# การสกัดใยอาหารจากไหมข้าวโพดและการประยุกต์ใช้ในผลิตภัณฑ์อาหาร

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## บทคัดย่อ

การวิจัยนี้ศึกษาความเป็นไปได้ในการสกัดและวิเคราะห์สมบัติทางเคมีกายภาพของใยอาหารจากไหมข้าวโพด ซึ่งเป็นหนึ่งในวัสดุเหลือใช้ที่สำคัญจากอุตสาหกรรมการแปรรูปข้าวโพดหวานในประเทศไทย ทั้งนี้เปรียบเทียบวัตถุดิบที่ผ่านการอบที่อุณหภูมิ 50 องศาเซลเซียสและบดก่อนการสกัด (DDF) และที่ไม่ผ่านการอบและบด (FDF) ตลอดจนการนำใยอาหารดังกล่าวไปประยุกต์ใช้กับผลิตภัณฑ์อาหาร โดยกรรมวิธีการสกัดใยอาหารจากไหมข้าวโพดทั้งสองชนิดกระทำด้วยวิธีเดียวกัน ใยอาหารที่สกัดได้นำไปวิเคราะห์การอุ้มน้ำและน้ำมัน [Water holding capacity (WHC), oil holding capacity (OHC)] สมบัติในการทำให้เกิดอีมัลชัน [Emulsifying capacity (EA) และ emulsion stability (ES)] ปริมาณใยอาหารของ DDF และ FDF มีค่าดังนี้คือ ปริมาณใยอาหารทั้งหมด (TDF) เท่ากับ 50.8% และ 76.9%, ปริมาณใยอาหารที่ไม่ละลายน้ำ (IDF) 44.3% และ 65.0% และปริมาณใยอาหารที่ละลายน้ำ (SDF) 11.9% และ 6.5% ตามลำดับ จากการวิเคราะห์ค่าการอุ้มน้ำและน้ำมันพบว่าค่าการอุ้มน้ำของ DDF และ FDF เป็น 4.9 และ 9.8 กรัม/น้ำหนักตัวอย่าง 1 กรัม และ ค่าการอุ้มน้ำมันของ DDF และ FDF เป็น 2.8 และ 5.4 กรัม/น้ำหนักตัวอย่าง 1 กรัม ตามลำดับ สำหรับสมบัติของการเป็นอีมัลชันพบว่า EA ของ DDF และ FDF เป็น 2.1 % และ 4.4% ส่วน ES เป็น 4.6% และ 13.0% ตามลำดับ ความแตกต่างของการเตรียมตัวอย่างก่อนการสกัดมีผลต่อสมบัติทางกายภาพของใยอาหารจากไหมข้าวโพด ($p \leq 0.05$) ทำการทดสอบการประยุกต์ใช้ในผลิตภัณฑ์อาหาร 2 ชนิด ได้แก่ เค้ก และแป้งชุบทอด พบว่า สำหรับผลิตภัณฑ์เค้กเมื่อเติมใยอาหารทั้งสองในระดับ 15% โดยการทดแทนแป้งสาลี เฉพาะ FDF เท่านั้นที่แสดงสมบัติในการเพิ่มปริมาตรของเค้ก นอกจากนี้พบว่าการเติมใยอาหารทั้งสองแบบทำให้เค้กมีสีที่เข้มขึ้นมากและมีผลกระทบต่อการยอมรับโดยรวมของผู้บริโภคเมื่อทำการทดสอบคุณลักษณะทางประสาทสัมผัส อย่างไรก็ตามเค้กที่มีการเติมใยอาหารจากไหมข้าวโพดให้ใยอาหารสูงกว่าร้อยละ 10 ของปริมาณที่แนะนำให้บริโภคในแต่ละวัน สำหรับการทดสอบเติมในผลิตภัณฑ์แป้งชุบทอด พบว่าการเติมใยอาหารไม่เกิดผลในการเพิ่มผลผลิต (yield) ความหนาของชั้นแป้ง (batter pick-up) และการลดการดูดซับน้ำมัน จากการทดสอบทางประสาทสัมผัสพบว่าผลิตภัณฑ์แป้งชุบทอดมีคะแนนการทดสอบทางประสาทสัมผัสไม่แตกต่างจากผลิตภัณฑ์ควบคุม สรุปได้ว่าใยอาหารจากไหมข้าวโพดมีสมบัติทางเคมีกายภาพที่ดี และสามารถนำมาใช้เป็นใยอาหารเสริมในอาหารบางประเภทโดยเฉพาะเส้นใยชนิด FDF

**คำสำคัญ :** ใยอาหาร / ไหมข้าวโพด / เค้ก / แป้งชุบทอด

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# Extraction of Dietary Fiber from Corn Silk (Zea mays) and Its application in Food Products

