Development of Frozen Churros Added with Shrimp and Squid By-Products

Kantapit Mektun

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Food Science and Technology

Prince of Songkla University

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

………………………………….Signature

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Candidate

ชื่อวิทยานิพนธ์ การพัฒนาผลิตภัณฑ์ชูโรสแช่เยือกแข็งจากวัสดุเศษเหลือจากกระบวนการผลิตกุ้งและหมึก
ผู้เขียน นายกันตพิชญ์ เมฆทันต์
สาขาวิชา วิทยาศาสตร์และเทคโนโลยีอาหาร
ปีการศึกษา 2562

บทคัดย่อ

การวิจัยนี้มีวัตถุประสงค์เพื่อใช้ประโยชน์และสร้างมูลค่าเพิ่มแก่วัสดุเศษเหลือจากกระบวนการผลิตกุ้งและหมึก โดยการพัฒนาผลิตภัณฑ์ชูโรส ผลิตภัณฑ์ต้นแบบชูโรสจากการศึกษาแนวความคิดโดยวิธีเจาะจงกลุ่ม (Focus group) ประกอบด้วยแป้งสาลีอเนกประสงค์ร้อยละ 26.62, น้ำร้อยละ 44.37, เนยร้อยละ 19.52, ไข่ร้อยละ 3.55 และเกลือร้อยละ 0.62 โดยผู้บริโภคให้ความสนใจผลิตภัณฑ์ที่มีการเติมทั้งกุ้งและหมึก รวมถึงลักษณะเนื้อสัมผัสที่นุ่มไม่อมน้ำมัน

การศึกษาสัดส่วนของแป้งโด เศษกุ้งและเศษหมึกที่เหมาะสม โดยการทดลองแบบ Augmented Simplex Centroid พบว่าชูโรสผสมกุ้งและหมึกประกอบ ส่วนแป้งโด กุ้ง และหมึกเท่ากับร้อยละ 63.81, 17.51 และ 18.68 ตามลำดับ โดยมีค่า desirability เท่ากับ 0.72 และความคลาดเคลื่อนของการทดลอง (Experimental error) มีค่าเท่ากับร้อยละ 0.03 ถึง 0.11

ผลของชนิดและปริมาณของสารไฮโดรคอลลอยด์ที่เหมาะสมระหว่างการเก็บชูโรสแบบแช่เยือกแข็ง โดยเติมไฮดรอกซี โพรพิล เมทิล เซลลูโลส (HPMC) ร้อยละ 0.5-1 กัวกัม (GG) ร้อยละ 0.5-1 และแซนแทนกัม (XG) ร้อยละ 0.05-1 พบว่าการเติม XG ส่งผลให้ชูโรสมีค่าความแข็งที่สูงกว่าตัวอย่างอื่นๆอย่างมีนัยสำคัญ ($p < 0.05$) โดยการเติมไฮโดรคอลลอยด์ในผลิตภัณฑ์ยังส่งผลให้มีความหนาแน่นที่เพิ่มขึ้น (ปริมาตรจำเพาะน้อยลง) แต่ในทางกลับกันการเติมไฮโดรคอลลอยด์สามารถช่วยรักษาความชื้นของชูโรส ส่งผลให้ปริมาณไขมันของชูโรสลง โดยการเติม XG มีค่าปริมาณไขมันน้อยที่สุดตาม ตามด้วยการเติม GG และ HPMC ตามลำดับ อย่างไรก็ตามผลการทดสอบการยอมรับแสดงให้เห็นว่าการเติมสารไฮโดรคอลลอยด์ไม่ส่งผลต่อคะแนนความชอบของผลิตภัณฑ์ชูโรส

เมื่อนำผลิตภัณฑ์ชูโรสและชูโรสผสมกุ้งและหมึกมาเก็บรักษาที่อุณหภูมิ -20 องศาเซลเซียสเป็นเวลา 3 เดือนพบว่า การเติมสารไฮโดรคอลลอยด์สามารถช่วยรักษาค่าความแข็ง ปริมาตรจำเพาะ และความหนาแน่นของผลิตภัณฑ์ชูโรส ยกเว้นการเติม HPMC ที่ระดับร้อยละ 0.5 อีกทั้งภาพถ่ายจากกล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด (SEM micrograph) ยังแสดงให้เห็นว่าตัวอย่างชูโรสชุดควบคุม (ไม่เติมสารไฮโดรคอลลอยด์) มีช่องว่างอากาศขนาดใหญ่ในโครงสร้าง และโครงสร้างของกลูเตนถูกทำลายไปมากเมื่อผ่านการเก็บรักษาแบบแช่เยือกแข็งเป็นเวลา 3 เดือน

ขณะที่ตัวอย่างที่เติมสารไฮโดรคอลลอยด์มีการเปลี่ยนแปลงเล็กน้อย ผลการศึกษารีโทรเกรเดชันในผลิตภัณฑ์ซูโรสแสดงให้เห็นว่าตัวอย่างซูโรสชุดควบคุมมีค่าเอนทัลปีที่สูงกว่าตัวอย่างที่ผ่านการเติมไฮโดรคอลลอยด์ นอกจากนี้จากการศึกษาผลของการเก็บรักษาผลิตภัณฑ์ซูโรสที่มีการเติมกุ้งและหมึก พบว่า การเติมไฮโดรคอลลอยด์สามารถป้องกันและยืดอายุการเก็บรักษาผลิตภัณฑ์ได้ ถึงแม้ว่าปฏิกิริยาออกซิเดชันของลิพิดจะเพิ่มขึ้นจากค่า TBA ที่สูงขึ้นเมื่อผ่านการเก็บรักษาเป็นเวลา 3 เดือน แต่ก็ไม่ส่งผลอย่างมีนัยสำคัญทางสถิติ ($p > 0.05$) ต่อคะแนนความชอบของผลิตภัณฑ์

Thesis Title	Development of frozen Churros added with shrimp and squid by-products
Author	Mr. Kantapit Mektun
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ABSTRACT

In order to add value to shrimp and squid by-products from the seafood industry, a new Churros product was developed (shrimp and squid Churros). Focus group was performed to study attitude and the product concept from the consumers (n = 30). The data obtained was used as the input for designing the product. The consumers opined that the new Churros product should be incorporated with both shrimp and squid meat and the texture of Churros should be soft with less oiliness. The prototype dough of the Churros consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt.

The proportion of wheat flour dough (WF), shrimp by-product (Sh) and squid by-product (Sq) was optimized using Augmented Simplex Centroid design. The optimized formulation of shrimp and squid Churros with the highest desirability (0.72) was composed of 63.81% WF, 17.51% Sh and 18.68% Sq. The acceptance scores in appearance, odor, flavor, texture and overall linking of the product were 7.22, 7.44, 7.34, 6.99 and 7.33, respectively. The experimental errors of all values ranged from 0.03 to 0.11%.

Different hydrocolloid types and levels (0.5 and 1% Hydroxylpropyl methylcellulose (HPMC), 0.5 and 1% Guar gum (GG), and 0.05 and 0.1% Xanthan gum (XG)) were applied to basic Churros for improving its quality especially preventing starch retrogradation of the Churros during frozen storage at -20 °C. The result of samples without frozen storage showed that the sample with XG had higher hardness than other samples ($p < 0.05$). Churros had lower specific volume and higher density when added with hydrocolloids. XG addition had the highest moisture retention, followed by GG and HPMC added samples ($p < 0.05$), respectively. In addition, Churros samples containing XG had the lowest fat content, followed by those with GG, HPMC and the control. Nevertheless, overall acceptance scores of all samples were not impacted by all hydrocolloid additions ($p > 0.05$). After 90 days of frozen storage, the hardness, specific volume and density of Churros added with hydrocolloids were not affected by frozen storage time with exception of 0.5% HPMC. Scanning electron micrographs showed that microstructure of the control (without hydrocolloid) showed gluten network with bigger void than other samples. While, the Churros with GG and XG showed dense and impact of the gluten network. However, after 90 days of frozen storage, the frozen control dough showed damage to the gluten network. The structure of Churros with HPMC, GG and XG showed slightly change throughout storage time. Starch retrogradation with prolonged time of storage in frozen was also observed. After 90 days of frozen storage, the control had higher enthalpies than sample with hydrocolloids ($p < 0.05$). The effect of frozen storage on quality changes of shrimp and squid Churros was carried out. The acceptance results showed that addition of hydrocolloid could prevent deteriorated effect and extend shelf-life of shrimp and squid Churros. Despite the fact that lipid oxidation, especially TBA, value was increased after 90 days of frozen storage, it did not affect on consumer acceptance.

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Kantapit Mektun

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CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

1.1 Introduction

Thai seafood has been received worldwide recognition and has been consistently maintained several top positions in the seafood industry including the world's top exporter of frozen seafood, especially for shrimp and squid products. Over 90% of Thai frozen seafood is exported to meet a global demand that continues to increase every year. In 2019, Thailand earned US$ about 6 billion from international export of aquatic animals/products sales (Department of Fisheries, 2019). The major export markets include The United States, the European Union, Canada, China, Japan, South Korea and Taiwan (Department of International Trade Promotion, 2018).

The phenomenal growth of Thailand's seafood export industry, seafood processing especially shrimp and squid also generates a large quantities of by-products which accounts for 50 – 70% by total volume of raw materials, depending upon the species and processing methods (Joseph *et al*., 1987; Nidheesh *et al.*, 2015). These by-products are nutrient rich but are normally, produced a low value-products. Nowadays, several techniques have been developed for the exploitation and recovery of these by-products in highly valuable product. In order to be more competitive, the seafood industry has emphasized increased investment in upgrading seafood or specialty food processing technologies and creating more value-added.

Churros is a Spanish and Mexican pastry resembling a doughnut or cruller which is very popular in Europe for breakfasts and snacks**.** Apart from these countries, this pastry product also quickly gained popularity in South America, and United Kingdom with their sticky, oily charms. An original churros was very simple breadsticks made from flour, water and then deep fry. In Spain, the Churros was modified by rolling the breadsticks in sugar, creating a new sweet. Nowadays, Churros is found in several styles from traditional non-filled versions rolled in cinnamon and sugar to filled varieties such as chocolate or vanilla (Morales and Arribas-Lorenzo, 2008). In addition, more versions of the churros were created depend on each region to match their taste preferences.

Churros is similar to bread with a short shelf-life and is classified as perishable foods. To extend the shelf life of the product, frozen storage becomes more interested in bakery industry. However, frozen process have disadvantage due to its affecting on the product qualities. Cauvain (1998) reported that bakery product made from wheat starch typically involves with change in physicochemical properties during frozen storage such as increase crumb firmness in bread or cake, lose moisture to the atmosphere, loss of crispiness in biscuits by water absorption, loss of crumb firmness in cake when moisture migrates from cream fillings to cakes, increase crumbliness in bread when it lose cohesion and loss of flavor and aroma. In recent years, hydrocolloids have been increasing interest due to their natural origins and have also been satisfactorily used as antistaling agents in bread and bakery products.

Thus, the objectives of this study are aimed to develop value added Churros with a new concept by addition of shrimp and squid by-products and to investigate the effect of hydrocolloids on the qualities of developed Churros during frozen storage.

1.2 Review of Literature

1.2.1 Churros

Churros is a deep-fried dough pastry with cylindrical in shape and ridged surface (Mir-Bel *el al.*, 2013). This product is very popular in Spain for breakfasts and snacks. The dough of Churros is prepared from wheat flour, water and salt, then extruded by extruder and deep-fried as strips. The temperature for frying Churros is between 185 and 200 °C and frying times of 3–4 min. Generally, color and crust formation are used as end point markers of the process of the crispy product (Morales and Arribas-Lorenzo, 2008).

1.2.2 Effect of frozen storage on bread quality

Frozen breads prepared from frozen dough or part-baked bread usually have quality of final product lower than fresh bread in term of loss of the dough strength, decrease in the retention capacity of CO_2, longer fermentation time, reduced yeast activity, lowering of bread volume and deterioration in the texture of final product (Selomulyo and Zhou, 2007).

There are several major problems happen during frozen storage of dough as followed:

1.2.2.1 Dough strength

The gradual loss of dough strength is due to the reduction of gluten cross-linking. This can be explained by these two main factors. First, the release of glutathione, reducing substance, from yeast during freezing weakens the dough by cleaving disulphide bonds in the gluten proteins (Kline and Sugihara, 1968 and Hsu *et al*., 1979). Another factor is ice crystallization resulted in the weakening of the gluten protein network, thereby weakening the dough (Varriano-Marston *et al*., 1980). This was supported by the findings of Berglund *et al*. (1991) who observed that the formation of ice crystals affected to rapture of the gluten matrix, thereby network with less continuous, more ruptured and separated from starch granules. In addition, the starch granules were also affected by ice crystals during recrystallization influencing on the decreased ability of the gluten to retain gas during proofing. Gelinas *et al*. (1995) also supported that proteins properties of frozen dough impacted by ice crystallization which affected in poor gas retain of the dough led to decrease in loaf volume and increase in proof time of frozen dough.

Moreover, redistribution of the total water present in the system occurring during frozen storage damaged the starch in a linear increase in the water absorption capacity of flour. It was possible that water was drawn away from the gluten matrix by the starch granules. This was confirmed by Lu and Grant (1999) who reported that the amount of freezable water (the fraction of free water which did not bind to gluten during formation of the dough) in frozen dough increased when storage time increased. The results clearly indicated that there was a redistribution of the total water present in the system during frozen storage. The loss of the dough strength was due to disruption of the protein structure during frozen storage especially evident in scanning electron microscopy (SEM) measurement. Selomulyo and Zhou (2007) revealed that the control (unfrozen dough) measured immediately after mixing obtained a very dense structure with few spherical voids and the spherical starch granules firmly embedded in the gluten matrix without ice crystals. On the other hand, frozen storage dough for 24h showed a structure with a porosity, more spherical voids and angular voids. Moreover, ice crystals were formed upon storage.

Moreover, the glutenin proteins were denatured as indicated by SDS-PAGE. Kennedy (2000) found that the frozen-thawed dough had a weakening of protein as evidence by increasing the number of lower molecular weight oligomers. Ribotta *et al.* (2001) also supported that the amount of glutenin subunits of high molecular mass was decreased with increasing frozen storage time. Gluten structure and depolymerization of glutenin subunits of high molecular mass may be attributed to water redistribution, ice recrystallization and an increase in the amount of freezable water.

1.2.2.2 Dough syruping

The properties of bread are influenced by the amount of liquid released from the frozen dough during thawing. This liquid is also known as dough syruping. The doughs syrup is brownish liquid which migrates to the surface of the dough and diminishes quality of the bread. The main cause of dough syruping during frozen storage has been recognized to be arabinoxylan (AX) degradation by endogenous endoxylanase and the loss of water-holding capacity in the dough because of freezing and the subsequent thawing (Gys *et al*., 2003; Kim *et al.*, 2017). There are several researches studied about effect of dough syrup on bread quality. Gys *et al.* (2003) reported that dough syruping increased from 0% (fresh dough) to 22% of dough weight, reaching a plateau after 16 days of storage at 6 °C. Moreover, Seguchi *et al*. (2003) found that height and specific volume of bread were mainly influenced by amount of dough syruping. The amount of dough syruping was increased by freezing-and-thawing cycle and had an opposite relationship with bread quality.

1.2.2.3 Retrogradation

There are two major basic mechanisms including moisture loss and starch retrogradation, which are responsible for the firming of bread crumb. The bread firming (staling) in frozen bread products are related with the change in the crystalline state of starch present. The change after baking in starch crystalline structure during frozen storage is called starch retrogradation. This phenomena in starch contribute to firming in bread crumb (Zobel and Kulp, 1996). Davidou *et al*. (1996) suggested that the water redistribution and ice recrystallization in dough during storage time could induce the changes in the structure and arrangement of both amylose and amylopectin molecules. Therefore, water mobility affects to amylopectin recrystallization and the formation of hydrogen bonds between gluten and starch, which are deteriorated in bread qualities.

Miles *et al.* (1985) and Ring *et al.* (1987) explained that both amylose and amylopectin had unique roles in the retrogradation of starch. In the short-term of storage, retrogradation is influenced by amylose, while the long-term retrogradation is effect by the reordering of amylopectin. This is a much slower process involving mainly the recrystallization of the outer branched-chains of amylopectin.

1.2.2.4 Hydrocolloids

Hydrocolloids or gums are a diverse group of long chain polymers. The main property depends on ability of forming viscous dispersions or gels when dispersed in water. The presence of a large number of hydroxyl groups noticeably results in binding water molecules which make them hydrophilic compounds. Besides, they produce a dispersion which has colloid particles spread throughout water creating the properties of a colloid. Among these two properties, the appropriate term is as 'hydrophilic colloids' or 'hydrocolloids' (Glicksman, 1983 cited by Ferrero, 2017).

1.2.2.4.1 Hydroxypropylmethylcellulose (HPMC)

HPMC belongs to the group of the cellulose ethers which hydroxyl groups have been substituted with one or more of the three hydroxyl groups by the etherification (Figure 1). The present of polar and non-polar in methylcellulose affects increasing water solubility and also confers some affinity for the non-polar phase in doughs. So, HPMC has been widely used in multiphase system of food like bread product. It can improve retaining the uniformity and protect the emulsion stability during bread making. HPMC can forms interfacial films at the boundaries of the gas cells affected to raises stability to the cells against gas expansion. When the temperature increase during baking, HPMC forms gels by interacting with the hydrocolloid chains creating a temporary network. From this phenomena, it improve the strength of the dough during expansion and protects against volume loss. This gel also acts as a barrier against a decrease in moisture content, however this barrier property does not remain after cooling. Therefore, it improve texture and softness on the bread (Selomulyo and Zhou, 2007).

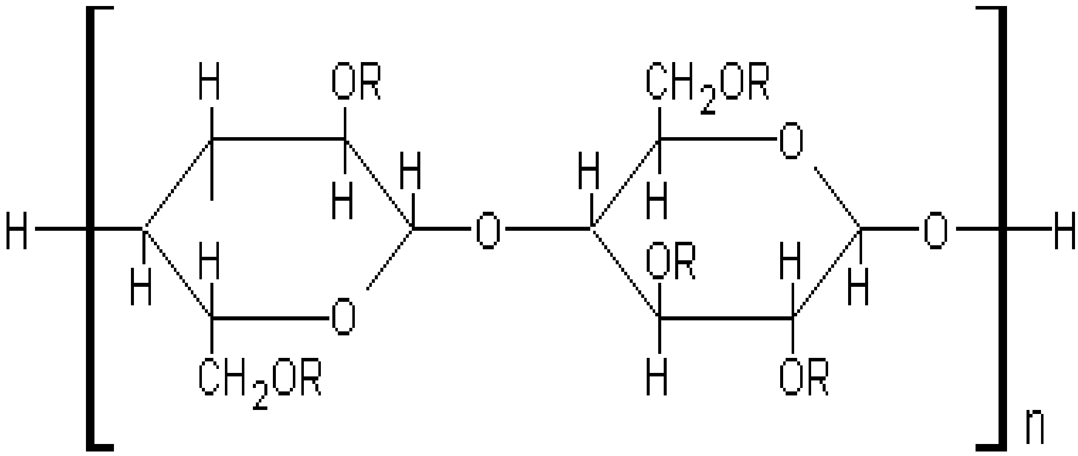

Figure 1 Hydroxypropylmethylcellulose (HPMC) structure.

Source: Alicia *et al*. (2015)

1.2.2.4.2 Guar gum (GG)

Guar gum is a non-ionic edible polysaccharide which produced from the endosperm of guar beans (*Cyamopsis tetragonolobus*). It consists of linear chains of *β*-D- mannopyranosyl units joined by (1-4)-linkages with α-D-galactopyranosyl residue linked to the main chain by a (1-6) linkage as shown in Figure 2 (Selomulyo and Zhou, 2007). The property of GG is its high viscosity at low concentrations. GG is use as thickening, stabilizing and water-binding agent. The beneficial of GG in bakery products is improving mixing and recipe tolerance, extending the shelf life by moisture retention and to prevent syneresis.

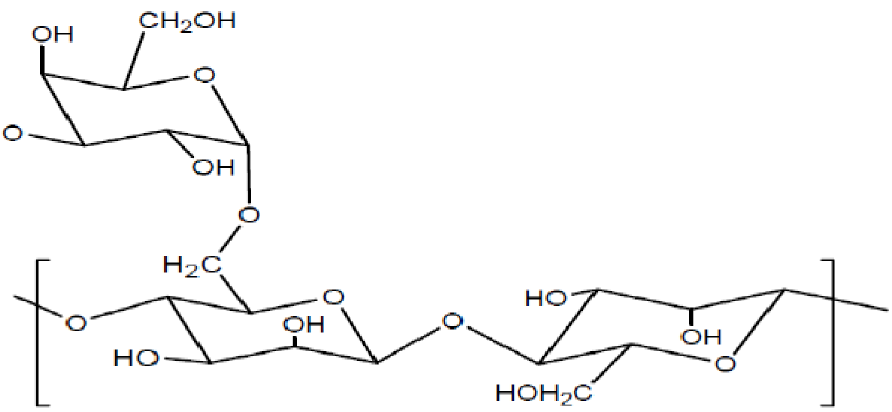

Figure 2 Guar gum structure

Source: Jain *et al*. (2005)

1.2.2.4.3 Xanthan gum (XG)

Xanthan gum is produced by biotechnological process, which is produced by the bacterium *Xanthomonas campestris*. XG is an extracellular polysaccharide. It consists of a backbone made of a linear (1-4)-linked β-D-glucose with trisaccharide side chains on every other glucose at C(O)3, containing a glucuronic acid residue linked (1-4) to a terminal mannose unit and (1-2) to a second mannose that connects to the backbone as shown in Figure 3 (Selomulyo and Zhou, 2007). The solutions of XG is stable in a wide range of pH and temperature.

