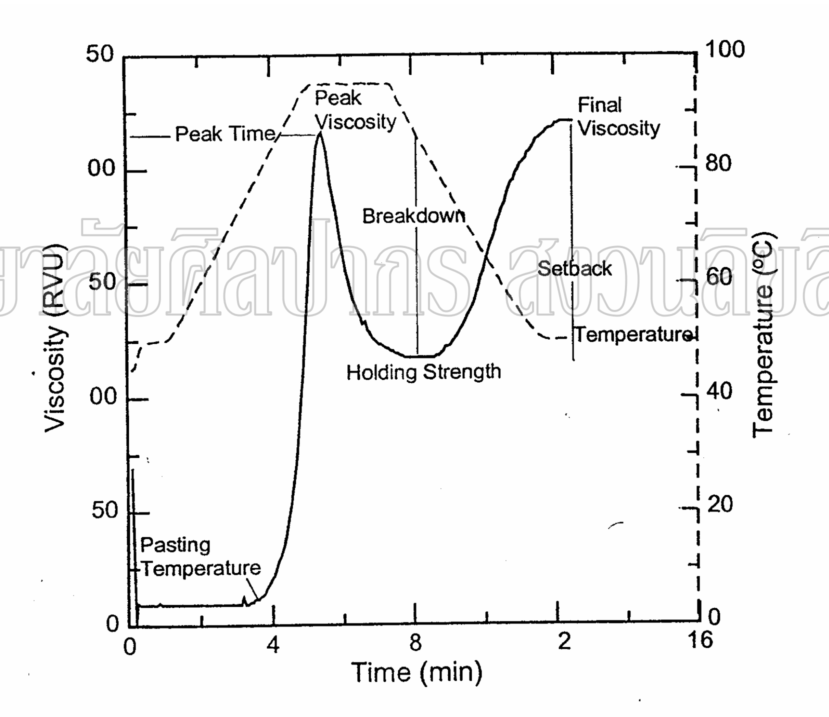
Starch (0.5 g d.b.) was heated with 15 ml of distilled water at 85^{o}C for 30 min. Lump formation was prevented by stirring. The mixture was centrifuged at 2,200 rpm for 15 min. The supernatant was decanted and the swollen starch sediment weighed. An aliquot of supernatant was evaporated overnight at 130^{o}C and weighed.

$$\text{Solubility (\%)} = \frac{\text{weight of the dried supernatant x 100}}{\text{weight of sample on dry basis}}$$

$$\text{Swelling power} = \frac{\text{weight of sedimented paste x 100}}{\text{weight of sample on dry basis x (100 - \% soluble, dry basis)}}$$

Viscoamylograph (**AACC, 1995**)

A Rapid Visco Analyzer (RVA) was used to determine the pasting properties of starch samples. 3.0 g starch sample (d.b.) and a weighed amount of distilled water were combined and stirred in the aluminum RVA sample canister to make a 12.0 % starch suspension (w/vol). A programmed heating and cooling cycle was used, where the sample was held at 50^{o}C for 1 min, heated to 95^{o}C in 3.8 min, held at 95^{o}C for 2.5 min, cooled to 50^{o}C in 3.8 min, and then held at 50^{o}C 1.4 min. Triplicate tests were used in each case. Parameters recorded were temperature at which peak viscosity was attained



Peak viscosity: highest viscosity during heating (RVU)

Peak time: time of peak viscosity (min)

Pasting temperature: initial temperature of viscosity changing (^{o}C)

Holding strength (trough): lowest viscosity during cooling (RVU)

Breakdown: difference between peak viscosity and holding strength (RVU)

Final viscosity: final viscosity of testing (RVU)

Setback: difference between final viscosity and holding strength (RVU)

APPENDIX C

PROPERTIES OF COMMERCIAL STARCHES

Initial moisture content

Starches	Moisture content (%)
Jasmine rice flour	28-30
Native tapioca starch	11.45
Native waxy corn starch	11.23
GELPRO M	11.62
GELPRO 40M	11.80
GELPRO AC50	11.21
GELPRO HC30	11.58
GELPRO HC48	12.22
NATIONAL 5730	11.58
NATIONAL 687	12.05
ULTRA-CRISP CS	6.25
NOVELOSE 240	12.98

Swelling Power and Solubility

Starches	Solubility (%)	Swelling power
Native tapioca starch	50.92 ± 3.85	10.23 ± 2.22
Native waxy corn starch	53.64 ± 7.47	5.66 ± 0.12
GELPRO M	14.38 ± 4.50	16.76 ± 0.89
GELPRO 40M	13.58 ± 1.81	15.33 ± 1.14
GELPRO AC50	5.04 ± 0.75	11.50 ± 1.09
GELPRO HC30	3.76 ± 0.04	10.42 ± 0.16
GELPRO HC48	4.60 ± 0.16	10.82 ± 0.35
NATIONAL 5730	74.37 ± 3.92	4.22 ± 0.52
NATIONAL 687	40.44 ± 8.94	5.82 ± 0.61
ULTRA-CRISP CS	54.31 ± 3.94	4.19 ± 1.35
NOVELOSE 240	1.53 ± 0.17	2.44 ± 0.04