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## Abstract

The purpose of this study was to investigate the possibility of extracting dietary fiber (DF) from corn silk, which is one of the industrial waste products from corn milk processing in Thailand, and to compare the difference in pre-treatment steps before extraction by studying the physico-chemical properties of the resulting fibers. The potential in application to food products was also studied. The pre-treatment steps included overnight drying at 50°C and grinding. After alcoholic extraction, the physico-chemical properties of dietary fiber from dried (pre-treated) corn silk (DDF) and from fresh corn silk (FDF), i.e. water and oil holding capacity (WHC and OHC), emulsifying activity (EA), emulsion stability (ES) and pH were determined. The results showed that the total dietary fiber (TDF) content of DDF and FDF was 50.8 % and 76.9 %, insoluble dietary fiber (IDF) was 44.3% and 65.0% and soluble dietary fiber (SDF) was 11.90% and 6.5%, respectively. WHC of DDF and FDF were significantly different ($p \leq 0.05$) with the values being 4.9 and 9.8 g/g sample, respectively. OHC values of DDF and FDF were also significantly different at 2.8 and 5.4 g/g sample, respectively. EA of DDF and FDF was 2.1 % and 4.4%, while ES was 4.6% and 13.0%, respectively. The pre-treatment steps before extraction significantly ($p \leq 0.05$) affected the physical properties of corn silk fiber. The application of corn silk fiber into foods was examined on cake and deep-fried chicken batter. The results showed that only FDF increased the volume of cake when being used to substitute for wheat flour at 15% level. However, the finished product had a darker color compared to the control, resulting in a decrease of overall acceptability score from the sensory evaluation. Nevertheless, the corn silk fiber-added cakes contained more than 10% of the daily recommendation of dietary fiber intake. For deep-fried chicken batter, addition of DDF and FDF fiber at 3% level in the batter suspension did not significantly increase ($p > 0.05$) the yield and batter pick-up and did not reduce oil absorption while the sensory acceptability scores were not different from those of the control product. Corn silk fiber, especially FDF type, exhibited good physicochemical properties and can be used as an additional fiber ingredient in some food products.

**Keywords :** Dietary fiber / Corn silk / Cake / Batter for deep frying

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## 1. Introduction

Dietary fiber is part of an edible portion of plant carbohydrates that is hardly digested and absorbed in human digestive tract. It could be digested completely or partially by bacteria in the large intestine. The major compositions of dietary fiber could be separated into two components, first is soluble dietary fiber; pectin, β-glucan, glucomanan, etc. and second is insoluble dietary fiber; cellulose, hemicellulose and lignin. More and more applications of dietary fiber from agricultural by-products or wastes including pineapple core, cactus pear plant [1, 2] and other sources as food ingredients for texture modifying, gel forming and emulsifying have been reported. Dietary fiber could also provide beneficial physiological effects such as laxation, decreasing blood cholesterol and glucose [3, 4].

Nowadays, Thai people, especially those who live in major cities such as Bangkok are facing with changes in their lifestyle and dietary habit. One of the emerging problems is a transition towards consumption of high fat and/or sugar diet with an inadequate intake of dietary fiber from vegetable and fruit sources. These changes have been related to an increase in the incidence of chronic diseases such as obesity, cardiovascular disease and cancer [5, 6]. One way to solve this problem besides the promotion to increase vegetable and fruit consumption could be to introduce dietary fiber-enriched food products as an alternative choice.

Corn silk is the part of corn stigmas and is a common agricultural by-product in Thailand. It is sometimes dried and used as tea. Nevertheless, the amount of corn silk discarded as waste remains significant. Its appearance is light green or yellow-brown strands about 20-30 cm long. Corn silk contains calcium, potassium, sodium, magnesium, volatile oil compounds, steroid compounds namely sitosterol and stigmasterol, alkaloid, saponin, tannin and flavonoids [7, 8]. Some reports suggested the beneficial quality of it as having antioxidant activity determined by inhibiting lipid peroxidation [9]. In the folk remedy, it is used for edema, gout, uro-cystitis, kidney stone and prostatitis [9, 10, 11, 12]. Another part of corn silk which could be utilized is dietary fiber. However, there is limited research involving corn silk fiber and its functional properties.

Therefore, this study aims to investigate the preparation of dietary fiber from corn silk and compare the physicochemical properties of two corn silk fibers that were different due to the pre-treatment of extraction methods as well as the potential application of those fibers in food products.

## 2. Materials and methods

### 2.1 Sample preparation

Corn silk from sweet corn (*Zea mays*) was obtained from the corn milk processing facility of the National Corn and Sorghum Research Center in Nakhon Ratchasima Province. The fresh corn silk sample was packed in polyethylene bags and kept at 4°C until further experiment.

Dried corn silk was prepared by drying the fresh corn silk at 50°C in a hot air oven (Memmert, Germany) for 12 hrs. The dried corn silk was then milled in a high speed mill (Moulinex Optiblend Duo, KRUPS, French and Kenwood CG100, USA.). The obtained powder packed in polyethylene bags and kept at 4°C until further experiment.