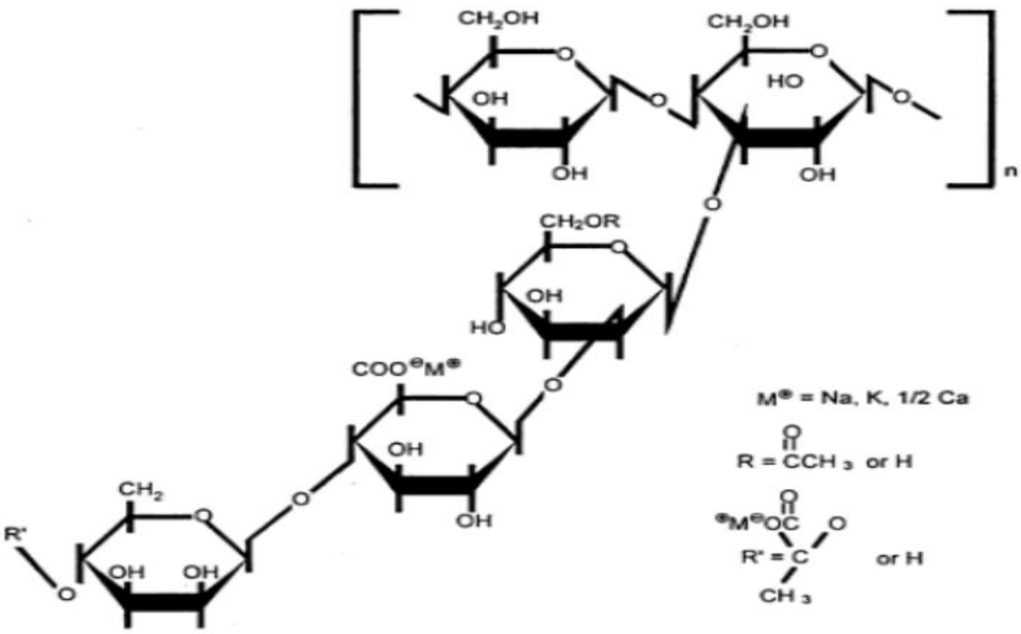

Figure 3 Xanthan gum structure

Source: Phillips and Williams (2000)

1.2.2.5 Effect of hydrocolloids on frozen bread qualities

The main mechanisms of hydrocolloids on frozen bread is change in water absorption. Ferrero (2017) suggested that the water absorbing capacity of wheat flour was mainly associated with gluten protein hydration and the development of the gluten network during kneading because of their hydrophilic nature. These compounds can control both the rheology and texture of aqueous systems as stabilization in emulsions, suspensions and foams systems. In the bread industry, hydrocolloids become more important as bread improvers. They can induce structural changes in the main components of wheat flour systems. Hydrocolloids affect the baking performance of dough and also the shelf life of the stored bread (Appelqvist and Debet, 1997). The formation in the complexes between amylose or amylopectin and hydrocolloids during pasting (Bahnassey and Breene, 1994). Therefore, the presence of hydrocolloid affects on melting, gelatinization, fragmentation and retrogradation processes of starch.

1.2.2.5.1 Effect of hydrocolloids on physical, chemical and sensory properties

The use of hydrocolloids in a small quantities (<1% w/w in flour) in the dough, they can increase water retention, loaf volume, decrease in firmness and starch retrogradation. Ferrero *et al*., (1993) revealed that frozen products (starch-based products) added with hydrocolloids could provide stability during freeze–thaw cycles and reduce the negative effects of freezing during frozen storage.

Zounis *et al*. (2002) reported that the addition of locust bean gum and gum arabic in frozen dough improved the qualities of the dough such as better capability to retain the gluten network, decreasing water activity because of the competition for water by the hydrocolloids with the bread polymers like protein and starch (Schiraldi *et al.,* 1996). However, the effects of hydrocolloid depend on the nature, origin and particle size, dosage of the hydrocolloids in the dough formulation and processing condition (Selomulyo and Zhou, 2007).

In addition, Ahmed *el al.* (2013) improved the storage stability, quality and shelf life of part-baked wheat flour Chapatti by using different hydrocolloids (hydroxylpropylmethylcellulose (HPMC), carboxy methylcellulose (CMC) and guar gum (GG)) at concentration of 0.5%. The sheeted dough was baked for 15 sec on one side and 10 sec on other side at 250 °C followed by frozen storage (-18 °C) for 28 days. The result of dough rheology showed an increase in the water absorption of flour containing HPMC and CMC. The highest value was found in HPMC sample (69.8 ± 0.7%) followed by CMC and GG respectively. This results of water absorption were similar to another study of Sahalini and Laxmi (2007). In additional, they found that dough treated with hydrocolloids showed higher dough development time than the control sample. The sensory evaluation results showed that the highest color score with whitish color was found in GG treatment followed by CMC and HPMC. However, an increase in storage time led to the decrease in color value due to the oxidation of fat and carotenoids. Furthermore, taste scores of the different treatments were not affected. However, the taste score decreased after frozen storage. The flavor score of CMC added sample had the highest scores followed by HPMC, while partially baked chapattis containing HPMC had the highest scores for texture, followed by that containing CMC and GG. The lowest color and texture scores were seen in control chapattis. Scores for texture decreased with storage time was due to the transport of water from the hydrated gluten to the ice phase (Bot, 2003). This texture result was similar with Barcenas *et al.* (2004) who also revealed that the highest scores for chewability, foldability and overall acceptability were found in chapattis containing HPMC, followed by CMC and guar gum, and the control sample obtained the lowest score.

Moreover, Maleki and Milani (2013) studied effect of different hydrocolloids (GG, Xanthan gum (XG), CMC and HPMC) with concentrations of 0.1, 0.5 and 1 % w/w flour basis on Barbari (Iranian bread) qualities. The results of dough Farinograph characteristics showed that water absorption was increased when the concentration of hydrocolloid increased. The highest value was found in CMC, followed by HPMC. These results were caused by carboxyl and hydroxyl groups in hydrocolloid structure resulting in more hydrogen links and a higher water-holding capacity. The dough development time (DDT) was slightly increased with all hydrocolloids additions. This result can explain that hydrocolloids addition resulted in flour strength. Nonetheless the highest value was found in 0.5 % CMC sample, followed by 1% CMC and HPMC samples. The greatest stability was observed in the dough adding with 0.1% CMC and 0.1% HPMC. Moreover, the degree of softening was reduced by adding all hydrocolloids, except for 1% CMC and HPMC because the addition of CMC and HPMC in highest concentration affected to reduce the stability. This was due to hydrocolloids increased the stability of dough by using water absorption. The water absorption increased with concentration of hydrocolloids increase, which led to softer network of dough affecting less stability especially CMC and HPMC containing more carboxyl and hydroxyl groups in their structure. Farinograph quality number (FQN) in all samples added with hydrocolloids was more than the control bread, showing the improved quality of the dough using hydrocolloids. The highest of FQN was found in 0.5% CMC. The result obtained from both the physical properties and moisture content were in agreement with farinograph parameters. The specific volume and oven spring were significantly increased with the addition of hydrocolloids. The highest of specific volume found in 0.1% HPMC followed by 0.5% CMC which followed the same trend as oven spring. In the addition, all hydrocolloids added samples led to lower crust-to-crumb ratio when compared with the control. A lower ratio showed thinner crust and higher quality. Thicker crust is caused by the migration of moisture from crumb to crust. The lowest ratio was found in 0.5% HPMC. Hydrocolloids were able to reduce the water migration and retain the moisture content. A lower width/height ratio showed that the difference between the width and height was smaller, therefore shape regularity was increased. All the hydrocolloids could decreased the width/height ratio. The greatest effect was found in HPMC. Furthermore, the addition of hydrocolloids led to significant increase in crumb moisture content indicating the soft of bread crumb. The highest moisture was observed in the bread containing 0.5% CMC followed by 0.5% and 1% HPMC. The result was in agreement with the results of farinograph. The sensory evaluation result showed that the bread containing 0.5% HPMC obtained the highest score in appearance and upper surface. Addition of hydrocolloids produced higher porosity scores comparing with the control and also better chewingability with the exception of 1% xanthan. It could be concluded that addition of CMC and HPMC could improve sensory properties of Barbari bread, giving higher scores for overall acceptability.

Mandala (2005) studied the effects of XG or GG at different concentrations (0.16 and 0.65 g/100 g flour) on the frozen bread properties stored at -18 °C for 7 days. After thawing in microwave oven at 70 w for 3 min, a more viscous crumb and large shrinkage were observed in all samples resulting in reduction of porosity. Whereas, a great crust failure force reduction was found in control samples. The addition of xanthan gum at low concentration (0.16 g/100 g flour) increased the specific volume. However, further increase in XG concentration and GG addition resulted in a decrease in specific volume and porosity values compared to the control samples. It was found that water loss during storage could contribute to the shrinkage. The crumb walls surrounding the air spaces could be damaged by ice crystals during frozen storage. This could cause a structure collapse led to a shrinkage observation and consequently in porosity reduction.

Barcenasa *et al.* (2004) studied the effect of HPMC and κ-carrageenan (κC) at 0.5% w/w flour basis on the staling of the part-baked frozen bread. Part-baking bread was prepared at 165 °C for 7 min and kept at -25 °C at different storage times (7, 14, 28 and 42 days) then thawed and rebaked at 195 °C for 14 min. The fresh sample with HPMC obtained the highest specific volume. In hydrocolloid addition, it was observed that the bread volume at 0 days was higher than the bread after storage. Regarding the storage time, the specific volume was not significantly ($p < 0.05$) affected by hydrocolloid additions, exception of κC. Both of HPMC and κC could remained moisture content during frozen storage. In fresh sample, the HPMC sample showed the greatest value. This result is in agreement with the ability of HPMC to increase the water absorption and to maintain the moisture content of the products where is added (Bell, 1990; Dziezak, 1991; Collar *et al.*, 1998). Whereas the control showed a progressive decrease in the moisture content with the storage time. In hydrocolloid addition, the water activity of fresh sample decreased from 0.983 to 0.977 due to the competition with the bread polymers like proteins and starch to bind with water. Regarding fresh finish baked bread added with HPMC and κC could reduce the hardness of the crumb, the lowest hardness of the crumb obtained in the presence of HPMC. After 42 days of frozen storage, the control (without additives) showed a progressive increase with the storage time increase. Whereas, the hardness of crumb was not affected by frozen storage. HPMC can increase the water solubility in bread dough because of the substitution of the hydroxyl groups of the cellulose by methoxyl and hydroxypropyl in the structure. Besides, the multiphase system like the bread dough can also confers some affinity in the nonpolar phase of the structure affecting the uniformity of the dough and stability of the emulsion stability during breadmaking. In addition, HPMC can forms interfacial films at the boundaries of the gas cells affected to raises some stability to the cells. Moreover, HPMC forms gels by interaction of the hydrocolloid chains among them during baking obtaining a temporary network. It contributes to some strength of the dough expansion protecting against the volume loss of the dough. This gel can acts as a barrier against the loss of moisture content, however it does not remain after the cooling. Among these effects, HPMC produced a better texture and softness without any adverse effects on the fresh bread. In the control sample, the crumb hardness showed a progressive increase when increasing storage time. On the other hand, the hardness of the crumb supplemented with HPMC was not influenced by the frozen storage time. The sample containing κC, the hardness increase was only observed until 14 days of frozen storage, after that time no further increase was produced.

1.2.2.5.2 Effect of hydrocolloids on microstructure

Sharadanant and Khan (2006) studied on quality changes of frozen doughs added with CMC, gum arabic (GA), κC and locust bean gum (LBG) at 1, 2, and 3% during frozen storage up to 16 weeks. Scanning electron micrographs (SEM) of unfrozen doughs on day 0 showed no damage of gluten structure was observed. The starch granules securely embedded in the gluten matrix. It was indicated by the continuous white filmy materials surrounding the starch granules. However, after storage up to 16 weeks, the frozen control dough without gum additives clearly showed damage of the gluten network. The gluten matrix presented less continuous, more ruptured, and the starch granules appeared to be separated from the gluten. This result was in agreement with Zounis *et al*. (2002) who reported that electron micrographs of the control sample (the frozen dough without gum additives) had a damage of the gluten network and separation of starch granules from the gluten. On the other hand, dough containing with 1% and 3% LBG exhibited the retention of gluten structure with less rupture of gluten strands after 16 weeks of frozen storage. This results indicated that the starch granules of LBG treated dough securely held and surrounded by gluten strands. In addition, the doughs containing with 1 and 3% GA evaluated after 8 weeks of frozen storage showed slightly rupture gluten network where the gluten was still stretched over the starch granules in a continuous network. The sample with 3% GA had less rapture gluten structure than that treated with 1% GA. The gum could immobilize the water, reduced water migration, and prevented large ice crystal formation that disrupted gluten structure on frozen storage. Thereby minimizing damage to the gluten by ice crystals.

1.2.2.5.3 Effect of hydrocolloids on protein

The proteins from different doughs were fractionated into NaCl-soluble, SDS-soluble, and residue proteins. The salt-soluble proteins contents were not significantly different between doughs after 8 weeks of frozen storage but the significantly differences were occurred after 12 weeks. SDS-soluble protein content was increased, while residue protein content was decreased as the frozen storage time increased. He *et al*. (1991) suggested that poor quality flour indicated by more SDS-soluble proteins, while strong flour proteins took longer to solubilize than weak flour proteins in the same extraction rate. The residue protein was indicated the aggregation of the highest molecular weight in gluten protein. The effect of gums on frozen doughs was indicated by the Changes in protein solubility. Orth and Bushuk (1972) reported that the correlation between acetic acid soluble proteins and loaf volume was negative, while positive correlation between residue proteins and loaf volume. However, there was no trend in salt-soluble proteins with gum additions. The least amount of SDS-soluble proteins was found in doughs containing with κC, followed by LBG, CMC, and GA. The dough containing with 3% κC showed significantly lower SDS-soluble protein content than those with 1 and 2% κC. It was noticed that the amount of the SDS-soluble fractions of dough treated with gum was all significantly lower than the dough without additives. For residue proteins results, it was observed that the control dough had lower amount of residue proteins than the doughs treated with gum. In addition, the dough containing with κC and LBG increased the residue proteins to a larger extent than those treated with gum arabic and CMC.

1.3 Objectives

1.3.1 To develop the product concept of frozen Churros with addition of shrimp and squid by-products.

1.3.2 To optimize Churros formulation added with shrimp and squid by-products.

1.3.3 To study effect of hydrocolloids on quality improvement of frozen Churros added with shrimp and squid by-products during frozen storage.

CHAPTER 2

MATERIALS AND METHODS

2.1 Ingredients

All-purpose flour (Kite wheat flour), unsalted butter (Allowrie), sugar (Mitr Phol), salt (Prung Thip), bread crumbs (Kruawangthip) and refined palm olein from pericarp were obtained from UFM Food Centre Co. Ltd., KCG Corporation Co. Ltd., Mitr Phol Sugar Co. Ltd., Thai Refined Salt Co. Ltd., R.S. Domestic Co. Ltd., Patum vegetable oil Co. Ltd., Thailand, respectively. Eggs with size of 60-64 g/egg (No.2) were purchased from a local market.

Hydroxylpropylmethylcellulose, Guar gum and Xanthan gum were obtained from Ziboxan® F80, China. All chemicals for chemical analysis in experiment were analytical grade.

The shrimp and squid by-products are the small or broken Pacific white shrimp (*Litopenaeus vannamei*) and squid (*Photololigo duvaucelii*) including the meat from cutting or trimming process. These by-products were taken from the frozen seafood factory, Songkhla province, Thailand and stored at -20°C for not longer than 3 months.

2.2 Instruments

Instruments	**Brand/ Model**	**Company/ City/ Country**
Analytical balance	Satorius, BP 221S	Data Weighing Systems, Elk Grove Village, Illinois, USA
Colorimeter	ColorFlex, C04-1005-631	Hunter Associates Laboratory, Reston, Virginia, USA
Texture Analyzer	TA-XT2i	Stable Micro System, Surrey, England

Hot air oven	Binder/FD115	Scientific Promotion, Comarillo, California, USA
SOXHLET apparatus	Gerhardt	Konigswinter, Germany
Evaporator	Eyela, N-1000	Aikakikai, Tokyo, Japan
UV-VIS Spectrophotometer	Shimadzu UV-1700 PhamaSpec	Tokyo, Japan
Homogenizer	T25 basic	IKA Labortechnik, Selangor, CA, USA
Vortex Mixer	G-560E	Scientific Industries Inc., NY, USA
High Speed Refrigerated Centrifuge	Hitachi , CR22GIII	Tokyo, Japan

2.3 Chemical

All chemicals are analytical grade obtained from different sources as followed.

2.3.1 Petroleum ether (J.T. Baker, USA)

2.3.2 Hydrochloric acid 37% (RCI Labscan, Ireland)

2.3.3 2-Thiobarbituric acid (Fluka, Buchs, Switzerland)

2.3.4 1,1,3,3-Tetramethoxypropane (Fluka, Buchs, Switzerland)

2.3.5 Acetic acid (RCI Labscan, Ireland)

2.3.6 Chloroform (Merck, Germany)

2.3.7 Methanol (Merck, Germany)

2.3.8 Sodium Chloride (Merck, Germany)

2.3.9 Ammonium thiocyanate (Sigma-Aldrich, USA)

2.3.10 Iron (II) Chloride (Sigma-Aldrich, USA)

2.3.11 Acetone (RCI Labscan, Ireland)

2.3.12 Glutaraldehyde (Merck, Germany)

2.4 Preparation of basic Churros formulation

The ingredients of different Churros formulations are shown in Table 1. Churros was prepared according to method of Hongwiwat (2017) as depicted in Figure 4 and Appendix B.1.

Mix butter, sugar and salt with cold water.

↓

Bring to boil over high heat at 100 °C approximately 1 min until the mixture dissolves completely, then reduce the heat to low about 80 °C.

↓

Stir the flour in the mixture for 5 min until all ingredients are well incorporated and formed a dough using the hand mixer (EHM3407, Electrolux, China), rested for 10 min.

↓

Beat the eggs into the dough and stir constantly for 5 min until incorporated (Appendix B.2, A).

↓

Mix the chopped seafood with the dough and stir constantly for 5 min until all the ingredients are combined (Appendix B.2, B).

↓

Form Churros with a piping bag fitted a closed star tip with diameter of 11 mm, then pipe Churros approximately 5 inch lengths into the preheated.

↓

Partially fry churros with palm oil at 160 °C for 5 min using the oil/product proportion approximately 1 L per 100 g of dough.

↓

Transfer the cooked churros to a plate lined with paper towels to drain.

↓

Cool down for 10 min at room temperature.

↓

Pack the partially cooked Churros and seal in a Nylon/LLDPE bag, store in the freezer for overnight at -20 °C for at least 24 h.

↓

Refry the partially fried Churros at 180 °C for 3 min until golden brown using the oil/product proportion of 1 L per 100 g of dough.

↓

Transfer the cooked churros to a plate lined with paper towels to drain.

↓

Cool for 10 min at room temperature.

Figure 4 Flow diagram of the Churros production.

Source: Hongwiwat (2017) with slight modification

Table 1 Formulation of Churros

Ingredient	Formulation (%)			
	Formulation1*	Formulation2**	Formulation3***	Formulation4****
All-purpose flour	26.55	25.27	23.64	20.91
Water	17.70	42.12	40.19	33.61
Butter	17.70	10.11	7.09	16.43
Egg	29.20	18.53	26.00	24.65
Sugar	-	3.37	2.48	4.18
Salt	-	0.60	0.60	0.22
Milk	8.85	-	-	-

Source: adapted from * Jadee (2012); ** Hongwiwat (2016); *** Vitale (2012); **** Stafford (2015)

The refried Churros samples were subjected to analyses as followed:

2.4.1 Determination of physical properties

2.4.1.1 Color (L*, a*, b* value)

The surface color of Churros with the length of 3 cm was performed using Hunter Lab (C04-1005-631 colorFlex, USA) and was reported in CIE LAB color scales including L*, a* and b* value. The measurements were performed in ten replicates.

2.4.1.2 Hardness and Fracturability

The texture of the Churros was determined after reheating (frying or baking) and rested until the products were at room temperature. Hardness and fracturability were performed using blade set (HDP/BS) probe equipped with a Texture Analyzer (TA-XT2i, Texture Technologies Corp., Scarsdale, New York, USA). Hardness value was used described for breaking of sample by measuring force (gforce). Fracturability was described for deformation distance at fracture (mm). The instrument was adjusted to compression test mode, trigger force of 10 g, distance (rupture distance) of 25 mm, pre-test speed of 1.00 mm/sec, test speed of 1.00 mm/sec and post-test speed 10.00 mm/sec. Churros samples were cut into a length of 6 cm. The Samples were horizontally compressed on the base of the equipment. Ten replicates were used for each sample.

2.4.1.3 Specific volume and density

Churros volume was measured by immersing the samples in a graduated cylinder filled with dehulled sesame seed. Each sample density was calculated by dividing the sample weight by the shifted volume using method of Garcia *et al*. (2002) with slight modification. The measurements were performed in triplicate.

2.4.2 Determination of chemical properties

2.4.2.1 Moisture content

Three gram of finely chopped Churros was dried in a forced convection oven, and the moisture content was determined by weight loss. Five replicas were analysed for each condition (American Association of Cereal Chemists, 2000 with slight modification).

2.4.2.2 Fat content

An extraction with petroleum ether of the dried and crushed Churros samples was carried out using SOXHLET equipment. The fat content was determined by weight difference (American Association of Cereal Chemists, 2000) and expressed per weight of dry product. The measurements were performed in triplicate.

