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Original Article

Effect of carboxymethyl cellulose on properties of wheat flour-tapioca starch-based batter and fried, battered chicken product

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ABSTRACT

Hydrocolloid is widely used to improve the quality of food. In this study, the effect of carboxymethyl cellulose (CMC) on the properties of batter and fried, battered product prepared from wheat flour (WF)-tapioca starch (TS) blends was investigated. The dry-mixes were prepared from the flour blends of 91.4% flour blend [WF/TS (1:1) and CMC (0%, 0.25%, 0.5%, 0.75% or 1.0%)], 5.5% salt and 3.1% leavening agent and then mixed with water (1:1.3) for batter preparation. The batters had a significant increase in consistency coefficient, yield stress and batter pickup with increasing CMC replacement in the dry mix. However, CMC did not significantly ($p > 0.05$) alter either the differential scanning calorimetry thermal properties of the batters or the rapid visco-analyzer viscosity after holding at 95 °C for 4 min. The substitution of CMC decreased the oil content but increased the moisture content in the pre-fried chicken wing sticks. After final frying at 180 °C, the oil content of the fried product was significantly ($p < 0.05$) reduced in the samples containing CMC (equal to or more than 0.5% in dry-mix). There were no significant ($p > 0.05$) differences in the overall liking scores in the fried products without and with 0.5% CMC replacement in the flour blend. The results indicated that CMC could be used in WF/TS batter preparation, enhancing the batter pickup and quality and especially acting as an oil barrier-forming ingredient for fried, battered foods.

Introduction

Starch-based batter coating on food pieces prior to deep-fat frying is a widely used method for food preparation, where the coating layer forms a crust surface on food pieces after frying, which enhances the desired texture, appearance and flavor of food after frying (Ketjarut and Pongsawatmanit, 2015). In addition, the flavors and juiciness are retained under a crisp crust (Fiszman and Salvador, 2003; Ketjarut et al., 2010). The thickness of the batter forming a continuous layer over the food surface depends on the viscosity of the batter (Ketjarut et al., 2010). Batters containing different flour types give differences in viscosity and gelatinization patterns which affect the unique flavors and textures in fried products.

Wheat flour (WF) in a batter system shows a gradual increase in viscosity with increasing shear rate due to the development of gluten protein (Mallikarjunan et al., 2010). During frying, gelatinized starch in addition to WF protein plays an essential role in the structural formation of the fried crust (Llorca et al., 2001). However, the quality of fried, battered product such as oil absorption reduction is enhanced by the partial substitution of WF with other flour types in the batter preparation using for example, corn flour and soy flour (Nasiri et al., 2012), rice flour (Lee et al., 2013) or corn flour and cross-linked tapioca starch (TS) (Gamonpilas et al., 2013). An increase in consumer awareness and demand for natural food ingredients (Li et al., 2014) mean that native starch plays an important role in product development. Tapioca starch (TS) produced from cassava roots, is extensively used in food industries especially in Southeast Asia because of its high viscosity, clear appearance including low production cost compared to WF, with about 17–20% amylose in TS with very low protein and lipid contents (Breuninger et al., 2009). Ketjarut and Pongsawatmanit (2015) reported that TS substitution up to 50% in WF-based batter could be used to enhance the quality of fried, battered product in terms of lowered oil content and higher sensory liking scores. However, the viscosity of WF-based batter decreased with the partial replacement of WF with

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native TS (Ketjarut et al., 2010) leading to lower batter pickup on the food surface.