**2.2 Extraction procedure**

**Extraction of dietary fiber from fresh and dried corn silk (FDF and DDF)**

The preparation of FDF was conducted by the modified alcoholic extraction process by Thumthanaruk (1996) [13]. The fresh corn silk sample was boiled in water for 3 hrs to remove soluble matters with changing water every hour. The sample was then extracted twice with 95% ethanol (1 kg corn silk: 5 liters ethanol) overnight with occasional agitation, then ethanol was removed by filtering through a nylon bag using a hydraulic press. Finally, the ethanol-insoluble solid fraction was collected and dried in a hot-air oven at 60°C for 6 hrs. The obtained FDF was ground using a high speed mill and kept in polyethylene bags at room temperature.

The preparation of dietary fiber from dried corn silk (DDF) was conducted using the same procedure as described above for fiber extraction from fresh corn silk except the boiling step was omitted.

**2.3 Determination of total dietary fiber content in the fiber from corn silk**

The total dietary fiber (TDF), insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) content were measured using an enzymatic gravimetric method according to AOAC (1990) [14].

**2.4 Determination of physicochemical properties of dietary fiber from corn silk**

**2.4.1 Water and oil holding capacity (WHC and OHC)**

According to the method described by Elkhalifa et al. [15], 2 g of sample were dispersed in 20 ml distilled water or soybean oil contained in a centrifuge tube using a Vortex mixer. The slurry was allowed to stand for 30 min and then was centrifuged at 4000xg for 25 min. After centrifugation the supernatant was drained off. The remaining wet precipitate was then weighed. The result was expressed as g of water or oil retained per g of sample.

**2.4.2 Emulsifying activity and emulsion stability**

Emulsifying activity (EA) and emulsion stability (ES) of FDF and DDF were determined following the procedure reported by Elkhalifa *et al*. [15].

Approximately 2 g of sample were suspended in 50 ml of water and then 50 ml of soybean oil was added. The mixture was emulsified using a homogenizer (IKA ULTRA TURAX-T25) with designation of a dispersing tool (S25N-25F) at 135,000 rpm for 1 min. The emulsion obtained was divided equally into 2 centrifuge tubes. One tube was centrifuged at 4,000xg for 5 min. The other tube was heated to 80°C for 30 min and cooled to room temperature then centrifuged at 4000xg for 10 min. EA and ES were calculated by the following formulas:

EA (%) = [Height of emulsion layer / Height of whole layer (cm)] x100

ES (%) = [Height of emulsion layer after heating/ Height of whole layer (cm)] x100

**2.4.3 pH**

The pH of the sample was measured using a pH meter. Sample with a known weight in g was mixed with 50 ml distilled water and let stand for 30 min at room temperature before measuring.

**2.4.4 Color**

The color of the sample was determined using a chromameter (Color Techno System Corporation, Tokyo, Japan). The color values are expressed as $L^*$ (lightness), $a^*$ (redness or greenness) and $b^*$ (yellowness or blueness).

**2.5 Application of dietary fiber from corn silk in food models**

**2.5.1 Preparation of corn silk fiber-added cake**

Cakes were prepared to test the effect of fiber ingredients in a baked product. FDF and DDF were used to substitute 15% of the total weight of wheat flour in the regular cake recipe while other ingredients were kept constant. The control formula for cake preparation was based on the one reported by Prakongpan [5]. Cake batter was prepared using an electric mixer (Verasu, Homemate HOM-12KP81, Thailand). All ingredients were mixed and blended at a low speed for 0.5 min in a mixing bowl. The speed was increased to high then continued mixing for 3 min and poured into a square pan size 0.5 pound, baked at 180°C for 30-40 min until a wooden pick inserted in the center came out clean. The finished cake was cooled to room temperature.

The procedure for cake making was the same as described above for the control cake.

**2.5.2 Quality determination of cake product**

**a. Volume** (ml) of cake was measured using the sesame seed displacement method.

**b. Color** values of crust and crumb of cake were measured by using a chromameter (Color Techno System Corporation, Tokyo, Japan).

**c. Water activity** of cake was measured by a water activity analyzer (Novasina IC-500 Aw-Lab, Axair Ltd., Pfäffikon, Switzerland)

**2.5.3 Determination of TDF content of cake product**

Corn silk fiber-added cake was determined for TDF content using the enzymatic-gravimetric method of AOAC [14].

**2.5.4 Preparation of deep-fried chicken batter**

DDF and FDF corn silk fiber were added to a batter suspension at 3% level by weight while other ingredients were kept the same as in the control batter. The fiber-added batter was allowed to hydrate for about 5 min before frying.