2.4.3 Acceptance Test

Churros was determined after reheating. The sample presentation was prepared in a consistent portion size (3 cm length) and served at room temperature. The samples were coded with 3 digit random code and served by random order of presentation. 30 consumer-type panelists who commonly consume pastry products were recruited from Songkhla province. The acceptance of Churros was judged using a 9-point hedonic scale for color, texture and overall liking (Appendix A.). The sample with the highest overall acceptance was chosen for further study.

2.5 Development of product concept of frozen Churros added with shrimp and squid by-products

From part 2.4, the basic Churros formulation obtained the highest acceptance scores consisted of 25.27% all-purpose flour, 42.12% water, 10.11% butter, 18.53% egg, 3.37% sugar and 0.60% salt (Hongwiwat, 2016). This formulation was modified by adding 30% shrimp or 30% squid or 15% shrimp and 15% squid (related to total formulation). In addition, some panelists commented that the texture of all Churros formulations were too soggy. Therefore, breading or batter coatings known to reduce moisture loss and oil absorption during frying (Balasubramaniam *et al*., 1997; Dogan *et al*., 2005; Gennadios *et al*., 1997; Mohamed *et al*., 1998) was applied into the formulation. The 20-30% bread crumb (based on total by-products weight) was mixed with shrimp and squid by-products. In addition, the amount of water was also decreased by 20% of the basic formulation.

2.5.1 Preparation of basic Churros and Churros added with shrimp and squid by-products formulations.

The ingredients of different Churros formulations are shown in Table 2. Churros was prepared according to method of Hongwiwat (2017) as depicted in Figure 4.

Table 2 Ingredients of various Churros formulations including basic, water reduction, addition of 30% shrimp, addition of 30% squid and addition of 15% shrimp and 15% squid

Ingredient	Formulations				
	Basic	Water reduction	30% Sh*	30% Sq**	15% Sh* 15% Sq**
Flour*	25.27	27.60	17.69	17.69	17.69
Water	42.12	36.80	29.49	29.49	29.49
Butter	10.11	11.04	7.08	7.08	7.08
Egg	18.53	20.24	12.97	12.97	12.97
Sugar	3.37	3.68	2.36	2.36	2.36
Salt	0.60	0.64	0.41	0.41	0.41
Sh**	-	-	30	-	15
Sq***	-	-	-	30	15

* All-purpose flour, ** Shrimp by-product and *** Squid by-product

2.5.2 Focus group discussion

In order to explore consumption preferences of Churros added with shrimp and squid by-products, the focus group was conducted for 3 sessions. The participants were recruited from Sea Wealth Frozen Food Co Ltd. and Prince of Songkhla University. Each session was taken 45 to 90 min and moderated by the same project team member using a prepared script as shown in Table 3. The various prototypes of Churros formulation according to Table 2 were served to the participants at room temperature. The participants were questioned about positive and negative quality attributes of the products. The data obtained was used as the input for design the product in the further study.

Table 3 Discussion guide for focus group session questions

Introduction (10 min)

Q_1 Welcome and explanation about the objectives of the study

Q_2 Explanation about the way of group discussion works

Q_3 Self-introductions (Name, job position, family information)

Rapport/ Reconnaissance (10 min)

Q_4 Tell us what is your general food consumption habits/practices and concerns?

Q_5 Bakery or Pastry consumption

- Consumption frequency of bakery or pastry product
- Reasons for consumption of pastry product (appearance, flavor, texture)

Q_6 Have you ever heard the product called "Churros?" If yes, What do you know about Churros?

Q_7 Have you ever eaten Churros? If yes, explain the Churros you like most.

Q_8 What kind of Churros do you purchase? (Roll fried churros in cinnamon and sugar or serve with a sauce such as chocolate or vanilla) What makes you buy this product?

Q_9 What is your opinion about Churros? (information, expectation, attitude, target consumers)

In-depth investigation (60 min)

Q_{10} Present the concept of Churros added with shrimp and squid meats to the participants

- How do you think if shrimp and squid meats are blended in Churros? Explain your answers.

Table 3 (Continued)

- Do you personally believe that it is more acceptable to you to have shrimp and squid meats in Churros? Why?

Serve the participants the Churros sample with different formula including basic, water reduction, adding only shrimp, adding only squid and adding both shrimp and squid. The participants were questioned as followed:

Q_{11} What are the positive and negative qualities of the products?

Q_{12} How do you like the products in term of appearance, flavor, texture and overall liking?

Q_{13} What do you think about Churros developed with new concept? Explain.

Q_{14} What do you think about the proportion of shrimp and squid added? The present samples was added at the level of 30% (related to total formulation). Should it be more or less?

Q_{15} Is it necessary to add any seasonings in these Churros? If yes, what kind of seasoning should be added?

Q_{16} Shelf-life of Churros product

- How long do you expect churros product to last?

- How to reheat partially fried Churros from frozen storage (frying or baking)? Explain your answers.

Q_{17} Churros purchase patterns

- Preferences for package size (6, 10, 12 pcs./pack)

- Preferences for Churros size or shape

Q_{18} Willingness to pay

- If Churros added with shrimp and squid meats are available in the supermarket, would you buy them? Explain your answer

Closure (10 min)

Q_{19} Do you have any other thoughts or comments that you would like to share with us about Churros added with shrimp and squid meats? Have we missed anything?

Sources: Adapted from Galvez and Resurreccion (1992); Pascall *el al*. (2009)

2.5.3 Factors influencing oil uptake of basic Churros and Churros added with shrimp and squid by-products

2.5.3.1 Effect of butter proportions on Churros qualities

The basic Churros formulation was chosen from part 2.4 consisted of 25.27% all-purpose flour, 42.12% water, 10.11% butter, 18.53% egg, 3.37% sugar and 0.60% salt. To reduce the fat content according to comment from focus group, the butter proportion of the basic formulation was decreased from 100% (B100, control) to 50% (B50), 40% (B40) and 30% (B30) of total amount of butter in the basic Churros formulation. The Churros with different butter proportions were subjected to analyse as described in part 2.4 with slight modification.

2.5.3.2 Effect of reheating methods on Churros qualities

The chosen Churros formulation from part 2.5.3.1 consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt**.** To continuously reduce in oil uptake, the effect of different reheating methods including frying at 180-200 °C for 3 min and baking at 200°C for 12 min. The baking temperature and time for reheat step of Churros came from preliminary study (data not shown). Golden brown on Churros's surface was used to indicate the endpoint of heating. The refried and rebaked Churros samples were subjected to analyse as described in part 2.4 with slight modification.

2.5.3.3 Effect of bread crumb proportions on Churros qualities

The chosen dough of Churros formulation from part 2.5.3.2 with consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt. The by-product meat (25% shrimp and 25% squid of total formulation) was coated with different bread crumb proportions (15% (BC 15%), 17.5% (BC 17.5%) and 20% (BC 20%), related to by-product weight). The partially fried Churros was then baked at 200 °C for 12 min. The Churros samples were subjected to analyse as described in part 2.4 with slight modification

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2.6 Optimization of wheat flour dough, shrimp and squid by-products proportion of frozen Churros

The optimized Churros was formulated according to the product concept obtained from part 2.5. Churros formulation with consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt. The shrimp and squid by-products were coated with 17.5% of bread crumb, based on total by-products weight. The amount of wheat flour was then replaced by the amount of bread crumb added in the formulations depending on the shrimp and squid proportions.

The maximum level of shrimp (Sh) and squid (Sq) by-product were 60% (related to total formulation). The level of wheat flour dough (WF) was ranged from 40 to 100% (related to total formulation). The Churros was then partially fried at 160-180 °C for 5 min and kept at -20°C. For reheating the product, the samples was baked at 200 °C for 12 min. The proportions of wheat flour dough, shrimp and squid by-products were optimized using augmented simplex centroid. The design points contained 10 points of treatment with 3 points of replication in order to calculate the error of experiment as shown in Table 4. The proportion was optimized using predicted model with the highest acceptance score criterias. The optimized formulation was validated by comparing the predicted and observed acceptance scores**.** The 13 experimental samples were evaluated over 3 sessions 4 - 5 samples per session. The serving order were according to serving plan designed to balance first-order carry-over effects (Macfie *et al*., 1989).

Table 4 Mixture design experiment for optimization of wheat flour dough, shrimp and squid by-products of Churros formulation

Treatment	Coded level			Actual level (%)		
	Wh	Sh	Sh	Wh	Sh	Sh
1	0	1	0	40	60	0
2	0	0.466	0.534	40	27.977	32.023
3	1	0	0	100	0	0
4	0.5	0	0.5	70	0	30
5	0	0	1	40	0	60
6	0.5	0.5	0	69.999	30.001	0
7	0.152	0.658	0.19	49.107	39.476	11.417
8	0.174	0.145	0.68	50.463	8.709	40.828
9	0.666	0.167	0.167	79.985	10.003	10.012
10	0.333	0.333	0.333	60	20	20
*11	0	1	0	40	60	0
*12	1	0	0	100	0	0
*13	0	0	1	40	0	60

Note: * Replicate design point

WF; Wheat flour dough, Sh; Shrimp by-product, Sq; Squid by-product

2.7 Effect of hydrocolloids on qualities of frozen Churros

2.7.1 Effect of hydrocolloids on qualities of Churros

The Churros formulation selected from part 2.5 and 2.6. The Churros consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt, while shrimp and squid Churros consisted of 63.81% wheat flour dough, 17.51% shrimp and 18.68% squid by-products. Various types and concentrations of hydrocolloids (Hydroxylpropylmethylcellulose (0.5-2% HPMC), Guar gum (0.5-1.5% GG) and Xanthan gum (0.1-0.3% XG)) was added to Churros. The level for each conditions obtained from preliminary study (data not shown). Choose the concentration obtaining the highest acceptance score of each hydrocolloid type for further study.

2.7.1.1 Determination of physical properties

2.7.1.1.1 Color (L*, a*, b* value) as describe in part 2.4.1.1

2.7.1.1.2 Hardness and Fracturability as describe in part 2.4.1.2

2.7.1.1.3 Specific volume and density as describe in part 2.4.1.3

2.7.1.2 Determination of chemical properties

2.7.1.2.1 Moisture content as describe in part 2.4.2.1

2.7.1.2.2 Fat content as describe in part 2.4.2.2

2.7.1.3 Acceptance Test as describe in part 2.4.3

2.7.2 Effect of hydrocolloid on quality changes of Churros samples during frozen storage

The Churros was prepared using selected concentration of hydrocolloids from part 2.7.1 including HPMC (0.5% and 1%), GG (0.5% and 1%) and XG (0.05% and 0.1%). The partially fried Churros samples were packed in Nylon/LLDPE bag and stored at -20 °C in the freezer (Arco, Thailand) for 3 months. The samples were collected every month until 3 month storage. The frozen Churros were baked at 200 °C using oven (Electrolux, Thailand) for 12 min until golden brown. The superficial oil retained in the samples were eliminated with paper towels. The reheating Churros samples and the control (0 day storage) were subjected to analyses as follows.

2.7.2.1 Determination of physical and chemical properties

2.7.2.1.1 Hardness and Fracturability as describe in part 2.4.1.2

2.7.2.1.2 Specific volume and density as describe in part 2.4.1.3

2.7.2.1.3 Moisture content as describe in part 2.4.2.1

2.7.2.2 Acceptance Test as describe in part 2.4.3

2.7.2.3 Starch retrogradation analysis

The thermal characteristics of the frozen partially fried Churros were performed by a Differential scanning calorimeter (Perkin Elmer, USA). The samples (without reheating step) were weighted (5-10 mg) in stainless steel pans and the empty one was used as a reference. The capsules were heated in Differential scanning calorimeter from 30 to 130 °C at 10 °C/min, in order to determine the possible retrogradation during frozen storage. On the basis of the thermograms, the values for the peak temperature (T_p), onset temperature (T_o), and end temperature (T_e) were determined. The enthalpy (ΔH) associated to the amylopectin retrogradation expressed in J/g of sample which was estimated by integrating the area under the endothermic peak.

2.7.2.4 Microstructure measurement

Microstructure observations were performed on frozen partially fried Churros (without reheating step) using scanning electron microscope (Quanta 400, Thermo Fisher Scientific). The frozen samples were evaluated on day 0 and 3 months of storage. The samples were cut into small rectangular pieces in the freezing room to avoid thawing. All samples were taken from the center of the sample. The samples were fixed in glutaraldehyde for 2 hours. After that, they were embedded in a graded acetone series including 25, 50, 75 and 80% (v/v) for 20 min at each concentration, followed by embedded in 100% acetone at three consecutive for 20 min at each concentration for assuring full dehydration. The samples were then critical point dried, followed by coated dehydrated samples with gold particles (Ribotta *et al*., 2004). SEM examination was done in triplicate for each sample using different magnifications including 2,500x and 5,000x. Several images were taken from different areas of each sample to obtain true representation of the sample.

2.7.3 Effect of different hydrocolloid on quality changes of shrimp and squid Churros during frozen storage.

The shrimp and squid Churros was contained with low concentration including 0.5% HPMC, 0.5% GG and 0.05% XG (related to total formulation). The shrimp and squid Churros added with only low concentration due to bread crumb proportion in this formulation which contributed to increase in the dough consistency as a consequence of water binding affecting the dough was harder. All mixes were prepared and packed as described in part 2.7.2. The reheating shrimp and squid Churros and the control (0 day storage) were subjected to analyses as follows.

2.7.3.1 Determination of lipid oxidation

2.7.3.1.1 Peroxide value (PV)

Peroxide value was determined according to the method of Richards and Hultin (2000). 1 g of chopped shrimp and squid Churros was mixed with 11 ml of chloroform/methanol (2:1, v/v) using homogenizer for 5 min. The homogenates were then filtered, followed by added 2 ml of 0.5% NaCl with 7 ml of the filtrate. The sample was vortexed for 30 second, followed by centrifuge using a speed for 3000 g at 4 °C for 3 min to separate the sample into two phases. 3 ml of lower phase from the sample was mixed with 2.35 ml of chloroform/methanol (2:1, v/v), followed by 25 µL of 30% ammonium thiocyanate (w/v) and 25 µL of 20 mM iron (II) Chloride solution in 3.5% HCL (w/v). The absorbance of the colored solution to assay for lipid hydroperoxides was read at 500 nm after 20 min of incubation using spectrophotometer. The distilled water was mixed instead of iron (II) Chloride solution for blank. The standard curve was prepared using cumene hydroperoxide with the concentration range 0-80 ppm. PV values were calculated after blank subtraction and expressed as mg cumene hydroperoxide equivalent/ g sample.

2.7.3.1.2 Thiobarbituric acid value (TBA)

Thiobarbituric acid value was determined according to the method of Egan *et al*. (1981). 10 g of chopped shrimp and squid Churros was mixed with 50 ml of distilled water using homogenizer for 1 min, followed by added to 2.5 ml of 4 N HCL and 47.5 ml of distilled water. The mixture was determine using distillation method. The collected 50 ml of distillate was taken in 5 ml, followed by mixed with 5 ml of 0.02 M thiobarbituric acid. The mixture was heated in a boiling water (95-100 °C) for 35 min to develop a pink color, cooled with running tap water. The absorbance was measured at 532 nm and used 1,1,3,3-tetramethoxypropane as a standard cure.

2.7.3.2 Acceptance test as describe in part 2.4.3

2.8 Statistical analysis

A randomized complete block design (RCBD) was performed for acceptance test. A completely randomized design (CRD) was used for the statistical analysis of physical and chemical property and lipid oxidation analyses. Data was subjected to analysis of variance (ANOVA). Mean comparisons were carried out by Dancan's multiple range test. Paired sample t-test was performed to compare the results from acceptance test, while independent t-test was used to determined significant differences in physical and chemical properties of reheating method. Analysis was performed using SPSS statistic program (version 10.0 for Windows, SPSS Inc., Chicago, IL, USA). Analysis of variance for regression and the mathematical model were analyzed using the software Design Expert version 7.0.3 (Stat-Ease, Inc., Minneapolis, MN, USA). The significance of the differences was defined at $p < 0.05$.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Preparation of basic Churros formulation

3.1.1 Physical properties of basic Churros formulation

The physical properties of 4 different Churros formulations are displayed in Table 5. The color parameters (L*, a* and b*) of Churros samples exhibited the brightness denoted by L* which were in the range of 41.55 - 52.50. The values of a* and b* were in the range of 8.53 – 13.82 and 30.01 – 34.11 respectively. Churros with formulation 2 and 3 had higher L* but lower a* than those with formulation 1 and 4. However, there was slightly different in b* value. Formulation 4 showed lower b* value than other samples ($p < 0.05$). The darker color of formulation 1 and 4 was due to the sugar proportion in the formulation as shown in Table 1. When Churros was fried, components undergo physical-chemical changed, which affected its color. The formation of Maillard browning reaction and caramelization of sugar in seasoning and milk sugar occured at the high frying temperature which are responsible for the development of gold to brown hues, implying darkening of the Churros crust. As well known, the rate of both browning reaction is influenced by many factors such as chemical composition of the food and the processing temperature (Carabasa and Ibarz, 2000). However, oil types could have made minor contribution to the color change. This was supported by Krokida *et al*. (2001) who reported that negligible effect of oil types on lightness of French fries.

The texture was one of the most important quality characteristic of Churros which affected to overall quality and acceptability. The development of Churros texture during frying was affected by combination of changes in carbohydrate polymers, proteins and fats. Texture data is presented in Table 5. Hardness was measuring force (gforce) required for breaking the process, while deformation distance at fracture (mm) was use to describe fracturability of Churros. It was found that Formulation 2 and 3 were harder than Formulation 1 and 4. Fracturability of Formulation 1 obtained the highest, and was significantly different from other formulations ($p < 0.05$).

The texture of Churros is depended on several factors including raw material and frying condition. The change of hardness was related to color value Churros effected by composition of different formulation. This may be due to high amount of water in Formulation 2 and 3 as shown in Table 1. The high initial moisture content are associated with the pore of samples which are formed by evaporation of water and formation of capillaries during frying (Bordin *et al*., 2013). The explosion during water evaporation creates wide pores and then a superficial crust is formed. In addition, starch gelatinization and protein denaturation also affect the forming of pores and shrinkage of food. Moreover, the high proportion of egg and butter also was contributed to a soft texture of samples made from Formulation 1 and 4.

However, the density and specific volume of 4 different Churros formulations were not significantly different ($p < 0.05$).

Table 5 Physical properties of 4 different Churros formulations

Treatment	Color*			Density**	Specific volume**	Texture properties*	
	L*	a*	b*	(g/cm^3)	(cm^3/g)	Hardness (g)	Fracturability (mm)
Formulation1	43.17 ± 4.43^b	13.64 ± 1.67^a	32.96 ± 2.21^a	0.65 ± 0.04^a	1.54 ± 0.09^a	938.5646 ± 98.61^b	62.43 ± 1.73^a
Formulation2	52.50 ± 3.96^a	9.65 ± 2.26^b	32.47 ± 1.39^a	0.74 ± 0.13^a	1.37 ± 0.25^a	1879.05 ± 185.77^a	60.11 ± 1.00^b
Formulation3	52.07 ± 4.27^a	8.53 ± 1.67^b	34.11 ± 1.86^a	0.67 ± 0.16^a	1.55 ±0.36^a	2029.10 ± 398.09^a	59.58 ± 1.38^b
Formulation4	41.55 ± 4.02^b	13.82 ± 0.85^a	30.01 ±3.56^b	0.55 ± 0.08^a	1.85 ± 0.28^a	1099.95 ± 175.07^b	60.33 ± 1.63^b

Note. Values are means ± SD with ten (*) or triplicate (**) determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

3.1.2 Chemical properties of basic Churros formulation

The moisture content and fat content of 4 different Churros formulation are demonstrated in Table 6. The highest moisture content was found in Churros formulation 3, followed by Formulation 2, 4 and 1, respectively ($p < 0.05$). From this result, it was possible that the moisture content after frying was mainly affected by ingredients in each formulation especially initial proportion of water and egg as shown in Table 1.

The fat content result showed that Churros formulation 4 had the highest content, followed by formulation 1, formulation 2 and formulation 3 which were was not significantly different ($p < 0.05$). This mainly caused by the initial butter proportion in formulation as shown in Table 1. In addition, it was possible that initial water content was related to final fat content. Moreira *et al*. (1997) reported that higher initial moisture content resulted in higher final oil content. They explained that higher initial moisture content could be related to the small pore radius that was formed during frying due to the higher water diffusion rate. During this period, the oil adhere to the product's surface at damaged area and enter into the food. However, oil absorption is affected by many factors including shape, composition, porosity, moisture content and others (Smith *et al* 1985; Gamble and Rice 1988).

Table 6 Chemical properties of 4 different Churros formulations

Treatment	Moisture content (% w.b.)	Fat content (% w.b.)
Formulation1	24.24 ± 0.24^{d}	37.94 ± 2.69^{ab}
Formulation2	26.71 ± 0.75^{b}	33.05 ± 0.75^{b}
Formulation3	30.18 ± 0.38^{a}	34.42 ± 2.51^{b}
Formulation4	25.35 ± 0.51^{c}	41.27 ± 4.09^{a}

Note. Values are means ± SD with triplicate determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

3.1.3 Acceptance of basic Churros formulation

The sensory acceptance test was conducted by 30 panelists who commonly consumed pastry product. 9-point Hedonic Scale was used to evaluate the acceptance of 4 different formulations of Churros. The results is shown in Table 7. The color scores of Formulation 1, 2 and 3 were not significantly different and were higher than Formulation 4 ($p < 0.05$). This result was due to the darker color of Formulation 4 as shown in Table 5. This sample contained high sugar proportion from both sugar and milk, when compared to Formulation 2 and 3. The Churros formulation with milk added (Formulation 1) had the lowest texture score ($p < 0.05$). It could be increased moisture of the product and led to soft texture which was unacceptable to the consumer. The highest overall liking score was found in Formulation 2 and 3. It was possible that the range of the hardness in Formulation 2 and 3 as shown in Table 5 had more tendency to get higher in texture score than Formulation 1 and 4, important resulting in the highest overall liking score. The texture is the most important characteristic of Churros contributing to overall liking score and acceptability.