In general, hydrocolloids are the most widely used ingredients for controlling texture and properties of food products including fried battered product to enhance the viscosity so that there is a greater amount of batter covering the food pieces to be fried and in addition, the hydrocolloids lower oil absorption and act as viscosity control agents, promote pickup control, improve adhesion and the freeze-thaw stability of the battered/breaded fried foods (Varela and Fiszman, 2011). Many studies have reported the influence of hydrocolloids on the rheological properties of batters or on the quality of fried, battered products prepared from flour blend of WF and other flour types such as methylcellulose or hydroxypropyl methylcellulose in batters prepared from WF-rice flour and WF-corn flour (Yılmaz et al., 2017), chitosan in batters made from rice flour and wheat flour (Sansano et al., 2018) and carboxymethyl cellulose (CMC) in fried batter obtained from rice flour and WF (Rahimi and Ngadi, 2014). CMC is a derivative of cellulose and is water soluble in both hot and cold water providing clear and colorless dispersion with a neutral flavor, low-to-high solution viscosity and good film forming ability (Coffey et al., 2006). It is widely used in food formulation due to these advantageous properties (Cancela et al., 2005) including its reduction of oil absorption. However, there have been no reports on CMC substitution in flour blends of WF and TS and such research is important to gain information related to the batter pickup, viscosity and yield stress for predicting and controlling the amount of batter on the food surface and the final quality of the fried battered product. Therefore, the objectives of this study were to investigate the effect of CMC on the properties of WF/TS batter (mixing ratio of WF:TS = 1:1) and fried, battered product using chicken wing sticks as a food model. The rheological, pasting and thermal properties of the WF/TS batters with and without CMC replacement in the dry-mix were determined. The relationship between the batter viscosity and batter pickup or yield stress using a Herschel-Bulkley model were established. Finally, the quality and sensory liking of the final fried, battered product with and without CMC were evaluated. The information gained will be important for the fried, battered industry to enhance the quality of the product in terms of oil absorption reduction using CMC in the flour blend of WF and TS. In addition, the TS utilization in the food batter is expected to lower the production cost.

Materials and methods

Materials

Commercial all-purpose wheat flour (WF) (United Flour Mill, Thailand), leavening agent ($Na_2H_2P_2O_7/NaHCO_3$), commercial refine salt and chilled chicken wing stick (35–40 g/piece) were purchased from local supermarket. Tapioca starch (TS) was obtained from a local manufacturer (Siam Quality Starch, Thailand). The moisture contents of the WF and TS were 11.7% and 11.2%, respectively (AOAC, 2000). The protein content of WF was 11.4% whereas that of TS was 0.12% (AOAC, 2000). Purified sodium carboxymethyl cellulose (CMC) with a degree of substitution of 0.65–0.90 was obtained from Ashland (France). The viscosity of 1% CMC dispersion was in the range 1500–2500 mPa s at 25 °C (Brookfield LVF viscometer, spindle No. 3 at 30 revolutions per minute; rpm). Sodium tripolyphosphate (STPP) (Union Chemical, Thailand) was used to marinate the chicken wing sticks. Refined palm olein oil was heated and held at frying temperature for at least 15 min before frying and was changed after 5 h of frying. Extended dried squid (2 cm × 3 cm, 1 mm thickness) was obtained from a local company.

Batter preparation, battering and frying

Flour blend (91.4%) of WF and TS at a mixing ratio of 1:1 was mixed with 5.5% salt (NaCl) and 3.1% leavening agent ($Na_2H_2P_2O_7/NaHCO_3$) for the dry-mix preparation. The CMC (0%–1%) was mixed to obtain 91.4% (WF/TS/CMC) by replacing flour blend as shown in Table 1. Each batter was prepared by mixing dry-mix (200 g) and water (10 °C) at a mixing ratio of dry-mix to water of 1:1.3 (weight per weight; w/w) using a hand mixer (Miracle FP-006BM; Moulinex; France) for 2 min at low speed. The homogeneous batter was kept at 10 °C for at least 1 h before quality measurement and further battering. Shear viscosity measurement, pasting and thermal properties of the batters were determined using a rheometer, a rapid visco-analyzer (RVA) and differential scanning calorimetry (DSC), respectively. Batter pickup on chicken wing sticks was also determined.

The effect of CMC (0%, 0.25%, 0.5%, 0.75% or 1% in the dry-mix) on the quality of fried battered chicken wing sticks was also investigated. The chilled chicken wing sticks were washed and mixed with 10% brine (consisting of 6% salt and 4% STTP) by tumbling in an ice bath for 30 min and then were drained for 30 min in a refrigerator (5 °C). Three pieces of wing sticks per batch of frying were manually pre-dusted with WF (3 g) for 10 s in a plastic bag, placed on wire mesh and dipped into each batter (15 ± 1 °C). Any excess batter on the food surface was allowed to drip off for 10 s. Immediately afterward, the three pieces of wing sticks were pre-fried at 180 ± 7 °C for 4 min in a commercial deep-fat fryer (FRI-1355; Fritel; Belgium) containing 3 L of refined palm olein oil. At the thickest part of each wing stick, the internal temperature was measured (about 75 °C). The pre-fried, battered chicken wing sticks were further heated in an oven at 195 ± 3 °C for 8 min, cooled, packed in polyethylene bags (10 pieces/bag) and kept at −18 °C for 2 wk. The frozen, pre-fried, battered chicken wing sticks were deep-fried at 180 ± 7 °C for 3 min without thawing prior to determining the moisture and oil contents and sensory liking scores.