The recipe of batter suspension and deep fried chicken preparation followed those described by Ang, 1993 with a slight modification in the percentage of ingredients [16]. Skinned, boneless chicken breast was cut into 3×3 cm pieces then dipped in a batter suspension to obtain good coating. Then the battered chicken pieces were deep-fried in palm oil in a deep-fryer at 180°C for 3 min. The fried chicken was cooled on a paper towel before further testing.

**2.5.5 Quality determination of deep-fried chicken batter**

**a. Yield**

was measured as a percentage of weight retained after frying according to the following formula.

$$\text{Yield (\%)} = \frac{\text{Cooked weight (g)} \times 100}{\text{Raw weight (g)}}$$

**b. Batter pick-up**

The amount of batter adhering to the samples during coating before frying was considered as the batter pick-up. The batter pick-up of FDF and DDF-added batter was measured as a percentage ratio of the weight of batter coating and the weight of batter-coated food [17]. It was calculated using the formula shown below.

Batter pick-up (%) = [(Weight of batter-coated sample) – (weight before coating) × 100]/ (Weight of batter-coated sample)

**c. Oil uptake of deep-frying batter**

Batter suspension before frying and the batter crust removed from deep-fried chicken pieces were analyzed for moisture content, fat content and oil uptake in triplicate analyses. Moisture and fat contents were analyzed using the hot-air oven method and Soxhlet extraction method following the AOAC method (1990) [14].

The criterion "UR", expressed the oil uptake ratio between the weight of oil uptake and the weight of water removed. The value was used to evaluate the effectiveness of dietary fiber ingredient to reduce oil absorption during deep-fat frying. The difference between moisture content before and after frying was calculated as water removed and the difference between initial and final fat content of frying batter was used as oil uptake. [17] The value of UR was calculated as follows.

$$U_R = \frac{\text{Oil uptake (g)}}{\text{Water removed (g)}}$$

**2.5.6 Sensory acceptability test**

Sensory acceptability test was performed for both control and dietary fiber-added products. The food samples were evaluated by thirty untrained test panelists recruited from staff and graduate students of the Institute of Nutrition, Mahidol University. For cake products, the samples were prepared one day before the evaluation, packed in polypropylene bags and stored at 4°C. For deep-fried chicken, samples were prepared on the same day of the evaluation. All samples were coded with a three-digit random number and randomly served to each panelist. Nine-point hedonic scales were used for evaluating color, flavor, general appearance, texture and overall acceptability of the product. The scale ranged from 1 to 9 where 1 = "dislike extremely", 5 = "neither like nor dislike", and 9 = "like extremely".

**2.6 Statistical analysis**

The mean values of data from chemical analysis and physical analysis were analyzed for significant difference at $p = 0.05$ using an independent sample t-test.

For sensory acceptability test, one-way ANOVA and Duncan's Multiple Range Test were used. All statistical analyses were performed using SPSS/PC+TM Program version 13.0.

## 3. Results and Discussion

**3.1 Fresh corn silk**

Fresh corn silk, a by-product from the corn milk processing facility, was high in moisture content, (67.9%). It was removed from the fresh corn along with the husk by the producer and discarded. The color of corn silk was not uniform because of its heterogeneity in cultivars and maturity. Furthermore, enzymatic browning reaction may occur during peeling.

**Table 1** Physico-chemical properties of dietary fiber from fresh and dried corn silk (FDF and DDF)[1]

| Property | Value | |
|---|---|---|
| | FDF | DDF |
| WHC (g/g sample) | 9.8 ± 0.7 | 4.9 ± 0.1 |
| OHC (g/g sample) | 5.4 ± 0.5 | 2.8 ± 0.1 |
| Dietary fiber content (% dry basis)[2] | | |
| TDF | 76.9 | 50.8 |
| IDF | 65.0 | 44.3 |
| SDF | 11.9 | 6.5 |
| Emulsifying activity (%) | 4.4 ± 0.6 | 2.8 ± 0.1 |
| Emulsifying stability (%) | 13.0 ± 2.2 | 4.6 ± 1.4 |
| pH | 6.5 ± 0.1 | 6.7 ± 0.0 |

[1]Results are mean ± SD of triplicate analyses.
[2]Results are mean of duplicate analyses

In terms of dietary fiber, corn silk contained 17.2% TDF on a fresh weight basis or around 54% on dry basis with the main fraction being insoluble fiber. Hence, it showed a potential as a starting material for preparation of a dietary fiber food ingredient.

### 3.2 Extraction of dietary fiber from fresh corn silk (FDF) and from dried corn silk (DDF)

Fresh corn silk was boiled in water to remove impurities, water soluble components (e.g. starch) and chlorophyll pigments in order to make the dietary fiber more purified [18]. Then it was extracted with 95% ethanol, dried and ground in order to obtain FDF. In considering the feasibility of handling a large amount of fresh corn silk which can decompose rapidly, dried corn silk was prepared and used as a starting material for dietary fiber extraction to yield DDF. Both resulted fibers were compared for their yield as well as physical and chemical properties.