Table 7 Acceptance scores of 4 different Churros formulations

Treatment	Attributes		
	Color	Texture	Overall liking
Formulation1*	6.93 ± 1.31^{a}	5.37 ± 1.79^{b}	5.73 ± 1.51^{c}
Formulation2*	7.23 ± 1.07^{a}	7.30 ± 1.02^{a}	7.37 ± 0.93^{a}
Formulation3*	7.23 ± 1.17^{a}	7.27 ± 1.11^{a}	7.33 ± 1.06^{a}
Formulation4*	6.40 ± 1.28^{b}	7.00 ± 1.14^{a}	6.83 ± 0.83^{b}

Note. Values are means ± SD (n=30). Different letters in the same column indicate significant difference ($p < 0.05$).

Source: adapted from * Jadee (2012), ** Hongwiwat (2016), *** Vitale (2012) and **** Stafford (2015)

From this result, Churros Formulation 2 and 3 obtained the highest overall liking, texture and appearance score ($p < 0.05$). However, some panelists commented that Formulation 3 had strong egg odor and slight soggy texture. Therefore, Churros Formulation 2 was chosen for further study.

3.2 Focus group result

According to focus group results, all participants had the same attitude and understanding about shrimp and squid by-products which were meat from cutting of trimming process. The questions were involved with the positive and negative qualities of the Churros added with shrimp and squid by-products. All groups were in the 22 – 48 age range.

3.2.1 Focus group discussion

The discussions and key findings from focus groups are discussed accordingly as shown in Table 8. The exploration questions were asked about appearance, flavor, texture and overall liking of various prototypes of Churros. The Churros formulations served in this study were basic, water reduction, adding 30% shrimp by-products, adding 30% squid by-products and adding 15% shrimp and 15% squid by-products.

Table 8 The result of Focus group discussion from 30 participants in 3 sessions

Questions	Answers and discussion
Introduction (10 min)	
Q_1 Self-introductions (Bakery or pastry consumption, reasons for consumption of pastry product (appearance, flavor, texture))	The bakery products that participants usually consume were doughnut, pies, cracker and cookie. All group of participants had positive attitude on adding the meat from cutting seafood process to Churros formulation.
Rapport/ Reconnaissance (10 min)	
Q_2 Have you ever eaten Churros? If you have, What do you like the best in Churros? Explain	Most participants (n = 20), they commonly had tried Churros rolling in sugar and cinnamon or dipping with chocolate or vanilla sauces. Crunchy outside and soft inside of Churros were the favorite characteristic of Churros and butter flavor was also the important characteristic. However, Churros had a greasy characteristic being the main negative effect of the product.

Table 8 (Continued)

Questions	Answers and discussion
In-depth investigation (60 min)	
Q_3 I am going to serve you a series of Churros added with shrimp and squid meats. After tasting the samples, I would like you to tell how you feel about this products (appearance, flavor, texture and overall liking).	The acceptance test result of the samples is shown in Table 9. Churros added with seafood had appearance score lower than basic and water reduction formulation. This was due to darker color from bread crumb addition in the formulation. The highest flavor, texture and overall liking score were found in Churros added shrimp15% squid15% ($p < 0.05$).
Q_4 How do you feel about the proportions of shrimp and squid meats in the products? (Is it enough for you?)	17 participants accepted the proportions of seafood (30% of total formulation), while 13 participants suggested to add more seafood meat in the formulation.
Q_5 What would you suggest about the flavor or seasoning of Churros added with shrimp and squid by-products?	There was 36.67% of participants (n = 11) suggested that Churros added with seafood should add more seasoning such as paprika, Tom yum and pepper flavor.

Table 8 (Continued)

Questions	Answers and discussion
Q_6 What size and shape of Churros do you prefer	60% of participants preferred Churros with a short breadsticks, while others preferred a long breadsticks.
Closure (10 min)	
Q_7 Do you have any other thoughts or comments that you would like to share with us about Churros added with shrimp and squid meats? Have we missed anything?	All of the participants had the same comment on oil absorption which was the most negative attribute of this product and should be solved. In addition, 50% of participants suggested that color of Churros added seafood formulation was uneven. Both issues were needed to be improved.

Table 9 Acceptance scores of Churros samples with and without seafood addition

Formulation	Attributes			
	Appearance	Flavor	Texture	Overall liking
Basic	7.50 ± 1.07[a]	6.80 ± 1.24[b]	6.77 ±1.63[ab]	6.83 ± 1.39[ab]
Water reduction	7.53 ± 1.11[a]	6.63 ± 1.33[b]	6.80 ± 1.42[ab]	6.83 ± 1.23[ab]
30% Sh *	6.37 ± 1.56[b]	6.77 ± 1.36[b]	6.27 ± 1.28[b]	6.30 ± 1.18[b]
30% Sq **	6.30 ± 1.47[b]	6.80 ± 0.96[b]	6.83 ± 1.49[ab]	6.77 ± 1.14[ab]
15% Sh 15% Sq***	5.77 ± 2.37[b]	7.37 ± 0.89[a]	7.00 ± 1.08[a]	7.00 ± 1.05[a]

Note. Values are means ± SD (n=30). Different letters in the same column indicate significant difference ($p < 0.05$).

* Churros added with 30% shrimp by-products

** Churros added with 30% squid by-products

*** Churros added with 15% shrimp and 15% squid by-products

The data obtained from focus group discussion was used as the input for design the Churros added with shrimp and squid by-products. Most of participants were pointed out that the new Churros product should be incorporated with both shrimp and squid meat. However, they had the same comment on oiliness of the product. Thus, the Churros was reformulated according to the product concept and suggestions from focus group. Several techniques including decreasing butter content in the formulation, reheating by baking instead of frying and addition of bread crumb were used for reducing oil content in basic churros formulation in the next study.

3.2.2 Factors influencing oil uptake of basic Churros and Churros added with shrimp and squid by-products

3.2.2.1 Effect of butter proportions on Churros qualities

Butter content is one of the most important quality attributes of Churros. Butter contributes to the mouthfeel, taste and texture of Churros. However, the fat content of the product was mainly influenced by addition of butter in Churros formulation as shown in Table 6. To reduce fat content, the butter proportion of the basic formulation was decreased from 100% (B100, the control) to 50% (B50), 40% (B40) and 30% (B30) of total amount of butter in basic Churros formulation. The results of different butter proportions on Churros qualities are discussed as followed:

3.2.2.1.1 Physical properties of Churros formulation with different butter proportions

The physical properties from Table 10 showed that hardness of Churros was increased with decreasing butter proportions in the formulation. The presence of butter allowed Churros to rise volume, giving Churros a softer texture. However, no significant differences in fracturability, specific volume and density of Churros samples were observed. It was unclear about effect of the brightness of Churros by decreasing butter proportion. The values of L*, a* and b* were in range of 47.34 - 52.57, 8.07 – 11.72 and 31.50 – 33.82, respectively.

Table 10 Physical properties of Churros formulation with different butter proportions

Treatment	Color*			Density**	Specific volume**	Texture properties*	
	L*	a*	b*	(g/cm^3)	(cm^3/g)	Hardness (g)	Fracturability (mm)
B100*	52.57 ± 4.48^{a}	8.07 ± 1.62^{b}	31.50 ± 2.14^{b}	0.51 ± 0.01^{a}	1.97 ± 0.4^{a}	1906.47 ± 322.80^{c}	12.85 ± 1.78^{a}
B50**	47.34 ± 2.93^{b}	10.43 ± 1.67^{a}	32.45 ± 1.85^{ab}	0.79 ± 0.13^{a}	1.28 ± 0.22^{a}	2421.98 ± 341.15^{b}	13.72 ± 0.87^{a}
B40***	48.00 ± 2.98^{b}	11.72 ± 1.85^{a}	33.82 ± 1.58^{a}	0.65 ± 0.09^{a}	1.55 ± 0.21^{a}	2821.33 ± 167.33^{b}	13.36 ± 0.58^{a}
B30****	51.37 ± 2.17^{a}	10.46 ± 2.14^{a}	33.71 ± 1.77^{a}	0.69 ± 0.18^{a}	1.50 ± 0.39^{a}	3339.53 ± 851.88^{a}	12.73 ± 1.45^{a}

Note. Values are means ± SD with ten (*) or triplicate (**) determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

* Basic Churros formulation (100% butter content)

** 50% butter proportion of basic Churros formulation

*** 40% of butter proportion of basic Churros formulation

**** 30% of butter proportion of basic Churros formulation

3.2.2.1.2 Chemical properties of Churros formulation with different butter proportions

The chemical properties of Churros samples are presented in Table 11. The highest moisture content was found in Churros formulation with the lowest butter of the formulation (B30). This may due to the fact that when decreasing butter proportion led to increase in proportion of water. It was clearly that the fat content was mainly influenced by addition of butter proportion in Churros formulation. The highest fat content was found in B100, while B50, B40 and B30 samples were not significantly different.

Table 11 Chemical properties of Churros formulation with different butter proportions

Treatment	Moisture content (% w.b.)	Fat content (% w.b.)
B100*	19.48 ± 1.04^{ab}	33.98 ± 0.75^{a}
B50**	19.15 ± 0.74^{ab}	29.95 ± 0.46^{b}
B40***	16.53 ± 1.92^{b}	30.87 ± 1.21^{b}
B30****	21.54 ± 2.00^{a}	29.88 ± 2.68^{b}

Note. Values are means ± SD with triplicate determinations. Different letters in the same column indicate significant difference ($p < 0.05$).
* Basic Churros formulation (100% butter content)
** 50% butter proportion of basic Churros formulation
*** 40% of butter proportion of basic Churros formulation
**** 30% of butter proportion of basic Churros formulation

3.2.2.1.3 Acceptance test of Churros formulation with different butter proportions

The acceptance scores of different butter content of Churros formulation is presented in Table 12. The appearance score was not influenced by decreasing butter proportion in Churros formulation ($p > 0.05$). The flavor score tended to decrease when butter content in formulation was decreased. This result was in agreement with focus group results as shown in Table 8 which found that butter flavor was one of the most important characteristics in Churros product. In addition, butter contribute to mouthfeel and texture. Hardness of Churros increased as butter proportion decreased as demonstrated in Table 10. However, the highest score of texture was found in B50.

Table 12 Acceptance scores of Churros formulation with different butter proportions

Treatment	Attributes			
	Appearance	Flavor	Texture	Overall liking
B100*	7.50 ± 0.82^{a}	7.60 ± 0.86^{a}	7.47 ± 1.17^{ab}	7.57 ± 1.04^{a}
B50**	7.37 ± 0.85^{a}	7.33 ± 0.61^{ab}	7.57 ± 0.68^{a}	7.53 ± 0.68^{a}
B40***	7.63 ± 0.89^{a}	7.27 ± 0.74^{ab}	7.07 ± 1.11^{bc}	7.23 ± 0.82^{ab}
B30****	7.27 ± 0.78^{a}	7.00 ± 1.02^{b}	6.87 ± 1.11^{c}	6.90 ± 0.80^{b}

Note. Values are means ± SD (n=30). Different letters in the same column indicate significant difference ($p < 0.05$).

* Basic Churros formulation (100% butter content)

** 50% butter proportion of basic Churros formulation

*** 40% of butter proportion of basic Churros formulation

**** 30% of butter proportion of basic Churros formulation

Acceptance test showed that B100 and B50 formulations had the highest overall liking. Nevertheless, formulation B50 had the highest in texture score and had lower fat content than B100 ($p < 0.05$). Therefore, Churros formulation B50 consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt was chosen for further study.

3.2.2.2 Effect of reheating methods on Churros qualities

The Churros in this study was formulated according to previously study. Apart from fat content in the formulation, there are several factors including frying time, prefrying and reheat treatment affecting oil uptake during Churros making. The objective of this study was to investigate effect of different reheated methods including frying (180 °C for 3 min) and baking (200 °C for 12 min) on Churros qualities. The baking temperature and time for reheat step of Churros came from preliminary study (data not shown). Golden brown on Churros's surface was used to indicate the endpoint of heating. The results of different reheating methods on Churros qualities were shown as followed:

3.2.2.2.1 Physical properties of Churros using different reheating methods

The physical properties as shown in Table 13 revealed that the baked Churros had higher hardness and fracturability than the fried one ($p < 0.05$). This may due to high loss of water during longer time of baking. A lower fracturability values indicated that Churros with frying method was more brittle when compared to another sample. The color values (Table 13) showed that a* value of fried method was lower than that of baking method ($p < 0.05$). However, lightness and yellowness values of both frying and baking samples were not significantly different. In addition, no significant differences in specific volume and density of both frying and baking methods were noticed ($p > 0.05$).

Table 13 Physical properties of Churros using different reheating methods

Treatment	Color*			Density** (g/cm^3)	Specific volume** (cm^3/g)	Texture properties*	
	L*	a*	b*			Hardness (g)	Fracturability (mm)
Frying	51.50 ± 4.78^a	5.97 ± 1.49^b	29.36 ± 2.35^a	0.42 ± 0.08^a	2.44 ± 0.47^a	2584.49 ± 414.61^b	20.20 ± 1.05^b
Baking	50.69 ± 4.94^a	9.84 ± 2.52^a	30.83 ± 2.16^a	0.45 ± 0.10^a	2.30 ± 0.46^a	4042.31 ± 472.87^a	21.45 ± 0.59^a

Note. Values are means ± SD with ten (*) or triplicate (**) determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

3.2.2.2.2 Chemical properties of Churros using different reheating methods

The chemical result demonstrated in Table 14 revealed that Churros after baking had lower moisture content than that of frying. The decrease in moisture content across this reheating treatment was due to evaporation of water affected by heat transferred from the heating medium to the Churros surface. The moisture content (P < 0.05) of baked Churros when compared to that of frying method. Thus, longer in heating time and higher heat transfer rates of baking could lead to the lower moisture content of the product. This result was in agreement with Tuta and Palazoglu (2016) who reported that baking time was longer than frying times in potato slices probably because of the formation of a dry surface acting as a barrier to heat transfer to the core. From this phenomena, it may cause higher in moisture loss rate. Moreover, Ngadi *et al*. (2006) studied effect of frying and baking on mass transfer characteristics of chicken nuggets. They showed that baking had higher mass transfer characteristics especially loss of moisture than deep frying. Furthermore, sample with baking method had lower fat content than that of frying (P < 0.05). This was caused by absorption of frying oil as the heating medium. In the frying process, the water is evaporated and then leaves pores that absorb oil into the food (Mohamed *et al*., 1998).

Table 14 Chemical properties of different reheating methods of Churros

Treatment	Moisture content (% w.b.)	Fat content (% w.b.)
Frying	24.90 ± 0.56^{a}	29.95 ± 0.46^{a}
Baking	21.03 ± 0.95^{b}	28.18 ± 0.84^{b}

Note. Values are means ± SD with triplicate determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

3.2.2.2.3 Acceptance test of Churros using different reheating methods

The acceptance test of the reheated Churros with different methods showed that no significant differences in appearance, flavor and texture scores between samples using frying and baking were noticed ($p > 0.05$) as shown in Table 15.

However, the higher overall liking score was found in Churros reheated by baking. This may due to lower fat content of Churros with baking ($P < 0.05$) as discussed previously. According to a high acceptance scores and lower fat content, baking was suggested as reheating method for a partially fried Churros in our study.

Table 15 Acceptance scores of different reheating methods of Churros

Treatment	Attributes			
	Appearance	Flavor	Texture	Overall liking
Frying	7.60 ± 1.04^{a}	7.20 ± 1.19^{a}	7.43 ± 1.10^{a}	7.23 ± 1.10^{b}
Baking	7.63 ± 0.93^{a}	7.67 ± 0.96^{a}	7.83 ± 0.79^{a}	7.80 ± 0.66^{a}

Note. Values are means ± SD (n=30). Different letters in the same column indicate significant difference ($p < 0.05$).

3.2.2.3 Effect of bread crumb proportions on qualities of Churros added with shrimp and squid by-products

From previously study, the Churros formulation with fat reduction according to consumer comments was developed. Churros was then warmed by baking at 200 °C for 12 min. In order to improve the sogginess of the shrimp and squid Churros, the adjustment of bread crumb proportion 15-20%, based on by-products weight (15% (BC 15%), 17.5% (BC 17.5%) and 20% (BC 20%)) in the formulation was carried out. The seafood meat was increased from previous study (30%) to 50% (25% shrimp and 25% squid by-products) for using by-products as much as possible and maintaining the shape of Churros (data not shown). The results of different bread crumb proportions on qualities of Churros added with shrimp and squid by-products were discussed as followed:

3.2.2.3.1 Physical properties of shrimp and squid Churros added with different bread crumb proportions

The physical property results (Table 16) showed that the hardness and fracturability of Churros was increased when increasing proportion of bread crumb. The highest values of hardness and fracturability were found in Churros treated with 20% bread crumb. While, the specific volume was decreased when increasing bread crumb proportion. This indicated the denser structure of the Churros. For the color values, treatment added with highest bread crumb proportion had the lower brightness and yellowness values but higher redness than other treatments ($P < 0.05$).

Table 16 Physical properties of shrimp and squid Churros added with different bread crumb proportions

Treatment	Color*			Density**	Specific volume**	Texture properties*	
	L*	a*	b*	(g/cm^3)	(cm^3/g)	Hardness (g)	Fracturability (mm)
15% BC*	51.06 ± 4.61[a]	12.21 ± 3.12[b]	35.62 ± 2.07[a]	0.54 ± 0.03[b]	1.85 ± 0.10[a]	3739.04 ± 575.26[b]	12.98 ± 0.43[b]
17.5% BC**	50.98 ± 3.69[a]	12.76 ± 3.45[b]	35.96 ± 2.47[a]	0.77 ± 0.09[a]	1.30 ± 0.14[b]	4394.97 ± 781.87[b]	12.96 ± 0.37[b]
20% BC***	40.96 ± 5.17[b]	16.62 ± 1.88[a]	32.15 ± 3.34[b]	0.70 ± 0.11[ab]	1.46 ± 0.24[b]	5345.58 ± 678.54[a]	13.77 ± 1.10[a]

Note. Values are means ± SD with ten (*) or triplicate (**) determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

* 15% BC Churros added with 15% bread crumb (based on total by-products weight)

** 17.5% BC Churros added with 17.5% bread crumb (based on total by-products weight)

*** 20% BC Churros added with 20% bread crumb (based on total by-products weight)

3.2.2.3.2 Chemical properties of shrimp and squid Churros added with different bread crumb proportions

The chemical properties both moisture and fat content was not influenced by addition of different bread crumb proportions in shrimp and squid Churros ($p > 0.05$) as demonstrated in Table 17.

Table 17 Chemical properties of shrimp and squid Churros added with different bread crumb proportions

Treatment	Moisture content (% w.b.)	Fat content (% w.b.)
15% BC*	33.37 ± 0.04^{a}	14.00 ± 0.26^{a}
17.5% BC**	33.78 ± 2.22^{a}	11.96 ± 1.18^{a}
20% BC***	31.61 ± 0.14^{a}	13.47 ± 0.36^{a}

Note. Values are means ± SD with triplicate determinations. Different letters in the same column indicate significant difference ($p < 0.05$).
* 15% BC Churros added with 15% bread crumb (based on total by-products weight)
** 17.5% BC Churros added with 17.5% bread crumb (based on total by-products weight)
*** 20% BC Churros added with 20% bread crumb (based on total by-products weight)

3.2.2.3.3 Acceptance test of shrimp and squid Churros added with different bread crumb proportions

The impact of different bread crumb proportions on the acceptance of shrimp and squid Churros are shown in Table 18. The lowest of appearance and color scores were found in Churros added with the highest of bread crumb proportion. This may due to bread crumb contributed to darker color of Churros. There were not significantly different in odor, flavor and texture liking scores ($p > 0.05$). However, the highest of overall liking scores was noticed in Churros with addition of 17.5 % bread crumb. Therefore this proportion was chosen for studying on optimizing proportions of wheat flour dough, shrimp and squid by-products.

Table 18 Acceptance scores of shrimp and squid Churros added with different bread crumb proportions

Treatment	Attributes					
	Appearance	Color	Odor	Flavor	Texture	Overall liking
15% BC*	7.33 ± 0.99^{ab}	7.57 ± 0.97^{a}	7.50 ± 0.68^{a}	7.70 ± 0.92^{a}	7.17 ± 1.12^{a}	7.43 ± 0.94^{ab}
17.5% BC**	7.63 ± 1.07^{a}	7.57 ± 1.04^{a}	7.57 ± 1.07^{a}	7.67 ± 0.92^{a}	7.47 ± 0.97^{a}	7.60 ± 0.93^{a}
20% BC***	7.03 ± 1.00^{b}	6.87 ± 1.14^{b}	7.50 ± 0.86^{a}	7.43 ± 0.97^{a}	7.27 ± 0.91^{a}	7.13 ± 0.94^{b}

Note. Values are means ± SD (n=30). Different letters in the same column indicate significant difference ($p < 0.0$).
* BC 15% Churros added with 15% bread crumb (based on total by-products weight)
** BC 17.5% Churros added with 17.5% bread crumb (based on total by-products weight)
*** BC 20% Churros added with 20% bread crumb (based on total by-products weight)

Regarding the development of shrimp and squid Churros according to the product concept from focus group discussion, it was pointed out that the basic Churros product should obtain the low oil uptake. Thus, the Churros was formulated by decreasing 50% butter proportion (related to total butter proportion in basic Churros formulation). The partially fried Churros was reheated by baking at 200 °C for 12 min. Finally, shrimp and squid Churros was adjusted bread crumb proportion to be 17.5% (based on total seafood weight). The amount of wheat flour was then replaced by the amount of bread crumb added in the formulations depending on the shrimp and squid proportions.