Measurement of batter quality

Batter viscosity

The steady shear viscosity of each batter (39.74% [WF/TS/CMC]) was measured as a function of the shear rate in the range 0.1–100/s at 15 °C using a rheometer (Physica MCR 300; Anton Paar GmbH; Germany) with a concentric cylinder geometry (CC27) and bottom plate (TEZ150P). The sample temperature was kept constant for at least 2 min before starting the measurement. The flow behavior of the batters was evaluated using a Herschel-Bulkley model as shown in Eq. (1):

$$\tau = K(d\gamma/dt)^n + \tau_o \quad (1)$$

where τ is the shear stress (in pascal), $(d\gamma/dt)$ is the shear rate (per second), K is the consistency coefficient (Pa s^n), n is the flow behavior index and τ_o is the yield stress (pascal) (Steffe, 1996).

Batter pickup

Batter pickup refers to the quantity of the batter adhering to the surface of the food before frying. Each wing stick was dipped into the batter (15 °C) and excess batter was allowed to drip off for 10 s before weighing. The batter pickup was calculated as the percentage of the batter weight compared to the initial weight of wing sticks (nonbattered sample).

Rapid visco-analyzer

Each batter with different WF/TS/CMC mixtures was diluted with water (1:1) yielding 19.87% w/w WF/TS/CMC before measurement of the pasting properties using a rapid visco analyzer

Table 1
Parameters of Herschel-Bulkley model (K = consistency coefficient, n = flow behavior index, τ_o = yield stress) determined from the shear rate at the range from 1 to 100/s and a batter pickup of 39.74% (WF/TS/CMC)[a].

(WF/TS/CMC) in dry-mix (%)			CMC in batter (%)	Herschel-Bulkley model			Batter pickup (%)
WF	TS	CMC		K (Pa s^n)	n (−)	τ_o (Pa)	
45.700	45.700	0	0	0.24 ± 0.00^e	0.911 ± 0.008^b	0.18 ± 0.01^e	8.1 ± 0.4^e
45.575	45.575	0.25	0.109	0.46 ± 0.05^d	0.915 ± 0.010^b	0.38 ± 0.06^d	11.1 ± 0.8^d
45.450	45.450	0.50	0.217	0.90 ± 0.07^c	0.895 ± 0.001^{ab}	0.63 ± 0.10^c	12.8 ± 0.6^c
45.325	45.325	0.75	0.326	1.42 ± 0.10^b	0.880 ± 0.001^a	0.92 ± 0.16^b	15.0 ± 0.8^b
45.200	45.200	1.00	0.435	1.83 ± 0.25^a	0.890 ± 0.038^a	1.16 ± 0.01^a	18.5 ± 1.1^a

[a] Mean ± SD values (n = 3) of the batter pickup and the parameters of Herschel-Bulkley model followed by different lowercase letters are significantly ($p < 0.05$) different using Duncan's multiple range test within the same column, where each batter was obtained from mixing the dry-mix (91.4% [WF/TS/CMC] and 8.6% of NaCl and leavening agent) and water at the ratio of 1:1.3 and the determination of viscosity and batter pickup was performed at 15 °C.

(RVA; 4500; Perten Instruments AB; Sweden). The temperature profile was set as: equilibrating the diluted batter at 50 °C for 1 min, increasing to 95 °C at a heating rate of 6 °C/min, holding at 95 °C for 4 min, then decreasing to 50 °C within 4 min and finally holding at 50 °C for 1 min (Ketjarut and Pongsawatmanit, 2015). For the first 10 s, the RVA paddle speed was set at 960 rpm and maintained at 100 rpm throughout the measurement. The pasting parameters were recorded.

Differential scanning calorimetry

Gelatinization profiles of batters containing different CMC concentrations were evaluated. Each batter was kept at room temperature (28 ± 2 °C) for 1 h while being stirred using a magnetic stirrer before measurement. About 15 mg of dispersions were weighed directly into a 40 μL aluminum pan. The pans were hermetically sealed. The gelatinization profiles of each WF/TS/CMC batter were investigated using differential scanning calorimetry (DSC; DSC822e; Mettler-Toledo GmbH; Switzerland) by heating the pans from 25 °C to 110 °C (heating rate of 2 °C/min). The onset temperature (T_o) peak temperature (T_p) and conclusion temperature (T_c) of the batters were determined based on the heating DSC thermograms according to the method of Pongsawatmanit et al. (2013). The gelatinized enthalpy (ΔH) was evaluated based on the area under the main endothermic peak and reported as joules per gram flour (dry basis; db). A sealed, empty pan was used as a reference. Each sample pan was weighed before and after measurement to ensure no weight loss during the measurement. Three freshly prepared samples were measured and the mean value was reported.