The yield of dietary fiber from ethanolic extraction of fresh (FDF) and dried (DDF) corn silk was 22 and 24%, respectively meaning that the pretreatment by drying did not affect the percentage yield of fiber. Nevertheless, when considering its respective fiber content on a dry weight basis, FDF contained more fiber than DDF. From Table 1 FDF contained mainly TDF at 77% dry weight with the major fraction being IDF (65% dry weight) whereas DDF contained 51% TDF (dry weight) with 44% IDF (dry weight). This may be due to the difficulty in extracting the dried material than its fresh counterpart. Similarly, the study of Burkus & Temelli in 1998 revealed that a small modification of the extraction procedure may cause a marked effect to the composition, functional behavior, viscosity, color, molecular weight and the physicochemical properties of the extracted β-glucan [19, 20] McCleary and Prosky quoted in 2001 that the physicochemical characteristics like molecular, structural and functional properties of dietary fiber could be changed by the processing that commonly are the effects from hydrolytic enzymatic reactions and chemical degradation or crafting reactions [21]. The result of these previous studies may explain the difference in dietary fiber content (TDF, SDF and IDF) of FDF and DDF. Total dietary fiber content of FDF and DDF was comparable to other fibers prepared from by-products from the food industry for example, rice bran (27%), citrus peel (57%) and corn bran (88%). [22, 23, 24] The high dietary fiber content makes them an interesting raw material for fiber preparation in order to enrich dietary fiber content in food products due to its high insoluble dietary fiber content.

The color of FDF and DDF were yellow-brown and dark-brown. The pH (6.5 and 6.7) was close to neutral pH. According to the Food

Chemical Codex, the pH of cellulose and insoluble fiber should be between 5.0 and 7.5 [25].

### 3.3 Physical and chemical properties of FDF and DDF

#### 3.3.1 Particle size of FDF and DDF

The major portion of FDF fiber was retained on 120 and 140 mesh screens (totaling around 60%) while the portion of DDF fiber retained on 60 and 80 mesh screen (totaling around 50%). Particle size, surface area and porosity can be affected by the shear forces in mechanical and physical processing. Differences in shape and size of fiber particles produce the heterogeneity in size distribution and influence the functional and physiological properties of dietary fiber. Application of fiber with various particle sizes in food product had a particular effect on the mouth feel characteristics (17).

#### 3.3.2 Water holding capacity

Water holding capacity (WHC) is a property of dietary fiber which is important from a technological point of view that it can be applied in food products as a new ingredient for a low-calorie healthy diet and for modifying the physical properties and texture of food products [21]. Dietary fiber binds with water by the interaction between polar and hydrophobic interactions [26]. WHC of FDF was 9.8 g/g fiber which was greater than the value obtained from DDF, 4.9 g/g fiber (Table 1). FDF seemed to have ability to trap water inside the fiber matrix more than DDF. Chaplin (2003) reported that dietary fiber bind with water by the interaction between polar and hydrophobic interactions. These reactions varied with the flexibility of the fiber surface [26]. The environment condition such as pH, ionic strength, temperature, nature of the ions can also make the hydration properties of dietary fiber change [27]. Mechanical properties such as shear force and drying process can also influence the surface of dietary fiber as the kinetics of water uptake, the decrease of water retention and water absorption capacity [27]. In this study the content of IDF of DDF was lower when compared with that of FDF. Hence, it resulted in a lower WHC value of DDF.

Overall, the WHC of FDF (9.8 g/g sample) and DDF (4.9 g/g sample) was comparable to other fiber sources reported in previous research such as seedless grapefruit (9.70), pear DF (6.8), apple DF (6.3), rice bran (4.94), citrus husk (3.60) and pineapple peel (3.50). [28, 29, 22, 28, 30] The high WHC of FDF corn silk fiber made it a good material to be used in food products requiring hydration, viscosity development and freshness preservation, e.g. baked foods and cooked meat products while DDF could work well in systems with less water.

#### 3.3.3 Oil holding capacity

Oil holding capacity (OHC) is the one of dietary fiber properties that could be affected by the particle size of dietary fiber and the mechanical sheer from grinding process and also related to the content of insoluble dietary fiber [31]. The importance of OHC is that when fiber is added to food products, it can absorb the oil. The absorbed oil can be determined as fat absorption capacity. From Table 1 OHC of FDF was 5.4 g/g fiber and DDF was 2.8 g/g fiber. The OHC value of DDF was lower when compared to the other literature of some agricultural by-products, such as sugar beet fiber, sugarcane bagasse and coconut fiber (5.1, 5.1 and 4.8 g/g fiber, respectively) [31, 32, 33]. The results agreed well with other studies. The difference in OHC observed in this study ($p \leq 0.05$) was due to the effect from pretreatment to corn silk fiber like the above explanation for water holding capacity. High OHC of FDF and DDF could be useful for flavor and fat retention in food products as cooked meat products since normally the flavor of meat could be lost after cooking [34].