Therefore, the prototyping model of the Churros dough consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt.

3.3 Optimization of wheat flour dough, shrimp and squid by-products proportion of frozen Churros

The predicted equations, coefficients of determination (R^2), probability of models, and lack of fit of models obtained for appearance, color, odor, flavor, texture and overall liking are depicted in Table 19. The models were linear and quadratic equations. According these results, R^2 score of color was 0.6443, implying that only 64.43% of the total variance was explained by the model. Therefore, it was not possible to apply this predicted model due to lower R^2 ($R^2 < 0.7$) (Myers and Montgomery, 2002; Koocheki *et al*., 2009). There might be other factors affecting the color acceptance apart from the factors studying (wheat flour dough, shrimp and squid by-product). From our results, bread crumb proportion in Churros might be another factors contributed to color score. WF was the most important variable determining appearance scores as shown by the highest coefficient. Appearance scores tended to decreased when Sh and Sq increased. This was due to the fact that small pieces of shrimp and squid by-products added led to the rough appearance of the Churros surface. However, the addition of Sh and Sq increased odor and flavor scores. Moreover, incorporation with both shrimp and squid by-products tended to get higher odor and flavor scores from consumer than those added either shrimp or squid. This results were in agreement with focus group discussion. The participants commented that the new Churros product should be incorporated with both shrimp and squid meat. The high value scores in texture and overall liking was found in region of high WF proportion. According to the results WF was the most important variable affecting appearance, texture and overall liking as shown in highest coefficient in predicted model. On the other hand, the most important variable of odor and flavor was found in Sh and Sq.

The predicted regression models with statistical significance ($p < 0.05$), non-significance of lack of fit ($p > 0.05$), and $R^2 > 0.7$ were used to generate the mixture response surface contour plot (Figure 5). To obtain the optimum region, a contour plot with predicted appearance, odor, flavor, texture and overall liking of scores at least 6.5, 7, 6.63, 6.5 and 6.5 respectively (closed to maximum values), were selected to derive a predicted optimum formulation range. The optimum region (shaded area in Figure 5) consists of 40-100% WF (were in range), 0-20% Sh and 0-20% Sq (closed to maximum values). The optimized formulation with highest desirability (0.72) obtained from software calculation was composed of 63.81% WF, 17.51% Sh and 18.68% Sq. The finished product is shown in Appendix B.3. From verifying the predicted model result, it was found that the observed acceptance scores of the samples for appearance, odor, flavor, texture and overall liking were 7.22, 7.44, 7.34, 6.99 and 7.33, respectively. The experimental errors for all values ranged from 0.03 to 0.11%.

Table 19 Predictive regression models and goodness-of-fit for appearance, color, odor, flavor, texture and overall liking scores of Churros added with various wheat flour dough, shrimp and squid by-product mixtures

Parameter	Regression models	R^2	Probability of model	Lack of fit (p)
Appearance	Y = 7.98WF + 6.13Sh + 7.26Sq	0.8640	< 0.0001	0.5201
Color	Y = 7.74WF + 6.43Sh + 7.33Sq	0.6443	0.0057	0.3216
Odor	Y = 7.04WF + 7.34Sh + 7.23Sq +0.80 WF x Sh + 0.44 WF x Sq + 1.13 Sh x Sq	0.8155	0.0166	0.8210
Flavor	Y = 7.08WF + 7.15Sh + 6.81Sq + 0.58 WF x Sh + 0.65 WF x Sq + 1.97 Sh x Sq	0.8328	0.0121	0.8815
Texture	Y = 7.75WF + 6.53Sh + 6.47Sq	0.8120	0.0002	0.8532
Overall liking	Y = 7.30WF + 6.58Sh + 6.57Sq + 1.31 WF x Sh + 1.21 WF x Sq + 1.77 Sh x Sq	0.8861	0.0034	0.9485

Note: WF; Wheat flour dough, Sh; Shrimp by-product, Sq; Squid by-product, p; probability level.

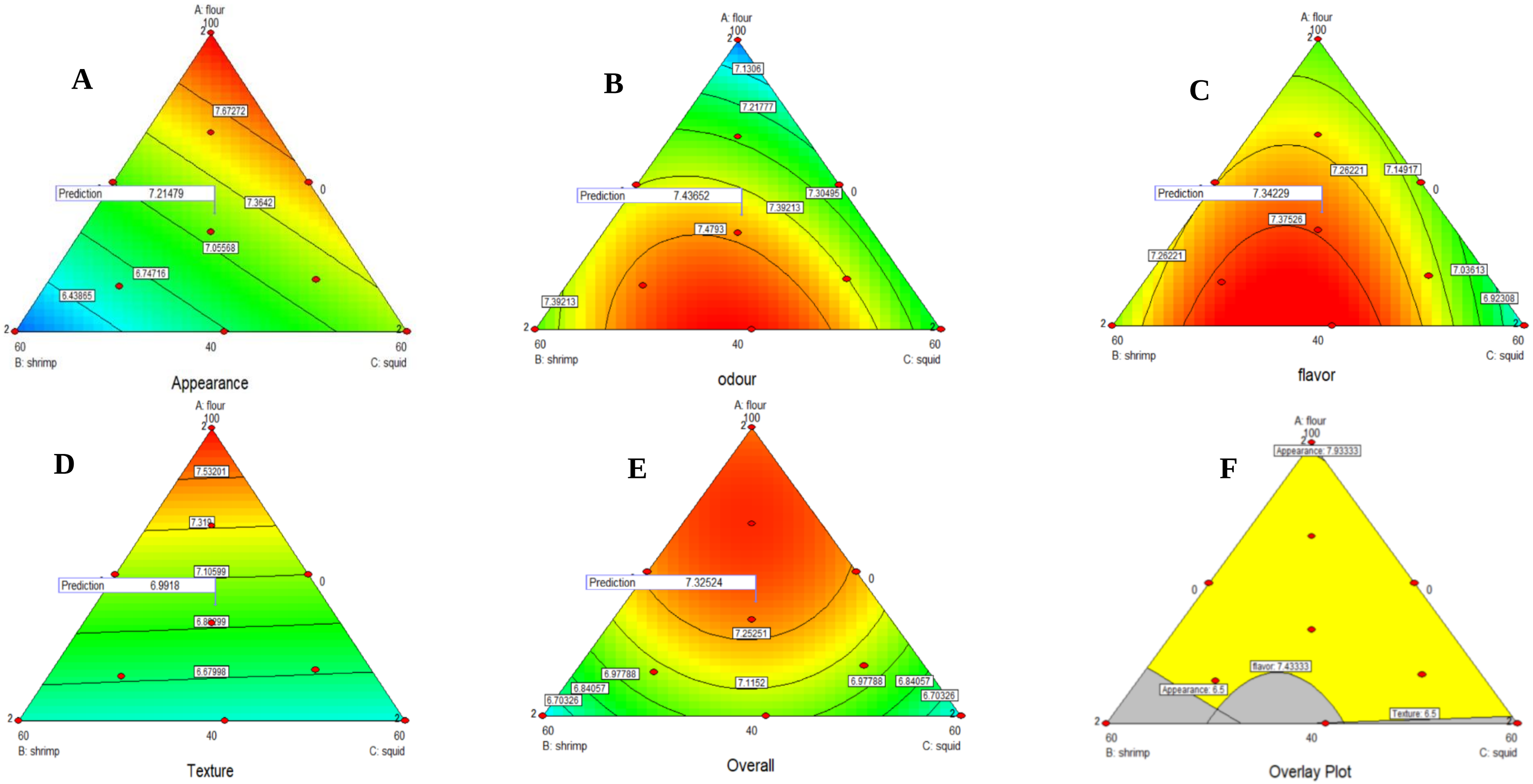

Figure 5. Mixture response surface contour plots displaying the combined effect of Wheat flour dough (WF), Shrimp by-product (Sh), and Squid by-product (Sq) on appearance (A), odor (B), flavor (C), texture (D) and overall liking (E) of Churros, and optimum region (yellow shade) that obtained high appearance, odor, flavor, texture and overall liking score level (>6.5, >7, >6.63, >6.5 and >6.5, respectively).

3.4 Effect of hydrocolloids on qualities of frozen Churros

3.4.1 Effect of hydrocolloids on qualities of Churros

3.4.1.1 Physical properties of Churros added with different types and concentrations of hydrocolloids

The physical properties of Churros added with different types and concentrations of hydrocolloids are displayed in Table 20. The levels of hydrocolloids used in this study were chosen depending on ability of forming Churros. The results showed that dough was harder (more consistency) by addition of hydrocolloids (data not shown). The highest hardness of wheat flour dough was found in dough added with XG, followed by GG and HPMC, respectively at the same level of addition. The rise was expected since the Churros making process was performed at constant dough consistency as a consequence of water binding by hydrocolloids capacity. This was agreement with Guard *et al*. (2004) who studied the effect of hydrocolloids on rheological properties of bread dough. They revealed that bread dough added with XG, HPMC, sodium alginate and κ-carrageenan increased cure configuration ration of the dough (the ratio between resistance to extension and dough extensibility) and deformation energy. Regarding this result, XG addition showed the highest values of both cure configuration ration and deformation energy. Moreover, harder dough directly affected to the forming Churros. Therefore, the various of hydrocolloid types and levels (0.5-2% Hydroxylpropylmethylcellulose (HPMC), 0.5-1.5% Guar gum (GG), and 0.1-0.3% Xanthan gum (XG), related to total formulation) were added to wheat flour dough using chosen formulation from previous.

In addition, Churros with XG at high concentration (0.2 and 0.3%) showed the extreme effects and had higher hardness than other samples. The effect obtained from XG was agreed with Guarda *et al*. (2004) who found that XG at both concentrations of 0.1 and 0.5% w/w on flour basis gave harder bread crumb than other additives (HPMC, Alginate and κ-carrageenan) or the control in the same concentrations. In addition, Rosell *et al*. (2001) also reported that XG showed a great increase in crumb firmness of fresh bread, when compared with other hydrocolloids (HPMC, Alginate and κ-carrageenan) or control at the same concentration 0.5% (w/w, flour basis). This may be due to the consequence of the thickening effect of crumb walls surrounding air spaces as proposed by Rosell *et al*. (2001). The lowest fracturability was found in addition of XG at all concentrations, while this gum also gave the higher hardness. This indicated that Churros added with XG were more brittle. In addition, all hydrocolloid additions did not impact on brightness of the Churros ($p > 0.05$).

Table 20 Physical properties of Churros added with different types and concentrations of hydrocolloids

Hydrocolloid	Concentration (%)	Color			Texture properties	
		L*	a*	b*	Hardness (g)	Fracturability (mm)
Control	-	54.41 ± 5.08^{a}	4.91 ± 2.58^{abcd}	32.68 ± 2.01^{a}	3053.94 ± 298.42^{b}	17.1362 ± 0.58^{c}
HPMC	0.5	58.23 ± 4.28^{a}	2.46 ± 1.87^{d}	27.57 ± 2.77^{bcd}	3029.48 ± 201.23^{b}	18.4710 ± 1.69^{abc}
HPMC	1	55.55 ± 3.96^{a}	5.21 ± 2.08^{abcd}	29.81 ± 2.12^{abc}	3044.31 ± 211.23^{b}	18.3938 ± 0.88^{bc}
HPMC	1.5	54.48 ± 2.36^{a}	5.55 ± 2.67^{abc}	30.42 ± 2.60^{ab}	3154.07 ± 424.69^{b}	17.9602 ± 0.89^{c}
HPMC	2	53.99 ± 2.27^{a}	7.31 ± 2.13^{ab}	32.33 ± 2.50^{a}	3509.50 ± 248.64^{b}	18.5802 ± 1.63^{abc}
GG	0.5	56.52 ± 3.18^{a}	3.41 ± 1.90^{cd}	26.59 ± 2.80^{d}	3080.12 ± 238.58^{b}	19.9870 ± 1.14^{a}
GG	1	55.29 ± 1.46^{a}	4.34 ± 0.83^{cd}	25.98 ± 0.84^{d}	3049.86 ± 209.78^{b}	19.6843 ± 0.91^{ab}
GG	1.5	54.88 ± 3.39^{a}	4.50 ± 2.19^{bcd}	26.67 ± 2.90^{d}	3035.74 ± 575.63^{b}	19.7738 ± 0.84^{ab}
XG	0.1	57.20 ± 1.65^{a}	5.06 ± 1.34^{abcd}	27.95 ± 1.55^{bcd}	3415.30 ± 341.37^{b}	17.9078 ± 0.98^{c}
XG	0.2	55.99 ± 2.24^{a}	7.70 ± 1.98^{a}	31.29 ± 1.62^{a}	4738.99 ± 600.91^{a}	17.3058 ± 0.64^{c}
XG	0.3	56.64 ± 2.06^{a}	5.14 ± 0.93^{abcd}	28.13 ± 1.50^{bcd}	4663.30 ± 544.72^{a}	17.6546 ± 0.77^{c}

Note. Values are means ± SD with ten determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

3.4.1.2 Chemical properties of Churros added with different types and concentrations of hydrocolloids

The moisture and fat contents of the sample with different types and concentrations of hydrocolloids are presented in Table 21. Moisture contents of the Churros sample added with XG and GG were higher than the control ($p < 0.05$). However, those of HPMC added samples were not significantly different from the control ($p > 0.05$). The highest moisture content was found in Churros with XG at high concentration (0.2 and 0.3%), followed by 0.1% XG and 0.5-1.5% GG samples ($p < 0.05$), respectively. This outcome is similar to those previously reported by Guarda *et al*. (2004) and Rosell *et al*. (2001) who found that XG addition also augmented the moisture content of the fresh bread and it was tended to be increased when the concentration increased. Moreover, Friend *et al*. (1993) also revealed that water absorption increased in tortilla supplemented with XG. However, effect of HPMC addition on moisture content was contrary to previous studies (Friend *et al*., 1993; Guarda *et al*., 2004; Rosell *et al*., 2001). They found that HPMC addition caused in water absorption increased in bread and tortilla product. This may due to different hydrocolloid concentrations used. In addition, the different chemical structure of the hydrocolloids tested and different product used in the experiments might be contributed to the differences. The fat content result showed that Churros samples containing XG had the lowest fat content, followed by those with GG, HPMC and the control ($p < 0.05$). The control of Churros (without hydrocolloid) had oil content as high as 29.32 g/100 g sample, whereas the sample with 0.3%, 0.2% and 0.1% XG exhibited a large reduction of oil uptake up to 25.89%, 21.01% and 15.93%, respectively, when compared to the control. The others treated with 1.5%, 1% and 0.5% GG obtained oil uptake to 13.03%, 8.05% and 9.07% oil uptake reduction, respectively. However, Churros with HPMC showed a small reduction of oil uptake, approximately 7.72% when compared to the control.

The negative correlation of chemical results (between moisture and fat content) in this study was observed ($r = -0.8608$). It was similar to other authors who used hydrocolloids especially cellulose derivatives and other gums as additives in the food products. Garmakhany *et al*. (2008) reported that the treatment of hydrocolloids significantly reduced the oil uptake and increased the water retention of the fried potato sample compared with the control (without hydrocolloids) ($p < 0.05$). The minimum fat content was found in 0.5% XG added sample, followed by samples with 0.3% GG and 1% XG, respectively. Another study of Balasubramaniam *et al*., (1997) showed that the moisture retention of fried poultry product was up to 16.4%, while the fat reduction was up to 17.9% and 33.7% for the surface layer and in the core, respectively. This oil barrier effect may due to thermal gelation capacity of HPMC. This gel layer controls the migration of water and oil during frying (Varela and Fiszman, 2011). Garmakhany *et al*. (2008) also explained that thermogelling affected a stronger coating which promoted the formation of wide punctures with low capillary pressures. In addition, the effectiveness of gums can improve adhesion affecting their gel-forming properties. The forming of gelled films give strength and integrity, preventing blow-off and pillowing. The results were agreed with Hsia *et al.* (1992) who found that batters containing XG had the highest apparent viscosity, followed by GG and the control. Apparent viscosity correlated highly positively with batter adhesion characteristics which measured on chicken nuggets. In zones with poor adhesion, the steam generated during frying causes a poor barrier against oil absorption and loss of food juices during frying (Varela and Fiszman, 2011). However, oil absorption is affected by many factors including shape, composition, porosity, moisture content and others (Gamble and Rice 1988). In addition, the negative correlation of hardness and fat content ($r = -0.854$) was observed ($p < 0.05$). This correlation was in agreement with Mohamed *et al.* (1998) who found that fried batter had the highest fracture force, when fried batter had minimal oil absorption. Moreover, Moreira *et al.* (1997) also found that the unbaked tortilla chips with the highest of fat content had the lowest values of peak force, the over-baked chips with the lowest of fat content had the highest values.

Table 21 Chemical properties of Churros added with different types and concentrations of hydrocolloids

Treatment	Concentration (%)	Moisture content (% w.b.)	Fat content (% w.b.)
Control	-	17.87 ± 1.23^{d}	29.32 ± 1.55^{a}
HPMC	0.5	18.49 ± 0.60^{d}	27.56 ± 0.97^{abc}
HPMC	1	18.75 ± 0.32^{d}	27.45 ± 1.03^{abc}
HPMC	1.5	19.65 ± 0.81^{d}	26.48 ± 0.18^{cd}
HPMC	2	17.52 ± 0.54^{d}	26.74 ± 0.43^{bc}
GG	0.5	24.83 ± 2.07^{c}	26.66 ± 0.49^{bc}
GG	1	25.20 ± 0.66^{c}	26.96 ± 1.04^{bc}
GG	1.5	25.70 ± 0.27^{c}	25.50 ± 0.26^{cd}
XG	0.1	27.87 ± 1.10^{b}	24.65 ± 0.80^{de}
XG	0.2	31.82 ± 0.81^{a}	23.16 ± 1.86^{ef}
XG	0.3	30.24 ± 2.28^{a}	21.73 ± 1.10^{f}

Note. Values are means ± SD with triplicate determinations. Different letters in the same column indicate significant difference ($p < 0.05$).

3.4.1.3 Acceptance scores of Churros added with different types and concentrations of hydrocolloids

The effect of different types and concentrations of hydrocolloids on Churros are presented in Table 20, 21 and 22. Regards to these results, the concentration of each hydrocolloid types were chosen according to acceptance score for further study.

The Churros added with different concentrations of HPMC are shown in Table 22. The results showed that appearance, color, flavor, texture and overall liking were not influenced by addition of HPMC at concentrations 0.5-2% when compared to the control (without hydrocolloids) ($p > 0.05$). In addition, odor scores exhibited a small difference between Churros added with HPMC and the control. However, the hardness measurement in Table 20 showed that the hardness of Churros tended to be harder when increased the concentrations of HPMC. This results were contrary to Barcenas *et al.* (2004) who revealed that the crumb hardness of finish baked bread was reduced when added with HPMC at 0.5% (w/w on flour basis). This may due to the different hydrocolloid concentration, product and process conditions used in our experiments. Therefore, Churros added with HPMC at 0.5% and 1% were chosen for further frozen storage study.

The acceptance scores of GG addition are presented in Table 22. The data showed that there were not significantly different between Churros added with 0.5-1.5% GG and the control (without hydrocolloids) in appearance, color and odor scores. However, the control sample had the highest in texture and overall liking scores ($p < 0.05$), while that with GG had the lowest in texture and overall liking scores. Thus, GG addition at 0.5-1% was chosen for further study.

For XG addition, the acceptance scores are demonstrated in Table 22. The results showed the addition of 0.1-0.3% XG was not influenced on appearance, color and odor scores ($p > 0.05$). However, the lowest scores in texture and overall liking was found in Churros added with XG at high concentrations of both 0.2 and 0.3%. This was agreement with hardness results of XG as shown in Table 20 which showed that the hardness progressive increased with increasing the concentration as described previously. It could be predicted that the high level of XG addition was unacceptable to the consumer. Thus, XG at 0.05-0.1% was chosen for the next study.