Viscoamylograph

Starches	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temperature
Native tapioca starch	492.55 ± 17.12	216.83 ± 4.51	275.72 ± 21.26	298.78 ± 10.84	81.95 ± 10.77	4.16 ± 0.10	70.47 ± 0.81
Native waxy corn starch	364.53 ± 7.17	158.75 ± 3.11	205.78 ± 7.62	196.22 ± 2.53	37.47 ± 4.95	3.80 ± 0.00	73.15 ± 0.48
GELPRO M	595.28 ± 17.31	490.36 ± 17.40	104.92 ± 0.69	765.11 ± 4.94	274.75 ± 22.31	4.11 ± 0.03	69.68 ± 0.80
GELPRO 40M	525.47 ± 15.84	356.53 ± 9.30	168.94 ± 7.63	519.25 ± 14.61	162.72 ± 6.23	4.18 ± 0.04	66.22 ± 4.72
GELPRO AC50	577.70 ± 22.21	483.58 ± 21.81	94.11 ± 14.28	781.47 ± 18.16	297.89 ± 6.54	4.29 ± 0.10	68.40 ± 0.43
GELPRO HC30	597.81 ± 7.32	491.58 ± 8.67	106.22 ± 6.79	823.20 ± 17.69	331.61 ± 9.92	4.13 ± 0.07	69.75 ± 0.00
GELPRO HC48	641.72 ± 3.37	506.64 ± 6.04	135.09 ± 2.67	839.34 ± 11.36	332.69 ± 10.60	3.82 ± 0.04	65.22 ± 0.51
NATIONAL 5730	78.03 ± 21.34	9.03 ± 0.87	69.00 ± 20.56	12.58 ± 0.80	3.56 ± 0.10	1.78 ± 0.60	50.92 ± 1.24
NATIONAL 687	23.67 ± 7.19	8.83 ± 0.44	14.83 ± 6.95	15.28 ± 3.31	6.45 ± 2.87	1.38 ± 0.04	58.87 ± 7.94
ULTRA-CRISP CS	23.36 ± 7.15	14.69 ± 1.51	8.67 ± 5.70	21.33 ± 4.14	6.64 ± 2.91	4.89 ± 0.89	57.42 ± 8.23
NOVELOSE 240	1.61 ± 0.31	-0.97 ± 0.19	2.58 ± 0.30	-0.11 ± 0.26	0.86 ± 0.35	1.75 ± 0.24	77.95 ± 14.91

APPENDIX D
MOISTURE ADJUSTMENT OF DOUGH

Example of moisture adjustment

Supplementation of Gelpro M at 5.0% in total weight 2,500 g

Total weight of jasmine rice flour = 2,500 x 0.95 = 2,375 g

Total weight of Gelpro M = 2,500 x 0.05 = 125 g

Initial %mc. of jasmine rice flour = 28.50%, require to adjust for 45% mc.

Water content in flour = 2,375 x 28.50% = 676.88 g

Solid content in flour = 2,375 - 676.88 = 1,698.12 g

Total weight of dough = $\frac{1,698.12 \times 100}{55}$ = 3,087.49 g

Water content in dough = 3,087.49 - 1,698.12 = 1,389.37 g

Input water = 1,389.37 - 676.88 = 712.49 g

Input water available from 20%steam and added water

Water from stream = 712.49 x 20% = 142.50 g

Added water = 712.49 - 142.50 = 569.99 g

Initial %mc. of Gelpro M = 11.62%, require to adjust for 45% mc.

Water content in Gelpro M = 125 x 11.62% = 14.53 g

Solid content in Gelpro M = 125 - 14.53 = 110.47 g

Total weight of dough = $\frac{110.47 \times 100}{55}$ = 200.85 g

Water content in dough = 200.85 - 110.47 = 90.38 g

Input water = 90.38 - 14.53 = 75.85 g

Input water available from 20%steam and added water

Water from stream = 75.85 x 20% = 15.17 g

Added water = 75.85 - 15.17 = 60.68 g

Total weight of water for adjustment = 569.99 + 60.68 = 630.67 g

APPENDIX E
DEFINITION AND CALCULATION OF TEXTURAL PARAMETERS

Hardness

The force necessary to attain a given deformation in unit of N/g

Hardness = maximum force (peak force)

Normal stress

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

Normal stress = maximum force/probe area

$$\sigma = F/A$$

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

Normal strain = distance at maximum force/thickness of sample

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

Shear stress

The force per unit area acting in the direction parallel to the surface of the plane in unit of N/g.mm^2, this experiment used Warner Bratzler blade

Shear stress = maximum shear force/(2 x width x thickness of sample)

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

VITA

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2000	Highest education level: Bachelor degree
	Institute: King Mongkhut University of Technology Thonburi
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	Branch: Food technology