#### 3.3.4 Emulsifying activity and emulsion stability

The emulsifying activity (EA) is the ability of molecules to act as an agent for dispersing one liquid in a second immiscible liquid. Emulsifying stability (ES) is the ability to maintain the integrity of the two phases in the emulsion [34]. Generally, polysaccharides do not have a function like an emulsifier, but they are usually used for providing emulsion stability [35]. The emulsifying activity of FDF and DDF corn silk fiber was 4.4% and 2.1% while the emulsion stability was 13.0 % and 4.6, respectively as shown in Table 1. EA and ES values of FDF and DDF revealed that they may not act as a good emulsifier probably because of their low SDF content from the boiling step in extraction. Some EA and ES of FDF and DDF in this study may happen because of some protein fractions that still remained in it as well as from the physical effect of the presence of fiber.

### 3.4 Application of corn silk fiber (FDF and DDF) in food products

#### 3.4.1 Cakes

From the results of preliminary experiments (10-20% substitution), FDF and DDF corn silk fiber was incorporated in the cake formula by partial substitution of wheat flour at 15% level without changing other ingredients. The addition of FDF was effective to significantly increase the volume of cake compared to the control formula (Table 2). In 2010, it was suggested from the study of Gomez *et al*. that the incorporation of wheat bran, oat bran and microcrystalline cellulose at 36% with a different particle size resulted in a decrease of cake volume while addition at 12-24% significantly increased the volume compared to the control formula [36]. Volume of cakes depends on the capacity of the batter to incorporate air during mixing and baking and on starch gelatinization temperature.

**Table 2** Volume, water activity and color ($L^*$, $a^*$, $b^*$)[1] of FDF and DDF-added cakes compared with the control formula[2, 3]

| | Cake sample | | |
|---|---|---|---|
| | Control (No fiber added) | 15% DDF[4] | 15% FDF[5] |
| Volume | 320.0 ± 34.6$^a$ | 346.7± 23.1$^a$ | 460.0 ± 34.6$^b$ |
| Water activity | 0.92 ± 0.01$^a$ | 0.91 ± 0.01$^a$ | 0.91 ± 0.01$^a$ |
| Crust color | | | |
| L* | 49.4 ± 2.4$^a$ | 33.5 ± 1.8$^b$ | 38.7 ± 3.3$^b$ |
| a* | 13.2 ± 0.4$^a$ | 9.8 ± 0.3$^b$ | 10.5 ± 0.7$^b$ |
| b* | 34.6 ± 3.2$^a$ | 15.5 ± 2.3$^b$ | 21.4 ± 3.3$^b$ |
| Crumb color | | | |
| L* | 77.0 ± 3.0$^a$ | 45.7 ± 1.3$^b$ | 33.5 ± 1.8$^c$ |
| a* | -0.8 ± 0.3$^a$ | 7.5 ± 0.2$^b$ | 9.8 ± 0.3$^c$ |
| b* | 24.7 ± 2.1$^a$ | 19.5 ± 0.4$^b$ | 15.5 ± 2.3$^c$ |

1 = -L = 0(black), +L= 100(white), +a = red, -a = green, +b = yellow, -b = blue.
2 = Results are mean ± SD of triplicate analyses. Each of which consisted of 3 cakes.
3 = Values in the same row bearing different letters are significantly different ($p \leq 0.05$)
4 = Dietary fiber from dried corn silk, substituted at 15% by weight of wheat flour
5 = Dietary fiber from fresh corn silk, substituted at 15% by weight of wheat flour

This may be explained by the results of Caprises et al., 2008 which stated that the addition of dietary fiber could slow down the rate of gas diffusion of batter viscosity and give enough strength for the cake to hold the expanded air cells during baking and retain the cells during the early stage of baking [37]. Hindering the change of batter from a fluid aerated emulsion to a solid with porous structure came about by an increase of starch gelatinization temperature. Then air bubbles were allowed to properly expand by the carbon dioxide gas and water vapor before the cake set and finally increased its volume [38].

Furthermore, the batter viscosity had to be sufficient to retain the air incorporated during mixing. Therefore, an increase of batter viscosity by the addition of fiber would help in gas retaining of the batter that result in the increase of cake volume. Hence, this study showed that to increase the volume of cake, FDF would be an appropriate choice.

The color of the control cake was light yellow while the color of corn silk fiber added cake, both of crust and crumb, was clearly different from the control (Table 2). The color of FDF and DDF-added cakes became darker. Many research found that crust color can be affected from the Maillard reaction. Adding fiber did not seem to have an effect on the reaction between the sugars and amino acids, even though the lower proportion of flour was used in the formulation. Color changes could also happen by the alteration of pH from the ability of dietary fiber to act as a buffer and a change in water availability. However, no clear evidence has been elucidated about the different kinds of fiber to use to make the reaction happen [39]. On the other hand, crumb color commonly depends on the color of raw materials because the increase in temperature inside the cake is not high enough for the Maillard reaction and caramelization to occur [39]. Hence, in this study a darker crust and crumb color might come from the appearance of fiber itself in the product. Considering the water activity of the cake, addition of both FDF and DDF did not significantly alter this property compared to the control. Therefore, it could be assumed that the fiber-supplemented cakes would have the same storage ability and shelf-life as the control cake.