Table 22 Acceptance scores of Churros added with different types and concentrations of hydrocolloids

Type	Concentration (%)	Attributes					
		Appearance	Color	Odor	Flavor	Texture	Overall liking
Control	0	7.60 ± 0.81[a]	7.47 ± 0.78[a]	7.57 ± 0.77[a]	7.53 ± 0.68[a]	7.57 ± 0.82[a]	7.43 ± 0.82[a]
HPMC	0.5	7.63 ± 0.76[a]	7.67 ± 0.80[a]	7.27 ± 0.87[ab]	7.10 ± 0.99[a]	7.67 ± 0.96[a]	7.30 ± 0.92[a]
HPMC	1	7.90 ± 0.66[a]	7.80 ± 0.61[a]	7.03 ± 0.93[b]	7.10 ± 1.03[a]	7.50 ± 0.73[a]	7.30 ± 0.75[a]
HPMC	1.5	7.70 ± 0.70[a]	7.70 ± 0.65[a]	7.00 ± 0.91[b]	7.27 ± 1.08[a]	7.53 ± 0.82[a]	7.37 ± 0.85[a]
HPMC	2	7.80 ± 0.66[a]	7.73 ± 0.58[a]	7.13 ± 0.78[b]	7.13 ± 0.73[a]	7.40 ± 0.89[a]	7.20 ± 0.76[a]
Control	0	7.63 ± 0.85[a]	7.67 ± 0.71[a]	7.63 ± 0.72[a]	7.80 ± 0.71[a]	7.97 ± 0.76[a]	7.80 ± 0.66[a]
GG	0.5	7.67 ± 0.76[a]	7.40 ± 0.89[a]	7.57 ± 0.82[a]	7.40 ± 0.89[b]	7.57 ± 0.82[bc]	7.43 ± 0.90[bc]
GG	1	7.73 ± 0.64[a]	7.70 ± 0.65[a]	7.43 ± 0.97[a]	7.63 ± 0.76[ab]	7.77 ± 0.82[ab]	7.67 ± 0.84[ab]
GG	1.5	7.53 ± 0.68[a]	7.43 ± 0.73[a]	7.37 ± 0.72[a]	7.40 ± 0.86[b]	7.27 ± 0.83[c]	7.30 ± 0.84[c]
Control	0	7.53 ± 0.82[a]	7.60 ± 0.81[a]	7.43 ± 0.94[a]	7.67 ± 0.80[a]	7.77 ± 0.86[a]	7.6000 ± 0.93[a]
XG	0.1	7.73 ± 0.78[a]	7.60 ± 0.81[a]	7.33 ± 0.88[a]	7.47 ± 0.90[ab]	7.53 ± 0.90[a]	7.4333 ± 0.97[ab]
XG	0.2	7.60 ± 0.77[a]	7.63 ± 0.76[a]	7.40 ± 0.86[a]	7.33 ± 1.06[b]	6.97 ± 1.00[b]	7.1333 ± 0.90[b]
XG	0.3	7.70 ± 0.75[a]	7.53 ± 0.82[a]	7.53 ± 0.78[a]	7.20 ± 0.89[b]	6.97 ± 0.96[b]	7.1333 ± 0.90[b]

Note. Values are means ± SD (n=30). Different letters in the same column and hydrocolloid type indicate significant difference ($p < 0.05$).

3.4.2 Effect of hydrocolloid on quality changes of Churros samples during frozen storage

3.4.2.1 Effect of hydrocolloid on physical and chemical properties of Churros during frozen storage

The texture properties of the partially fried Churros samples were stored at -20 °C, then reheating by baking at 200 °C for 12 min. The texture results were similar to the previously study in part 3.4.1.1. The hardness of Churros was increased by adding hydrocolloids especially in GG and XG addition at both concentration. However, the low fracturability values were found in Churros with XG at both concentrations (Table 23). However, the influence of frozen storage on hardness was found in the Churros without hydrocolloids. The results showed that Churros hardness was increased with increase in storage time. This results was similar with previous study. Barcenas *et al*. (2004) reported that the finish baked bread after frozen partially baking were progressive increased after 42 days of frozen storage. This may due to staling process. Staling is a very complex process such as amylopectin retrogradation, reorganisation of polymers within the amorphous region and loss of moisture content (Guarda *et al*., 2004). Nevertheless, hardness increase affected by the frozen storage was not dramatic to consumer acceptance as shown in Table 25. In opposition, hardness of Churros added with hydrocolloids were not affected by frozen storage time. This results were in agreement with Barcenas *et al*. (2004) who reported that the hardness of bread crumb added with HPMC and κ-carrageenan were not influenced by 42 days of frozen storage time. This may due to hydrocolloids had a water retention capacity and possible inhibition of the amylopectin retrogradation by binding with starch and in consequence avoid interaction between starch and gluten (Collar *et al*., 1998). Fracturability of Churros added with hydrocolloids tended to increase with frozen storage time with the exception of 0.5% HPMC. According to texture results, especially hardness, confirmed that addition of hydrocolloid in the Churros gave a good shielding effect of the texture during frozen storage.

The highest specific volume and lowest density were found in the Churros sample without hydrocolloids at 0 day of frozen storage as shown in Table 23. Churros had lower specific volume and higher density when added with hydrocolloids. The higher specific volume and lower density demonstrated that Churros had open structure, while lower specific volume and higher density indicated a very compact and closed structure. This was in agreement with Mandala (2005) who reported that specific volume of bread was decreased when adding 0.65% of GG and XG (based on flour basis). However, Guarda *et al*. (2004) reported that the bread specific volume was increased when adding o.1 and 0.5% of XG, HPMC, Alginate and κ-carrageenan (based on flour basis). This was supported by the finding of Rosell *et al*. (2001) who reported that the specific volumes of fresh bread were increased with addition of hydrocolloids exception of alginate addition. The highest specific volume was found in κ-carrageenan, followed by HPMC and XG. In case of XG. This may due to the strong interaction between XG and protein in wheat flour affecting increase in elastic resistance of the dough and led to low volume. Bell (1990) proposed a theory to explain the function of HPMC on bread loaf volume that HPMC gave a stability to interface of the dough system during proofing affecting increase in gas retention capacity. After frozen storage, the control sample was affected by frozen storage time. The control sample showed a progressive decrease in specific volume with storage time. The results were in the line with Morimoto *et al*. (2015) and Sharadanant and Khan (2003a) who observed that a specific volume was highest for unfrozen bread dough and decreased during frozen storage. This may due to the ultrastructural changes in the starch and gluten affected by frozen storage. The damage starch and gluten contributed to lower loaf volume (Berglund *et al*., 1991). In contrast, specific volume and density of Churros with hydrocolloids were not significantly different with time of frozen storage with the exception of 0.5% HPMC. Therefore, the addition of hydrocolloids with exception of 0.5% HPMC could prevent the quality deterioration of the Churros during frozen storage.

Table 23 Physical properties of basic Churros added with different types and concentrations of hydrocolloids during frozen storage

Sample	Concentration (%)	Physical properties			
		Specific volume (cm^3/g) *	Density (g/cm^3) *	Hardness (g) **	Fracturability (mm) **
0 day					
Control	-	2.33 ± 0.37^{aw}	0.44 ± 0.06^{by}	2733.39 ± 530.76^{cy}	20.09 ± 2.58^{abx}
HPMC	0.5	2.16 ± 0.06^{abw}	0.46 ± 0.01^{abz}	2901.42 ± 401.21^{cx}	20.17 ± 1.83^{abx}
HPMC	1	1.66 ± 0.18^{abcw}	0.61 ± 0.07^{abx}	3081.76 ± 566.58^{bcx}	20.26 ± 1.16^{ay}
GG	0.5	1.67 ± 0.32^{abcw}	0.61 ± 0.11^{abx}	3016.70 ± 549.50^{bcx}	20.71 ± 1.66^{axy}
GG	1	1.64 ± 0.52^{abcw}	0.67 ± 0.26^{abx}	3435.63 ± 495.41^{abx}	19.60 ± 0.96^{aby}
XG	0.05	1.45 ± 0.64^{bcw}	0.77 ± 0.29^{abx}	3125.43 ± 734.96^{bcx}	19.74 ± 2.10^{aby}
XG	0.1	1.30 ± 0.61^{cw}	0.90 ± 0.43^{ax}	3759.14 ± 199.31^{ax}	18.69 ± 0.85^{by}
30 days					
Control	-	2.26 ± 0.40^{aw}	0.45 ± 0.07^{cy}	$3002.59 \pm 317.37^{abxy}$	20.94 ± 1.47^{ax}
HPMC	0.5	1.75 ± 0.17^{bx}	0.57 ± 0.06^{bcz}	2795.77 ± 246.27^{bx}	20.30 ± 3.16^{abx}
HPMC	1	1.29 ± 0.33^{bw}	0.80 ± 0.18^{ax}	3204.84 ± 347.13^{abx}	18.48 ± 1.53^{bz}
GG	0.5	1.64 ± 0.27^{bw}	0.62 ± 0.10^{abcx}	2836.10 ± 581.84^{bx}	19.52 ± 1.21^{aby}
GG	1	1.58 ± 0.16^{bw}	0.64 ± 0.06^{abcx}	3179.36 ± 434.92^{abx}	20.15 ± 1.10^{aby}
XG	0.05	1.49 ± 0.12^{bw}	0.68 ± 0.06^{abx}	3498.34 ± 513.94^{ax}	19.90 ± 1.02^{aby}
XG	0.1	1.72 ± 0.02^{bw}	0.58 ± 0.01^{bcx}	3179.40 ± 437.93^{abx}	20.79 ± 1.24^{ax}

Table 23 (continued)

Sample		Concentration (%)	Physical properties			
			Specific volume (cm^3/g) *	Density (g/ cm^3) *	Hardness (g) **	Fracturability (mm) **
60 days						
	Control	-	1.58 ± 0.17^{ax}	0.64 ± 0.07^{bxy}	3146.17 ± 581.65^{abcxy}	21.35 ± 1.60^{ax}
	HPMC	0.5	1.42 ± 0.20^{aby}	0.71 ± 0.10^{aby}	2656.11 ± 456.23^{cx}	21.84 ± 1.94^{ax}
	HPMC	1	1.28 ± 0.11^{abw}	0.78 ± 0.07^{abx}	2937.21 ± 558.45^{bcx}	20.53 ± 1.37^{aby}
	GG	0.5	1.40 ± 0.16^{abw}	0.72 ± 0.09^{abx}	2945.08 ± 364.01^{bcx}	21.23 ± 1.81^{ax}
	GG	1	1.09 ± 0.30^{bw}	0.96 ± 0.24^{ax}	3626.98 ± 741.86^{ax}	20.38 ± 1.38^{aby}
	XG	0.05	1.24 ± 0.06^{abw}	0.81 ± 0.04^{abx}	3144.05 ± 270.35^{abcx}	20.37 ± 0.87^{abxy}
	XG	0.1	1.12 ± 0.30^{bw}	0.95 ± 0.29^{ax}	3510.98 ± 688.52^{abx}	19.43 ± 1.42^{by}
90 days						
	Control	-	1.33 ± 0.41^{ax}	0.79 ± 0.21^{bx}	3738.02 ± 289.42^{ax}	17.50 ± 0.29^{bx}
	HPMC	0.5	0.86 ± 0.01^{bz}	1.16 ± 0.01^{ax}	2604.99 ± 437.97^{cx}	22.32 ± 2.30^{ax}
	HPMC	1	1.26 ± 0.11^{abw}	0.80 ± 0.07^{bx}	3111.70 ± 571.85^{abcx}	22.26 ± 0.85^{ax}
	GG	0.5	1.22 ± 0.24^{abw}	0.85 ± 0.19^{bx}	2937.33 ± 764.63^{bcx}	22.15 ± 2.40^{ax}
	GG	1	1.02 ± 0.10^{abw}	0.99 ± 0.10^{abx}	3374.65 ± 618.72^{abx}	21.43 ± 1.36^{ax}
	XG	0.05	1.12 ± 0.37^{abw}	0.95 ± 0.27^{abx}	2965.40 ± 364.67^{bcx}	21.70 ± 1.16^{ax}
	XG	0.1	1.09 ± 0.06^{abw}	0.92 ± 0.05^{abx}	3388.51 ± 715.96^{abx}	21.38 ± 1.09^{ax}

Note. Values are means ± SD with triplicate (*) or ten (**) determinations. Values with the same following letter do not differ significantly from each other ($p < 0.05$). a,b,c,d,e Same letters within each column and same day of frozen storage do not significantly differ ($p < 0.05$). w,x,y,z Same letter within each treatment do not significantly differ ($p < 0.05$).

For the moisture content of the Churros samples during frozen storage is shown in Table 24. At 0 day of storage, the moisture content was increased with the addition of hydrocolloids. This effect was attributed to the high water-holding capacity of hydrocolloids. Churros containing with XG showed the highest moisture content, followed by GG and HPMC, respectively. While Churros without hydrocolloids showed the lowest value. This results were similar to Maleki and Milani (2013) who revealed that hydrocolloid additions including GG, XG, CMC and HPMC led to increase in water absorption of Barbari bread. However, they also propose that the increasing hydrocolloid concentration more than 1% (based on flour basis) contributed to reduction of moisture content. The hydrocolloids might reduce the mobility of water molecules and transform free water to bound water when increasing concentration. In addition, Friend *et al*., (1993) also reported that addition of XG and HPMC increased water absorption of Tortilla. This may due to carboxyl and hydroxyl groups in their hydrocolloid structure. No significant difference in moisture content of the control sample during storage was observed, while the hydrocolloid added Churros showed a different tendency on each hydrocolloid treatment. However, Churros containing hydrocolloids had higher moisture content throughout storage time (90 days) when compared to the control.

Table 24 Moisture content of basic Churros added with different types and concentrations of hydrocolloids during frozen storage

Hydrocolloid	Concentration (%)	Moisture content (% w.b.)			
		0 day	30 days	60 days	90 days
Control	-	15.95 ± 1.83^{dx}	14.75 ± 0.60^{cx}	15.61 ± 1.44^{dx}	14.49 ± 0.61^{ex}
HPMC	0.5	19.25 ± 1.34^{cx}	15.42 ± 0.79^{cy}	18.29 ± 1.02^{cx}	18.20 ± 1.16^{dx}
HPMC	1	21.09 ± 1.15^{bcxy}	19.72 ± 0.62^{byz}	21.47 ± 1.01^{bx}	19.48 ± 1.43^{cdz}
GG	0.5	19.68 ± 0.36^{bcy}	18.81 ± 0.88^{by}	21.38 ± 0.49^{bx}	19.84 ± 0.92^{cy}
GG	1	22.10 ± 2.72^{by}	22.90 ± 0.99^{axy}	25.17 ± 0.91^{ax}	23.79 ± 1.21^{bxy}
XG	0.05	24.75 ± 1.81^{ay}	22.92 ± 0.83^{az}	24.36 ± 1.06^{ayz}	26.93 ± 0.36^{ax}
XG	0.1	25.26 ± 1.25^{axy}	23.93 ± 0.45^{ay}	24.82 ± 0.73^{axy}	25.81 ± 1.16^{ax}

Note. Values are means ± SD with triplicate determinations. Values with the same following letter do not differ significantly from each other ($p < 0.05$). a,b,c,d,e Same letters within each column do not significantly differ ($p < 0.05$). x,y,z Same letter within each treatment do not significantly differ ($p < 0.05$).

3.4.2.2 Effect of hydrocolloid on acceptance scores of Churros during frozen storage

The acceptance results of basic Churros during frozen storage were showed in Table 25. The overall liking scores of all samples seemed constant until 30 days of frozen storage. However, the control samples showed a lower overall liking scores than Churros with hydrocolloids after 60 and 90 days of frozen storage ($p < 0.05$). This was in agreement with physical and chemical properties results in part 3.4.2.1. After frozen storage, the highest hardness and lowest moisture content was found in Churros without hydrocolloids. Selomulyo and Zhou (2007) revealed that the loss of moisture content and increase in hardness of bakery products (a process known as retrogradation or staling) contributed to loss of consumer acceptance. This was supported by Guarda *et al*. (2004) who proposed that the addition of hydrocolloids at concentration of 0.1%, w/w flour basis was sufficient to prevent the staling effect of bread products (increasing crumb hardness) from frozen storage. In addition, the important attribute of Churros such as texture and flavor showed the lowest scores in the control sample after 60 days of frozen storage even though there was significantly different in flavor score. After 90 days of frozen storage, the control showed the lower flavor and texture scores when compared to Churros containing with hydrocolloids with exception of 0.5% GG. Finally, there was no tendency in effect of different types and concentration of hydrocolloid addition on consumer acceptance during frozen storage.

Table 25 Acceptance scores of basic Churros added with different types and concentrations of hydrocolloids during frozen storage

samples		Concentration (%)	Attributes					
			Appearance	Color	Odor	Flavor	Texture	Overall liking
0 day								
	Control	-	7.17 ± 0.83^{abx}	6.77 ± 0.77^{bx}	7.07 ± 0.83^{abx}	7.37 ± 0.72^{ax}	7.40 ± 0.81^{ax}	7.17 ± 0.70^{abx}
	HPMC	0.5	7.50 ± 1.01^{ax}	7.50 ± 1.11^{ax}	7.20 ± 0.89^{abx}	7.40 ± 1.07^{ax}	7.57 ± 1.14^{ax}	7.43 ± 1.04^{abx}
	HPMC	1	7.50 ± 0.68^{ax}	7.60 ± 0.77^{axy}	7.17 ± 0.75^{abx}	7.30 ± 0.65^{abxy}	7.37 ± 0.67^{axy}	7.30 ± 0.60^{abxy}
	GG	0.5	7.20 ± 0.85^{abx}	7.17 ± 0.87^{abx}	6.90 ± 0.76^{bx}	6.87 ± 0.78^{bx}	6.73 ± 0.91^{bx}	6.70 ± 0.60^{cx}
	GG	1	7.30 ± 0.70^{abx}	7.43 ± 0.94^{ax}	7.07 ± 0.83^{abx}	7.20 ± 0.81^{abx}	7.47 ± 1.01^{ax}	7.33 ± 0.84^{abx}
	XG	0.05	6.97 ± 1.03^{bx}	6.97 ± 0.96^{bx}	7.13 ± 0.94^{abxy}	7.17 ± 1.02^{abx}	7.30 ± 0.88^{ax}	7.07 ± 1.01^{bcx}
	XG	0.1	7.53 ± 0.86^{ax}	7.43 ± 0.77^{ax}	7.33 ± 0.76^{axy}	7.40 ± 0.67^{ax}	7.50 ± 0.68^{ax}	7.53 ± 0.63^{ax}
30 days								
	Control	-	6.97 ± 1.22^{bxy}	6.80 ± 1.49^{bx}	7.20 ± 1.06^{abx}	7.30 ± 1.24^{abx}	7.20 ± 1.03^{axy}	7.10 ± 1.12^{abx}
	HPMC	0.5	7.33 ± 1.06^{abx}	7.43 ± 0.94^{ax}	6.90 ± 0.84^{bx}	7.20 ± 0.89^{abx}	7.20 ± 0.96^{ax}	7.13 ± 0.94^{abx}
	HPMC	1	7.40 ± 0.81^{abx}	7.40 ± 0.97^{axy}	7.07 ± 0.91^{bx}	6.93 ± 1.08^{abyz}	6.87 ± 1.28^{aby}	6.97 ± 1.07^{aby}
	GG	0.5	7.27 ± 0.98^{abx}	7.20 ± 1.16^{abx}	6.97 ± 1.10^{bx}	6.90 ± 0.92^{bx}	6.43 ± 1.14^{bx}	6.73 ± 0.94^{bx}
	GG	1	7.37 ± 1.10^{abx}	7.27 ± 1.26^{abx}	7.00 ± 1.02^{bx}	7.13 ± 1.04^{abx}	7.07 ± 1.20^{ax}	7.03 ± 1.10^{abx}
	XG	0.05	7.20 ± 1.00^{abx}	6.83 ± 1.21^{bxy}	7.47 ± 0.97^{ax}	7.27 ± 0.94^{abx}	7.10 ± 1.16^{ax}	7.20 ± 0.92^{abx}
	XG	0.1	7.60 ± 0.93^{ax}	7.63 ± 0.81^{ax}	7.40 ± 0.77^{ax}	7.37 ± 0.76^{ax}	7.23 ± 0.90^{axy}	7.43 ± 0.82^{ax}

Table 25 (continued)

samples		Concentration (%)	Attributes					
			Appearance	Color	Odor	Flavor	Texture	Overall liking
60 days								
	Control	-	6.37 ± 1.40^{byz}	6.20 ± 1.37^{cxy}	6.63 ± 1.40^{ax}	6.83 ± 1.26^{ax}	6.63 ± 1.45^{by}	6.63 ± 1.03^{bx}
	HPMC	0.5	7.13 ± 1.20^{ax}	7.37 ± 1.16^{ax}	6.83 ± 1.44^{ax}	7.17 ± 1.12^{ax}	7.47 ± 1.14^{ax}	7.27 ± 1.14^{ax}
	HPMC	1	7.13 ± 1.28^{ax}	7.20 ± 1.24^{ay}	6.97 ± 1.19^{ax}	6.73 ± 1.64^{az}	7.10 ± 1.40^{abxy}	7.03 ± 1.25^{aby}
	GG	0.5	6.70 ± 1.56^{abx}	6.83 ± 1.21^{abx}	6.80 ± 1.06^{ax}	6.97 ± 1.25^{ax}	6.70 ± 1.29^{bx}	6.97 ± 1.00^{abx}
	GG	1	7.10 ± 1.52^{ax}	7.13 ± 1.28^{ax}	6.77 ± 1.17^{ax}	6.97 ± 1.13^{ax}	6.90 ± 1.27^{abx}	6.97 ± 1.00^{abx}
	XG	0.05	6.60 ± 1.63^{abx}	6.40 ± 1.54^{bcxy}	6.97 ± 1.22^{axy}	7.07 ± 1.28^{ax}	7.03 ± 1.22^{abx}	6.97 ± 1.10^{abx}
	XG	0.1	7.13 ± 1.01^{ax}	7.33 ± 0.92^{ax}	6.80 ± 1.49^{ay}	7.00 ± 1.39^{ax}	6.77 ± 1.52^{by}	6.90 ± 1.21^{aby}
90 days								
	Control	-	6.27 ± 1.48^{cz}	6.00 ± 1.49^{cy}	6.83 ± 1.26^{ax}	6.83 ± 1.32^{bx}	7.00 ± 1.17^{abxy}	6.67 ± 1.21^{cx}
	HPMC	0.5	7.40 ± 1.10^{ax}	7.60 ± 0.89^{ax}	6.97 ± 0.89^{ax}	7.27 ± 0.69^{abx}	7.47 ± 0.86^{ax}	7.33 ± 0.71^{abx}
	HPMC	1	7.67 ± 1.37^{ax}	7.83 ± 0.91^{ax}	7.07 ± 1.20^{ax}	7.50 ± 0.82^{ax}	7.57 ± 0.97^{ax}	7.60 ± 0.97^{ax}
	GG	0.5	7.03 ± 0.96^{abx}	6.83 ± 1.15^{bx}	6.93 ± 0.94^{ax}	6.97 ± 0.93^{abx}	6.73 ± 0.98^{bx}	6.97 ± 0.81^{bcx}
	GG	1	7.20 ± 1.00^{abx}	7.43 ± 0.90^{ax}	7.13 ± 0.73^{ax}	6.80 ± 1.27^{bx}	7.10 ± 1.30^{abx}	6.97 ± 1.03^{bcx}
	XG	0.05	6.63 ± 1.50^{bcx}	6.27 ± 1.39^{cy}	6.83 ± 0.87^{ay}	7.00 ± 1.17^{abx}	7.10 ± 1.30^{abx}	6.83 ± 1.02^{bcx}
	XG	0.1	7.67 ± 0.96^{ax}	7.60 ± 0.89^{ax}	7.07 ± 0.98^{axy}	7.17 ± 0.99^{abx}	7.13 ± 1.36^{abxy}	7.27 ± 0.98^{abxy}

Note. Values are means ± SD (n=30). Values with the same following letter do not differ significantly from each other ($p < 0.05$). a,b,c Same letters within each column and same day of frozen storage do not significantly differ ($p < 0.05$). x,y,z Same letter within each treatment do not significantly differ ($p < 0.05$).