**Table 3** Sensory acceptability scores of the DDF and FDF-added cakes[1, 2, 3, 4]

| Control, DDF and FDF-added cakes[3] | General appearance | Overall acceptability | Color | Flavor | Texture | Taste |
|---|---|---|---|---|---|---|
| 0% | 7.37 ± 0.81[a] | 7.53 ± 0.90[a] | 7.30 ± 0.84[a] | 7.30 ± 1.15[a] | 6.93 ± 1.05[a] | 7.70 ± 0.80[a] |
| 15% DDF[3] | 5.13 ± 1.85[b] | 5.53 ± 1.61[b] | 5.60 ± 1.59[b] | 5.00 ± 1.72[b] | 4.87 ± 1.94[b] | 5.37 ± 1.81[b] |
| 15% FDF[3] | 5.60 ± 1.63[b] | 5.40 ± 1.99[b] | 5.50 ± 1.61[b] | 6.33 ± 1.75[c] | 5.23 ± 1.77[b] | 6.17 ± 1.76[c] |

[1]Results are mean ± SD, n= 30.
[2]Values in the same column bearing different letters are significantly different ($p \leq 0.05$).
[3]DDF= Dietary fiber from dried corn silk, FDF = Dietary fiber from fresh corn silk.
[4]Nine-point hedonic scale (9=like extremely, 5=neither like nor dislike, 1=dislike extremely).

The sensory quality of FDF and DDF-added cakes were significantly inferior ($p \leq 0.05$) to the control formula in all characteristics (Table 3). Color and appearance seemed to be the major factors leading to this result (r = 0.575 and 0.693, data not shown). However, the fiber added cakes were still acceptable to a certain number of panelists. According to the research by Schafter *et al*., dietary fiber extracted from corn bran was used to increase the fiber content of widely consumed foods like bread. They found undesirable changes of the product quality when fortified at 200 g/kg.

The sensory acceptability scores including texture, color and flavor were all decreased [40]. Ayadi et al. also studied about the effect of the incorporation of cladodes flour in cake product and found that it affected the sensory scores of cake when substituted at 15% and 20% level resulting in poor sensory scores [6]. Corn silk fibers (FDF and DDF) were applied in cakes primarily for the purpose of nutritional benefit through increasing the dietary fiber content. Both products could be labeled as “a source of”, “contain” or “have” dietary fiber according to the Ministry of Public

Health Notification No. 182 [41]. One serving of the formulated cakes provided more than 10% of the Thai RDI for dietary fiber (2.5 g). FDF and DDF-supplemented cake contained around 2.7 g dietary fiber per 80 g reference amount.

#### 3.4.2 Deep-fried battered chicken

In terms of deep-fried battered chicken product, 3% level of FDF and DDF were added to the batter suspension. Most of the quality characteristics of FDF and DDF-added products were not significantly different ($p$>0.05) when compared to the control formula (Table 4 and 5). Coating is a common preparing step before frying that is composed of dipping the material in a coating suspension for a short time instantly before beginning of frying process. Normally it is one of the surface treatments that have a feasibility in the reduction of surface porosity by making a barrier and then preventing oil uptake. In addition coating technique also decreases the water loss during frying [42]. Moreover, the high water binding capacities of hydrocolloids in coating generally develop viscosity in batter systems and prepare the batter to catch the gas released by fast-acting leavening agents.

**Table 4** Batter pick-up and yield of the DDF and FDF fiber-added deep-fried battered chicken[1, 2]

| | **Deep-fried battered chicken sample** | | |
|---|---|---|---|
| | **Control (No fiber added)** | **3% DDF [3]** | **3% FDF [3]** |
| Batter pick-up (%) | 42.4 ± 1.5[a] | 46.4 ± 4.2[a] | 41.9 ± 4.2[a] |
| Yield (%) | 90.2 ± 2.7[a] | 94.4 ± 2.0[a] | 93.1 ± 2.6[a] |

[1]Results are mean ± SD of triplicate analyses, Each of which consisted of 9 nuggets.
[2]Values in the same row bearing different letters are significantly different ($p$ ≤0.05).
[3]DDF= Dietary fiber from dried corn silk, FDF = Dietary fiber from fresh corn silk.