3.4.2.3 Effect of hydrocolloid on starch retrogradation of Churros during frozen storage

Starch retrogradation of Churros samples were evaluated by measuring peak temperature (T_p), onset temperature (T_o), end temperature (T_e) and enthalpy (ΔH) after 30, 60 and 90 days of frozen storage as depicted in Table 26. T_p, T_o and T_e of frozen Churros were in range of 58.83-68.67, 52.11-59.75 and 64.57-78.14 °C, respectively. Barcenas *et al*. (2004) suggested that the amylopectin retrogradation of baked frozen bread after 30 days of storage, followed by 7 days of aging at 4 °C showed a transition temperatures including T_p, T_o and T_e in range of 57.3-59.5, 38.4-44.1 and 74.6-79.3 °C, respectively. The present of hydrocolloids in the Churros had higher enthalpy when compared to the control in the fresh Churros (Churros before storage). This may due to hydrocolloid addition resulted in a compact structure of the gluten network (more dense) especially in Churros added with GG and XG (Figure 6). This results were coincidental with physical properties results which showed that hydrocolloid addition caused in increasing density (low specific volume) and hardness. Moreover, the lowest hardness was found in Churros without hydrocolloids. However, after frozen storage, retrogradation enthalpy of the control tended to increase with increasing storage time. In addition, the control had higher enthalpy than the samples with hydrocolloids especially after 60 and 90 days of frozen storage. There were slightly different in ΔH of samples with different types and concentration of hydrocolloid throughout storage time. These results indicated that frozen storage mainly influenced on the control samples. In the fast process, retrogradation involves crystallisation of amylose, while recrystallisation of amylopectin was involved in the slow process (Zeleznak and Hoseney, 1987; Biliaderis, 1992). Several studies of the different influences of various hydrocolloids on the retrogradation have been previously reported. Barcenas *et al*. (2004) found that the highest retrogradation enthalpy of pre-baked frozen bread was found in the control sample (without hydrocolloids), while the sample with bread improvers (HPMC, κC, sourdough and α-amylase) could minimize a negative effect from frozen storage and led to slight increase in retrogradation enthalpy (Barcenas *et al.*, 2003). Czuchajowska and Pomeranz (1989) explained the function of hydrocolloids that the hydrocolloids could contribute to redistribution of water and also avoid interactions between starch and gluten.

Table 26 Retrogradation parameters of basic Churros added with different types and concentrations of hydrocolloids during frozen storage

Samples		Concentration (%)	Retrogradation parameters			
			T_p (°C)	T_o (°C)	T_c (°C)	ΔH (J/g)
0 day						
	Control	-	60.00	55.15	65.29	0.354
	HPMC	0.5	60.50	54.96	66.91	0.522
	HPMC	1	63.67	57.63	70.98	0.482
	GG	0.5	61.33	53.17	69.29	0.592
	GG	1	61.33	54.46	66.75	0.425
	XG	0.05	59.00	53.17	64.57	0.561
	XG	0.1	58.83	53.61	64.73	0.410
30 days						
	Control	-	62.17	52.78	65.98	0.406
	HPMC	0.5	61.67	53.92	67.91	0.609
	HPMC	1	68.67	59.75	78.14	0.556
	GG	0.5	60.50	53.79	67.09	0.604
	GG	1	59.67	53.53	65.27	0.553
	XG	0.05	59.83	53.66	64.86	0.676
	XG	0.1	58.83	52.11	64.85	0.717
60 days						
	Control	-	60.33	53.55	68.36	0.995
	HPMC	0.5	63.67	56.3	69.48	0.762
	HPMC	1	61.17	57.36	67.03	0.743
	GG	0.5	59.83	54.23	67.25	0.61
	GG	1	63.67	56.25	70.1	0.486
	XG	0.05	62.33	55.11	68.34	0.526
	XG	0.1	60	53.6	66.84	0.594
90 days						
	Control	-	61.33	54.93	67.32	0.724
	HPMC	0.5	63.17	56.35	69	0.475
	HPMC	1	62	55.62	69.05	0.475
	GG	0.5	61.33	54.65	67.89	0.652
	GG	1	62.83	56.67	68.9	0.592
	XG	0.05	61.5	55.58	66.58	0.345
	XG	0.1	65	57.3	71	0.482

Note: T_p peak temperature, T_o onset temperature, T_e end temperature and ΔH enthalpy

3.4.2.4 Effect of hydrocolloid on microstructure of Churros during frozen storage

The microstructure results of Churros added with different types and concentrations of hydrocolloids were displayed in Figure 6. The control (without hydrocolloids) and both of HPMC addition samples showed the gluten network with the bigger void than those with GG and XG. Moreover, the Churros added with hydrocolloids especially in addition of GG and XG at both concentrations (low and high concentrations) showed a dense and impact of the gluten network. This results were in agreement with specific volume and density result as described in part 3.4.2.1. The lowest specific volume and highest density was found in the control, while hydrocolloid additions contributed to dense structure resulted from water binding capacity. This was also confirmed by starch retrogradation results which showed that Churros added with hydrocolloids contributed to increase ΔH.

After 30 days of frozen storage, the microstructure results were presented in Figure 7. The control sample still showed the structure with no evidence of damage from storage. However, the control samples evaluated after 60 and 90 days of frozen storage showed the structure with bigger void and air space in the structure as shown in Figure 8 and 9. In contrast, the Churros added with hydrocolloids showed the structure with slightly changes throughout storage time. This was due to the fact that hydrocolloid could immobilize the water and led to reduction in water migration. Thus, it could prevent a large ice crystal formation and minimize the damage to the gluten. This outcome was similar to Sharadanant and Khan (2006) who reported that the structure (gluten matrix) of frozen control bread dough was discontinuous and separated from the starch granules after 16 weeks of frozen storage. While the frozen dough treated with hydrophilic gum showed the gluten matrix with less rapture. On the contrary, Ribotta *et al*. (2004) observed that the non-frozen bread dough showed the structure with starch granules embedded in the gluten network. However, the dough structure had gluten stands with more porous and less uniform after 60 days of frozen storage. Neither diacetyltartaric acid (DATEM) nor gum guar could avoid the effect of ice recrystallization on the dough structure damage.

Therefore, the SEM results showed that Churros treated with hydrocolloids and stored for extended periods of time had less structure disruption than the control (without hydrocolloids) at equivalent periods of frozen storage. The hydrocolloids seem to immobilize water from formation of large ice crystals affected to disrupt gluten structure during frozen storage. Even though Churros added with hydrocolloids contributed to the structure with more impact.

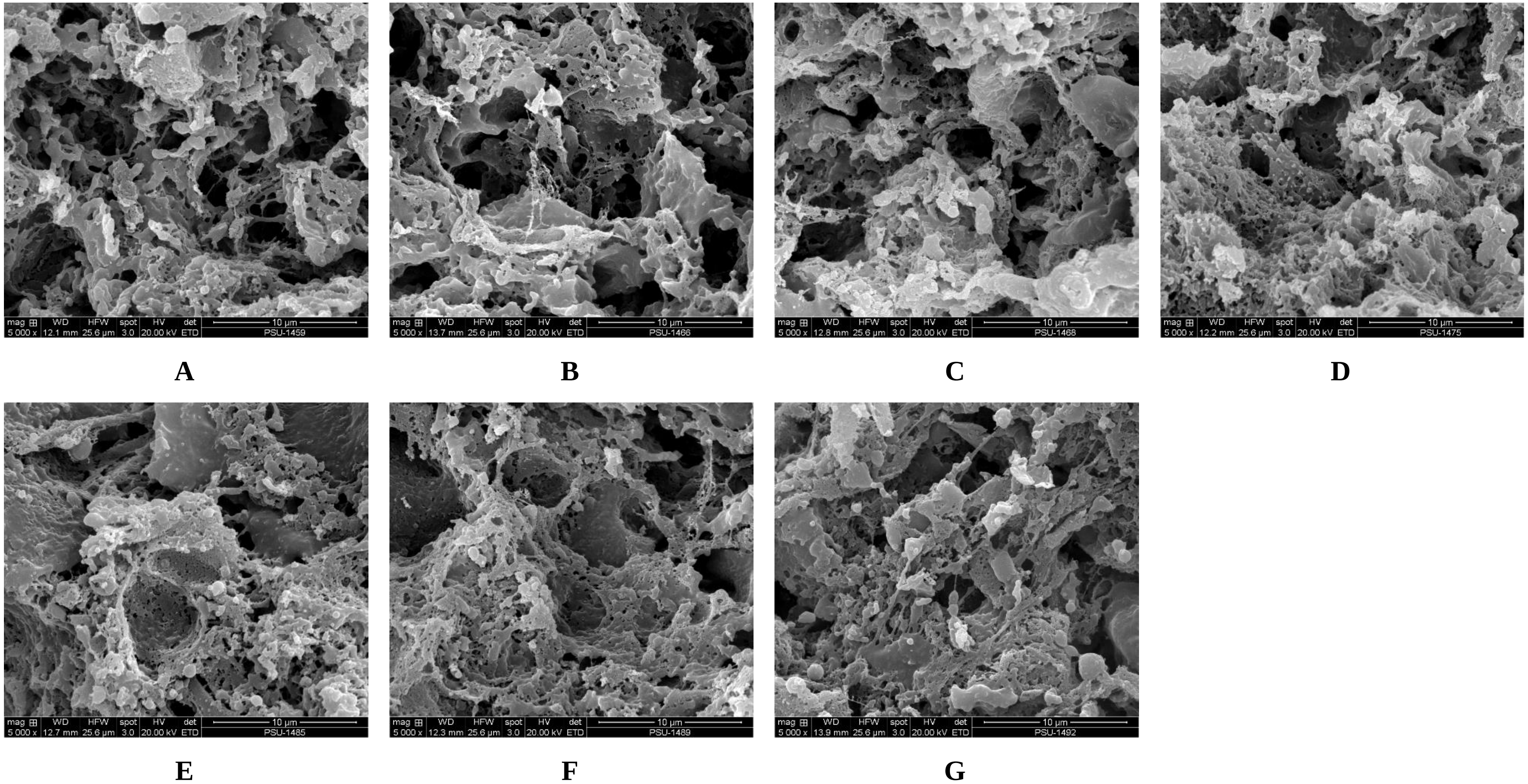

Figure 6. Scanning electron micrographs of partially fry frozen Churros without hydrocolloids (A), with 0.5% HPMC (B), with 1% HPMC (C), with 0.5% GG (D), with 1% GG (E), with 0.05% XG (F) and 0.1% XG (G) at 0 day of frozen storage.

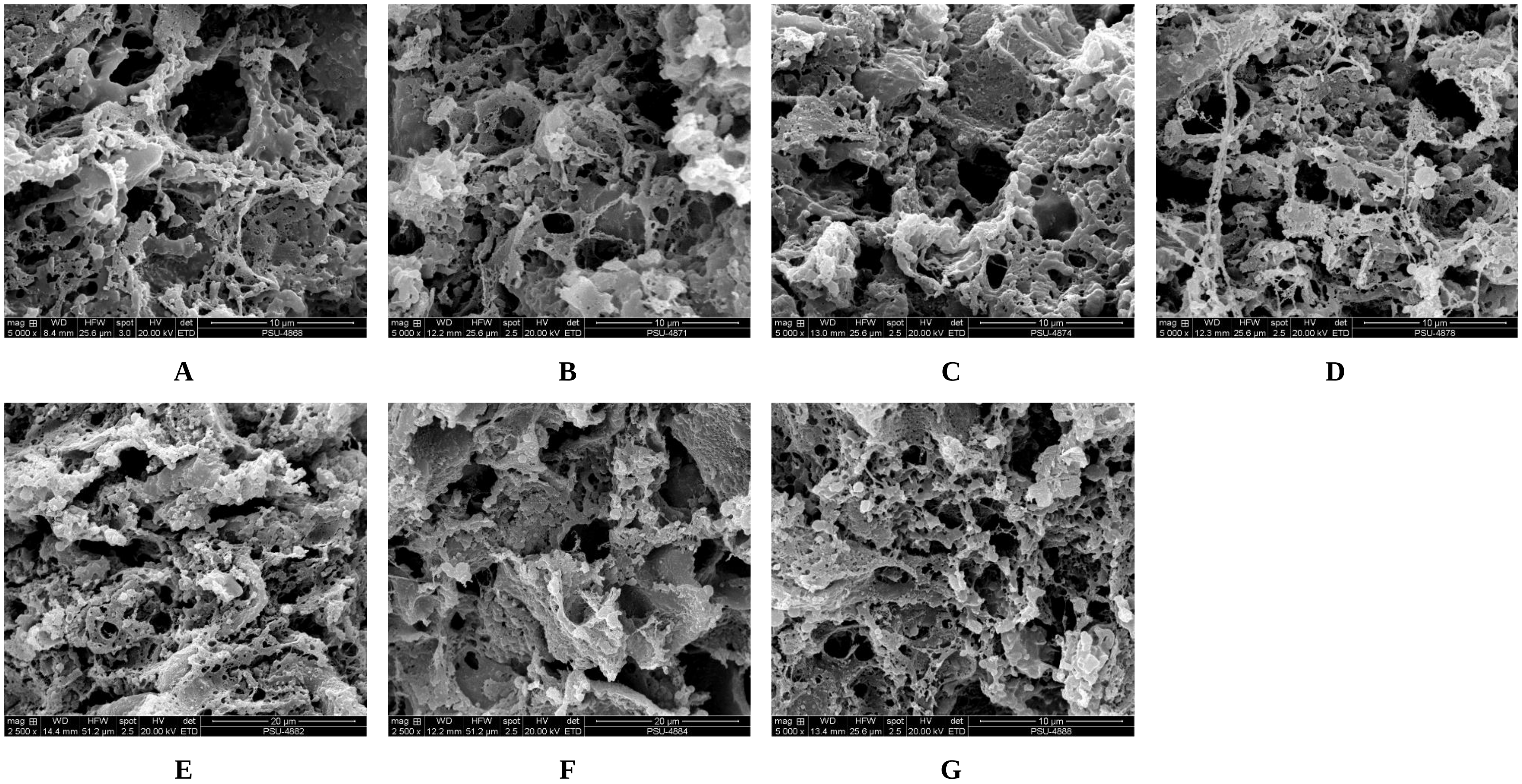

Figure 7. Scanning electron micrographs of partially fry frozen Churros without hydrocolloids (A), with 0.5% HPMC (B), with 1% HPMC (C), with 0.5% GG (D), with 1% GG (E), with 0.05% XG (F) and 0.1% XG (G) after 30 days of frozen storage.

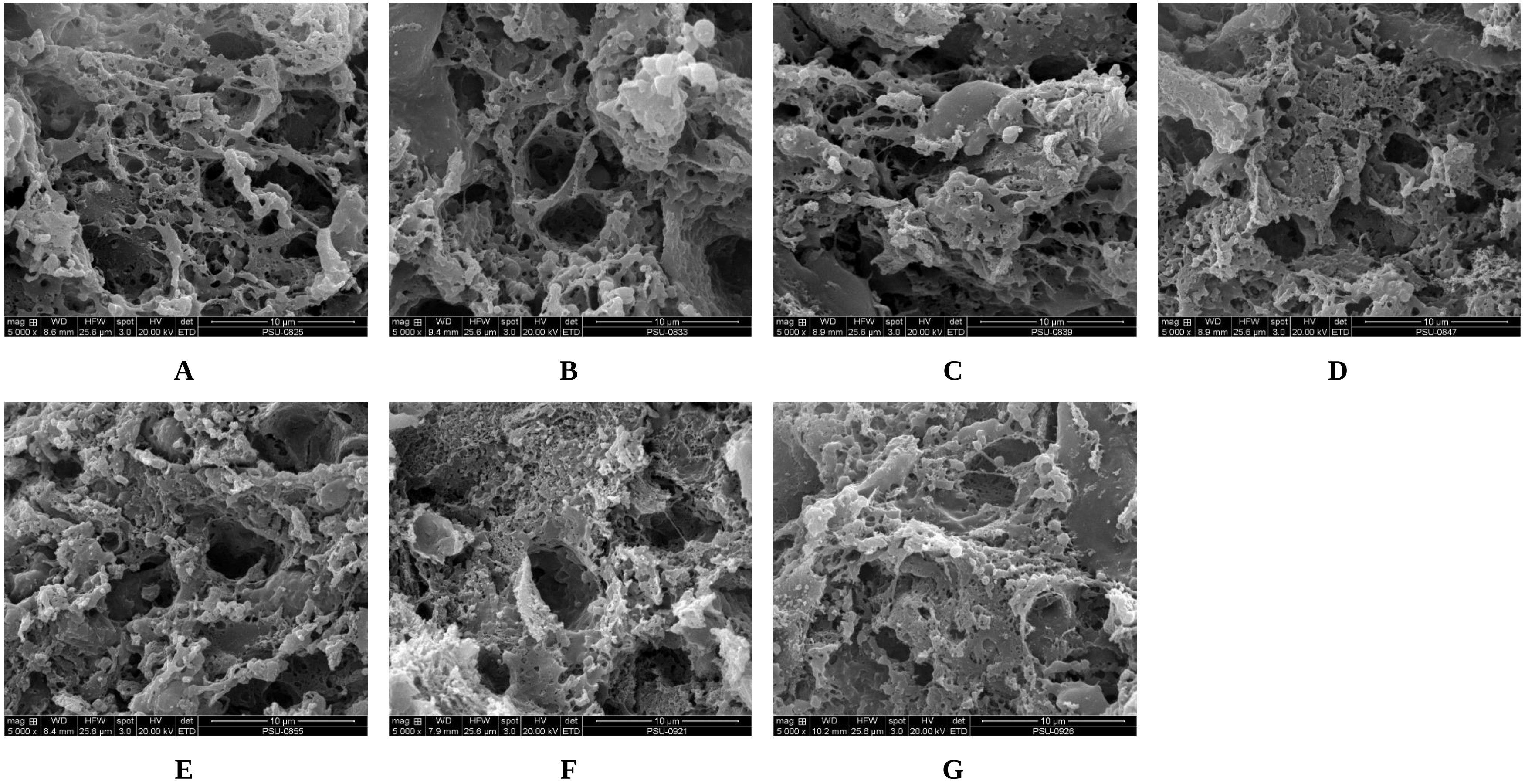

Figure 8. Scanning electron micrographs of partially fry frozen Churros without hydrocolloids (A), with 0.5% HPMC (B), with 1% HPMC (C), with 0.5% GG (D), with 1% GG (E), with 0.05% XG (F) and 0.1% XG (G) after 60 days of frozen storage.

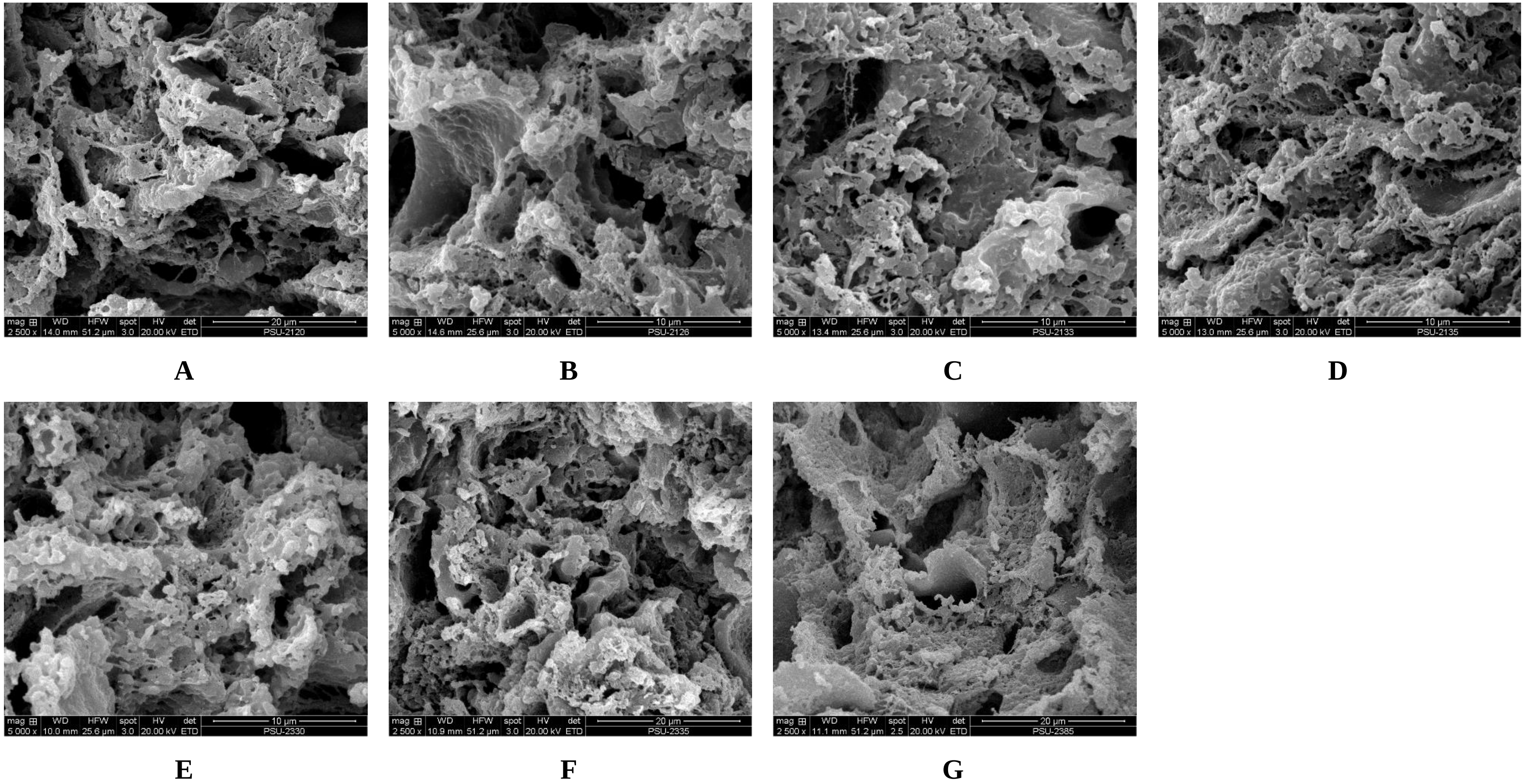

Figure 9. Scanning electron micrographs of partially fry frozen Churros without hydrocolloids (A), with 0.5% HPMC (B), with 1% HPMC (C), with 0.5% GG (D), with 1% GG (E), with 0.05% XG (F) and 0.1% XG (G) after 90 days of frozen storage.

3.4.3 Effect of different hydrocolloid on quality changes of shrimp and squid Churros during frozen storage

3.4.3.1 Lipid oxidation of shrimp and squid Churros added with different hydrocolloids during frozen storage

Lipid oxidation is a major cause of deterioration in the fried food and affecting on sensory quality such as flavor, color and texture. The measurement of lipid oxidation is essential to determine its effect on quality of product during storage. Although storage at -20 °C could extend the products shelf-life, the lipid oxidation process could be slowed down by frozen storage, but it was not completely prevent (Hansen *et al*., 2004). Thus, the mechanisms of lipid oxidation in the shrimp and squid Churros was investigated in order to study the stability of the product during frozen storage.

The results of lipid oxidation was measured as peroxide value (PV) and thiobarbituric acid (TBA) as shown in Table 27. The formation of hydroperoxides as primary product of lipid oxidation process was measured by PV values. The PV value was used to be an indicator of the initial stages of oxidation process. The results showed that the amount of PV values in all shrimp and squid Churros samples seemed to constant throughout storage time. However, the amount of lipid oxidation measured as secondary products (TBA values) in shrimp and squid Churros showed a increase with frozen storage. After 90 days of frozen storage showed the highest TBA values for each treatments ($p < 0.05$). The rate of lipid oxidation was similar with Hansen *et al*. (2004) who revealed that the level of TBARS in patties made from pork belly was constant during storage at -40 °C for 10 months. However, TBARS values were increased with stored time at -23 °C.

Table 27 Lipid oxidation of shrimp and squid Churros added with different hydrocolloids during frozen storage

Storage time (days)	Hydrocolloid		Lipid oxidation	
	Type	Concentration (%)	PV (mg cumene/ g sample)	TBA (mg MDA/kg sample)
0 day	Control	-	0.63 ± 0.17^{abw}	2.07 ± 0.24^{ay}
	HPMC	0.5	0.75 ± 0.12^{aw}	1.88 ± 0.11^{az}
	GG	0.5	0.48 ± 0.05^{bw}	1.99 ± 0.18^{ax}
	XG	0.05	0.47 ± 0.02^{bw}	1.87 ± 0.08^{ax}
30 days	Control	-	0.41 ± 0.08^{bw}	2.41 ± 0.06^{ax}
	HPMC	0.5	0.48 ± 0.04^{abx}	2.19 ± 0.07^{by}
	GG	0.5	0.57 ± 0.08^{aw}	1.87 ± 0.05^{cx}
	XG	0.05	0.57 ± 0.02^{aw}	1.3 ± 0.02^{dy}
60 days	Control	-	0.39 ± 0.05^{bw}	2.00 ± 0.13^{bcy}
	HPMC	0.5	0.52 ± 0.03^{abx}	3.05 ± 0.26^{ax}
	GG	0.5	0.41 ± 0.04^{abw}	2.27 ± 0.36^{bx}
	XG	0.05	0.60 ± 0.16^{aw}	1.75 ± 0.16^{cx}
90 days	Control	-	0.63 ± 0.18^{aw}	3.56 ± 0.08^{aw}
	HPMC	0.5	0.70 ± 0.08^{aw}	3.42 ± 0.16^{abw}
	GG	0.5	0.55 ± 0.11^{aw}	2.93 ± 0.07^{cw}
	XG	0.05	0.64 ± 0.13^{aw}	3.25 ± 0.07^{bw}

Note. Values are means ± SD with triplicate. Values with the same following letter do not differ significantly from each other ($p < 0.05$). a,b,c,d Same letters within each column and same day of frozen storage do not significantly differ ($p < 0.05$). w,x,y,z Same letter within each treatment do not significantly differ ($p < 0.05$).

3.4.3.2 Acceptance test of shrimp and squid Churros added with different hydrocolloids during frozen storage

The acceptance results of shrimp and squid Churros added with different hydrocolloids are presented in Table 28. The overall liking scores (6.70-7.40) of all sample were slightly different throughout storage time ($p < 0.05$). At the end of study, the scores ranged from 7.00 to 7.40. The results indicated that frozen storage could prevent deteriorated effect and extend shelf-life of shrimp and squid Churros. Despite the fact that lipid oxidation, especially TBA value, was increased after 90 days of frozen storage, it did not affected to consumer acceptance. This was confirmed by flavor liking scores. The score of the shrimp and squid Churros collected at 30 day intervals were not significantly different up to 90 days of frozen storage ($p > 0.05$). In addition, the important attribute such as texture acceptance scores were not influenced by frozen storage. Even though 0.05% XG addition sample showed the lowest scores at 0 days of frozen storage. This may be due to the thickening effect of crumb walls surrounding air spaces affecting on hardness (Rosell *et al*., 2001).

Table 28 Acceptance scores of shrimp and squid Churros added with different hydrocolloids during frozen storage

samples		Concentration (%)	Attributes					
			Appearance	Color	Odor	Flavor	Texture	Overall liking
0 day								
	Control	-	6.63 ± 1.27^{abx}	6.70 ± 1.18^{bx}	7.20 ± 0.81^{ax}	7.17 ± 0.91^{ax}	7.20 ± 0.92^{ax}	7.07 ± 0.94^{ax}
	HPMC	0.5	6.90 ± 1.16^{ax}	7.27 ± 1.08^{ax}	6.93 ± 0.98^{ax}	6.77 ± 1.01^{ax}	6.97 ± 1.19^{abx}	6.77 ± 0.94^{ax}
	GG	0.5	6.27 ± 1.17^{by}	6.93 ± 0.91^{abx}	7.17 ± 1.05^{axy}	6.83 ± 1.15^{ax}	6.83 ± 1.29^{abx}	6.70 ± 1.18^{ay}
	XG	0.05	6.63 ± 1.30^{aby}	7.17 ± 1.15^{ax}	6.83 ± 1.18^{ax}	6.97 ± 1.22^{ax}	6.47 ± 1.22^{by}	6.67 ± 1.12^{ay}
30 days								
	Control	-	6.57 ± 1.28^{abx}	6.53 ± 1.31^{bx}	7.17 ± 0.99^{ax}	7.30 ± 0.79^{ax}	7.30 ± 0.99^{ax}	7.30 ± 0.70^{ax}
	HPMC	0.5	7.00 ± 1.05^{ax}	7.33 ± 0.76^{ax}	7.00 ± 0.83^{ax}	6.90 ± 0.84^{abx}	6.87 ± 0.97^{ax}	6.87 ± 0.82^{bx}
	GG	0.5	6.27 ± 1.70^{by}	7.00 ± 1.17^{ax}	7.03 ± 1.22^{axy}	6.97 ± 0.96^{abx}	7.07 ± 1.01^{ax}	6.90 ± 0.96^{abxy}
	XG	0.05	6.93 ± 1.14^{axy}	7.20 ± 0.89^{ax}	7.20 ± 1.00^{ax}	6.80 ± 1.13^{bx}	7.13 ± 1.17^{ax}	6.97 ± 1.16^{abxy}
60 days								
	Control	-	7.07 ± 1.08^{ax}	7.17 ± 0.99^{ax}	7.03 ± 0.96^{abx}	7.10 ± 1.06^{ax}	7.00 ± 1.08^{ax}	7.07 ± 1.05^{ax}
	HPMC	0.5	7.07 ± 1.39^{ax}	7.20 ± 0.92^{ax}	6.90 ± 1.03^{abx}	7.10 ± 0.84^{ax}	7.03 ± 1.07^{ax}	6.97 ± 1.03^{ax}
	GG	0.5	6.97 ± 1.16^{axy}	7.23 ± 0.82^{ax}	6.77 ± 1.19^{by}	7.27 ± 1.01^{ax}	6.83 ± 1.37^{ax}	7.03 ± 1.00^{axy}
	XG	0.05	6.60 ± 1.35^{ay}	7.10 ± 1.03^{ax}	7.20 ± 0.96^{ax}	7.03 ± 0.89^{ax}	6.93 ± 0.98^{axy}	6.97 ± 0.96^{axy}
90 days								
	Control	-	6.63 ± 1.45^{bx}	6.70 ± 1.29^{bx}	7.03 ± 1.10^{ax}	7.10 ± 1.16^{ax}	7.37 ± 1.25^{ax}	7.00 ± 1.20^{ax}
	HPMC	0.5	7.10 ± 0.88^{ax}	7.37 ± 0.85^{ax}	6.93 ± 1.08^{ax}	7.07 ± 1.05^{ax}	7.07 ± 1.14^{ax}	7.27 ± 0.98^{ax}
	GG	0.5	7.30 ± 1.02^{ax}	7.47 ± 1.11^{ax}	7.40 ± 1.00^{ax}	7.20 ± 1.06^{ax}	7.30 ± 1.18^{ax}	7.40 ± 1.00^{ax}
	XG	0.05	7.30 ± 0.88^{ax}	7.60 ± 0.77^{ax}	7.30 ± 1.06^{ax}	7.23 ± 0.97^{ax}	7.33 ± 0.92^{ax}	7.40 ± 0.93^{ax}

Note. Values are means ± SD (n=30). Values with the same following letter do not differ significantly from each other ($p < 0.05$). a,b Same letters within each column and same day of frozen storage do not significantly differ ($p < 0.05$). x,y Same letter within each treatment do not significantly differ ($p < 0.05$).

CHAPTER 4

CONCLUSION AND SUGGESTION

4.1 Conclusion

The prototype dough of the Churros obtained from focus group discussion consisted of 26.62% all-purpose flour, 44.37% water, 5.32% butter, 19.52% egg, 3.55% sugar and 0.62% salt**.**

The optimized formulation with the highest desirability (0.72) of Churros added with shrimp and squid by-products (shrimp and squid Churros) consisted of 63.81% Wheat flour dough, 17.51% shrimp and 18.68% squid by-products. The product produced with the optimized formula appeared to possess the appearance, odor, flavor, texture and overall liking scores of 6.5, 7, 6.63, 6.5 and 6.5, respectively.

The addition of hydrocolloids in Churros formulation seemed to increase hardness and moisture content, but decreased the fat content. The sample with XG at high concentration (0.2 and 0.3%) had higher hardness and moisture content than other samples ($p < 0.05$). 0.3% XG exhibited the highest reduction of oil uptake to 25.89%, when compared with the control. Nevertheless, overall acceptance scores of all samples were not impacted by all hydrocolloid additions ($p > 0.05$). For the improving Churros quality during 90 days of frozen storage, the different hydrocolloids were applied. The hardness, specific volume and density of Churros added with hydrocolloids were not affected by frozen storage with exception of 0.5% HPMC. SEM results showed that the frozen control dough had damaged gluten network, while Churros with hydrocolloids had better retention of the gluten network. Moreover, the control showed a higher enthalpies than sample with hydrocolloids at the end of storage. Addition of hydrocolloids could prevent the quality deterioration of shrimp and squid Churros during frozen storage. Even though lipid oxidation, especially TBA value, was increased after 3 months storage, it did not affect on consumer acceptance.

4.2 Suggestion

The shrimp and squid Churros production should be up scale for the industrial scale production. For the further development, consumer test for shrimp and squid Churros should be evaluate for measuring performance of the product and acceptability to consumer. Even though consumer acceptance it did not affect throughout frozen storage time (90 days), lipid oxidation, especially TBA tended to increase. Therefore, the shelf-life of the product should be consider as important factor affecting the quality of product.

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APPENDIX A.

Score Sheet of Acceptance Test

1. Score sheet of acceptance test for part 2.4.3

หมายเลขแบบทดสอบ..........

วันที่.............................

แบบทดสอบคุณลักษณะทางประสาทสัมผัสผลิตภัณฑ์ชูโรส

ชื่อ...วันที่..............เวลา..............ชุดที่..............

คำแนะนำ: กรุณาทดสอบตามลำดับที่เสนอ แล้วให้คะแนนความชอบในแต่ละคุณลักษณะของผลิตภัณฑ์ โดยกำหนดให้

1 = ไม่ชอบมากที่สุด	2 = ไม่ชอบมาก	3 = ไม่ชอบปานกลาง
4 = ไม่ชอบเล็กน้อย	5 = บอกไม่ได้ว่าชอบหรือไม่ชอบ	6 = ชอบเล็กน้อย
7 = ชอบปานกลาง	8 = ชอบมาก	9 = ชอบมากที่สุด

คุณลักษณะ	รหัสตัวอย่าง			
สี				
เนื้อสัมผัส				
ความชอบโดยรวม				

- หมายเหตุ: กรุณากลั้วปากด้วยน้ำเปล่าระหว่างตัวอย่างทุกครั้ง

ข้อเสนอแนะ

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2. Score sheet of acceptance test for part 2.5.1, 2.5.3.1 and 2.5.3.2

หมายเลขแบบทดสอบ.........

วันที่............................

แบบทดสอบคุณลักษณะทางประสาทสัมผัสผลิตภัณฑ์ชูโรสผสมเนื้อกุ้งและหมึก

ชื่อ...วันที่..............เวลา..............ชุดที่...............

คำแนะนำ: กรุณาทดสอบตามลำดับที่เสนอ แล้วให้คะแนนความชอบในแต่ละคุณลักษณะของผลิตภัณฑ์ โดยกำหนดให้

1 = ไม่ชอบมากที่สุด 2 = ไม่ชอบมาก 3 = ไม่ชอบปานกลาง
4 = ไม่ชอบเล็กน้อย 5 = บอกไม่ได้ว่าชอบหรือไม่ชอบ 6 = ชอบเล็กน้อย
7 = ชอบปานกลาง 8 = ชอบมาก 9 = ชอบมากที่สุด

คุณลักษณะ	รหัสตัวอย่าง				
ลักษณะปรากฏ					
กลิ่นรส					
เนื้อสัมผัส					
ความชอบโดยรวม					

- หมายเหตุ: กรุณากลั้วปากด้วยน้ำเปล่าระหว่างตัวอย่างทุกครั้ง

ข้อเสนอแนะ

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3. Score sheet of acceptance test for part 2.5.3.3, 2.6, 2.7.1.3, 2.7.2.2 and 2.7.3.2

หมายเลขแบบทดสอบ.........

วันที่............................

แบบทดสอบคุณลักษณะทางประสาทสัมผัสผลิตภัณฑ์ชูโรสผสมเนื้อกุ้งและหมึก

ชื่อ..วันที่..............เวลา..............ชุดที่..............

คำแนะนำ: กรุณาทดสอบตามลำดับที่เสนอ แล้วให้คะแนนความชอบในแต่ละคุณลักษณะของผลิตภัณฑ์ โดยกำหนดให้

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คุณลักษณะ	รหัสตัวอย่าง		
ลักษณะปรากฏ			
สี			
กลิ่น			
กลิ่นรส			
เนื้อสัมผัส			
ความชอบโดยรวม			

- หมายเหตุ: กรุณากลั้วปากด้วยน้ำเปล่าระหว่างตัวอย่างทุกครั้ง

ข้อเสนอแนะ

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APPENDIX B.

Churros Production

1. Churros production

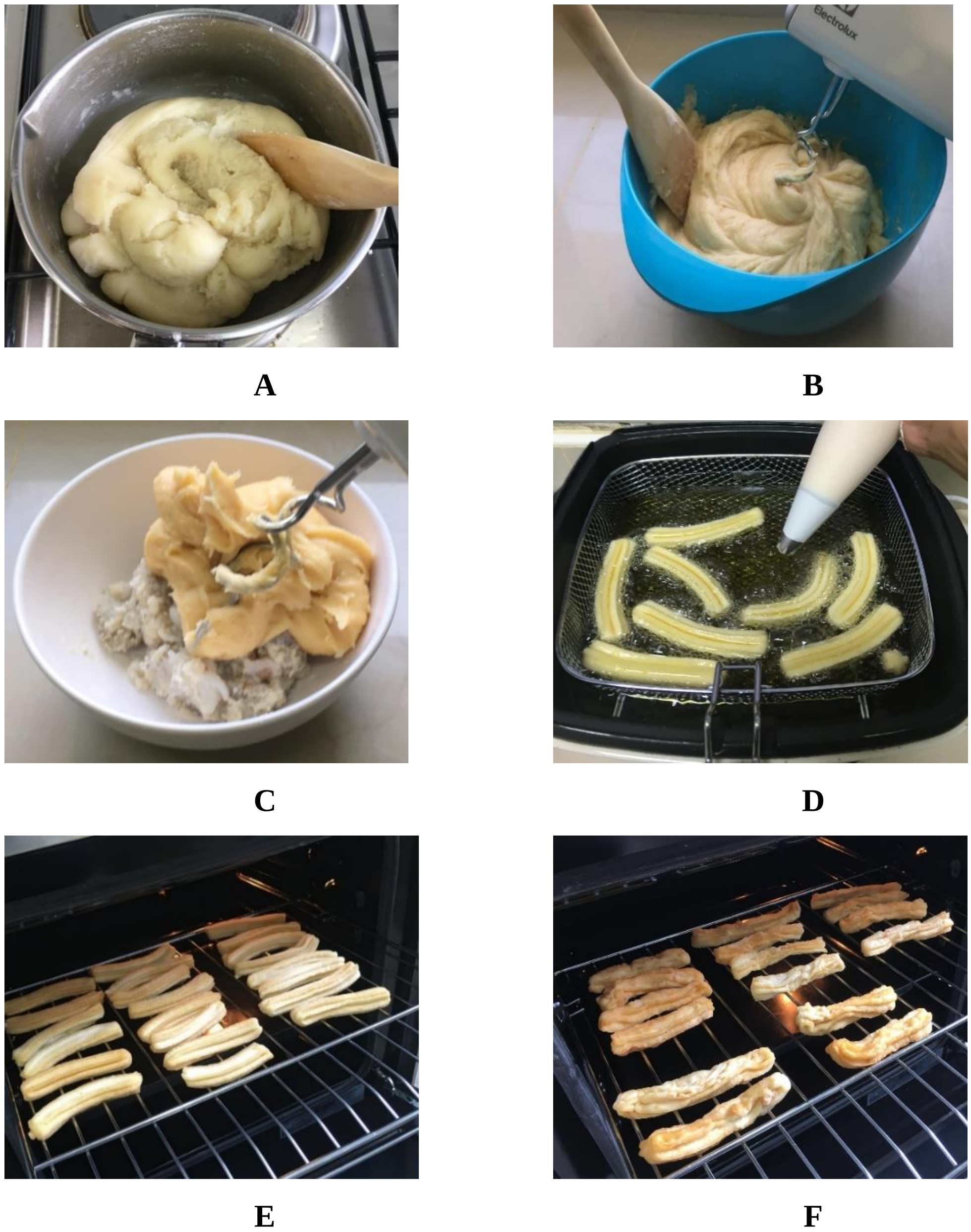

Figure B.1 Churros production: the dough before mixing with egg (A), the dough after mixing with egg (wheat flour dough) (B), wheat flour after mixing with shrimp and squid by-products (C), the partially fried Churros (D), the baking of the partially fried basic and shrimp and squid Churros (E and F).

2. Wheat flour dough of basic and shrimp and squid Churros

Figure B.2 Wheat flour dough of basic (A) and shrimp and squid Churros (B)

3. Finished product of shrimp and squid Churros

Figure B.3 Finished product of shrimp and squid Churros

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- Agro-Industry Practice School from Faculty of Agro Industry

List of Publication and Proceedings

Mektun, K. and Kijroongrojana, K. 2020. The development and use of hydrocolloids for quality improvement of frozen Churros added with shrimp and squid by-products. In proceedings of International Conference on Food and Applied Bioscience. Chiang Mai, Thailand. 6-7 February. p. 372-379.