Reduction of oil absorption is achieved by reducing the porosity in the surface of batter [43]. The mechanisms of addition of dietary fiber in batter coating system was explained by Ang *et al.* that the longer cellulose fibers had a capacity to bind the water molecules and reduced the fat content by increasing the number of hydrogen bonding between water molecules and longer cellulose fibers. These reactions resulted in the limitation of the displacement of fat during frying process [16]. In this study, the addition of corn silk fiber, both DDF and FDF, in batter suspension could not form a good enough hydrocolloid in order to create an effect on the water removal process.

The type and level of fiber added may influence the kinetic of fiber in absorbing oil and water. The 3% level used may not be sufficient to provide the desirable effect. Furthermore, the internal structure of corn silk fiber may not support this application. WHC and OHC definitely played an important role. Sanchez-Zapata *et al.* in 2009, described that their dietary fiber extracted from tiger nut waste by-product (having a similar OHC to FDF) could be a potential ingredient to apply in cooked meat product for flavor and fat retention [34] since this type of foods ordinarily lose fat during cooking. It might also be possible to apply corn silk fiber in the kinds of products mentioned in their study.

In terms of sensory acceptability (Table 6), the addition of FDF and DDF corn silk fiber in deep-fried battered chicken showed that only the color and general appearance scores were poor.

All other sensory characteristics were accepted at a similar level to the control.

**Table 5** Oil uptake, water removed and UR value of DDF and FDF-added deep-frying batter compared with the control formula[1, 2, 3]

| Sample | Oil uptake (g) | Water removed (g) | $U_R$[4] |
|---|---|---|---|
| Control | 27.8 ± 4.7[a] | 40.2 ± 1.5[a] | 0.7 ± 0.1[a] |
| 3% DDF[5] | 29.1 ± 1.6 (+1.3)[a] | 37.0 ± 2.8 (-3.3)[a] | 0.8 ± 0.1 (-8.2)[a] |
| 3% FDF[6] | 28.2 ± 2.3(-0.4)[a] | 31.4 ± 2.3 (8.8)[b] | 0.9 ± 0.1 (-0.2)[a] |

[1]Results are mean ± SD from triplicate analyses.
[2]Numbers in ( ) indicate percent difference from the control formula.
[3]Values in the same column bearing different letters are significantly different ($p \leq 0.05$).
[4]$U_R$ expresses the oil uptake ratio between the weight of oil uptake and the weight of water removed.
[5]DDF = Dietary fiber from dried corn silk.
[6]FDF = Dietary fiber from fresh corn silk

## 4. Conclusion

A dietary fiber ingredient could be prepared from fresh and dried corn silk, which is a by-product from the corn milk processing facility. Both FDF and DDF corn silk fiber contained a large amount of dietary fiber which was neutral in pH. This may make them possible for wide range of food applications. The water holding capacity of FDF and DDF was high. For the oil holding capacity, only the value for FDF was considered to be high while that of DDF was low.

Moreover, the emulsifying activity and emulsion stability were lower than some other sources of Regarding food applications, fiber-supplemented products were acceptable to a certain extent although they were less preferred than the control formula, particularly in cake. The fiber-enriched cake products could be labeled as a source of dietary fiber according to the nutrition labeling regulation. fiber from agricultural by-products in previous studies.

Hence, from their physicochemical properties, FDF and DDF showed a good potential for use as an alternative source of dietary fiber in food products. A further study to improve the color of fiber may be carried out to expand the application of corn silk fiber in greater varieties of food.

## 5. Acknowledgement

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**Table 6** Sensory acceptability scores of the DDF and FDF fiber-added deep-fried battered chicken[1, 2]

| Sample | General Appearance | Overall Accpetability | Color | Flavor | Texture | Taste |
|---|---|---|---|---|---|---|
| Control | $7.47 \pm 1.04^{a}$ | $6.67 \pm 1.54^{a}$ | $7.30 \pm 1.09^{a}$ | $6.20 \pm 1.24^{a}$ | $6.40 \pm 1.61^{a}$ | $6.07 \pm 1.76^{a}$ |
| 3% DDF[3] | $4.90 \pm 1.90^{b}$ | $5.97 \pm 1.52^{a}$ | $4.73 \pm 1.64^{b}$ | $6.03 \pm 1.87^{a}$ | $6.07 \pm 1.55^{a}$ | $5.97 \pm 1.58^{a}$ |
| 3% FDF[3] | $5.71 \pm 2.10^{b}$ | $5.40 \pm 1.99^{a}$ | $5.40 \pm 2.04^{b}$ | $6.23 \pm 1.50^{a}$ | $6.25 \pm 1.52^{a}$ | $6.41 \pm 1.39^{a}$ |

[1]Results are mean ± SD, n = 30.
[2]Values in the same column bearing different letters are significantly different ($p \leq 0.05$).
[3]DDF = Dietary fiber from dried corn silk, FDF = Dietary fiber from fresh corn silk.
[4]Nine-point hedonic scale (9= like extremely, 5= neither like nor dislike, 1= dislike extremely.

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