Determination of fried, battered product quality

The moisture and oil contents of pre-fried crust samples and final fried samples were evaluated within 1 h using a hot-air oven at 105 °C (AOAC, 2000) and an automated extraction system (Soxtec™ Avanti 2050 automatic system; Foss Tecator AB; Sweden) with petroleum ether, respectively. The final fried crust layers were difficult to peel off without the skin of wing sticks resulting in higher values of oil content. Therefore, for the final fried products, the samples were deboned and ground prior to determining the moisture and oil contents within 1 h. Both values were reported as percentages of the original sample weight of crust or deboned product.

Texture evaluation of the fried batters was performed according to the method of Ketjarut and Pongsawatmanit (2015) using the dried squid sheet (2 cm × 3 cm, 1 mm thickness) as a base for battering and frying at 180 ± 7 °C for 4 min. Then, the fried samples (about 60 g) were filled into an Ottawa cell (71.2 mm length × 90 mm width × 45 mm height) and compressed using a square flat probe (70 mm × 70 mm) at 2 mm/s to a distance of 20 mm after a 1500 g trigger force using a texture analyzer (TA.XT Plus; Stable Micro Systems; UK). The area under the force-deformation curve and a number of major peaks (over 200 g force threshold) were evaluated using the texture analysis software and considered as an indication of "crispness".

Sensory evaluation

The frozen, pre-fried, battered chicken wing sticks (prepared from dry-mixes containing 0%, 0.5% or 1% CMC) were deep-fried at 180 ± 7 °C for 3 min without thawing. Fifty untrained panelists were recruited from the students and staff in the Department of Product Development at Kasetsart University, Bangkok, Thailand with an age range of 18–50 years old for the affective test. Each panelist was randomly provided with the samples being served (one piece per treatment, one by one), immediately after frying and asked to rate the liking scores of each quality attribute according to appearance, color of the product, crust thickness, adhesion between the crust layer and the chicken piece, oil absorption, crispness and overall liking using a nine-point hedonic scale (9 = like extremely, 5 = neither like nor dislike, 1 = dislike extremely) according to Ketjarut and Pongsawatmanit (2015).

Statistical analysis

All measurements were carried out using at least three independently prepared samples. Mean values with standard deviation were reported. An analysis of variance (ANOVA) was performed using the SPSS V.12 statistical software package (SPSS (Thailand) Co., Ltd., Thailand). Duncan's multiple range test was applied to determine any differences of mean values at a test level of $p < 0.05$ from the ANOVA.

Results and discussion

According to the results of Ketjarut and Pongsawatmanit (2015), TS substitution up to 50% in WF-based batter could be used to enhance the quality and sensory liking scores of the fried, battered product. Therefore, WF and TS blends at a mixing ratio of 1:1 for dry-mix preparation were used to evaluate the effect of CMC on the WF/TS batter and fried battered product.

Properties of wheat flour/tapioca starch-based batters with and without carboxymethyl cellulose

Steady shear viscosity

The shear stress and steady shear viscosity of each batter (39.74% [WF/TS/CMC]) was determined as a function of shear rate in the range 0.1–100/s at 15 °C after 1 h preparation to ensure the complete hydration of CMC and starch granules. The 0%, 0.25%, 0.5%, 0.75% and 1% CMC concentrations in dry-mix were 0%, 0.109%, 0.217%, 0.326% and 0.435% CMC in the dispersions, respectively.

The rheograms of the batters with and without CMC at 15 °C were plotted (Fig. 1A) indicating non-Newtonian fluid. The shear stress values of the batters increased with increasing shear rate and CMC concentration. The Herschel-Bulkley model as shown in Eq. (1) was used to characterize the flow behavior and yield stress (τ_o) of all WF/TS batters with and without CMC with the coefficient of determination (r^2) closed to unity (r^2 of 0.996–1.000). The consistency coefficient values (K) of the batters containing CMC (0.46–1.83) were higher than that without CMC (0.24) ($p < 0.05$, Table 1). The results were in good agreement with the batters obtained from WF and corn flour blends containing CMC (Chen et al., 2009). The CMC addition in the batters altered the flow behavior index (n) of the WF/TS batter. The n values decreased significantly

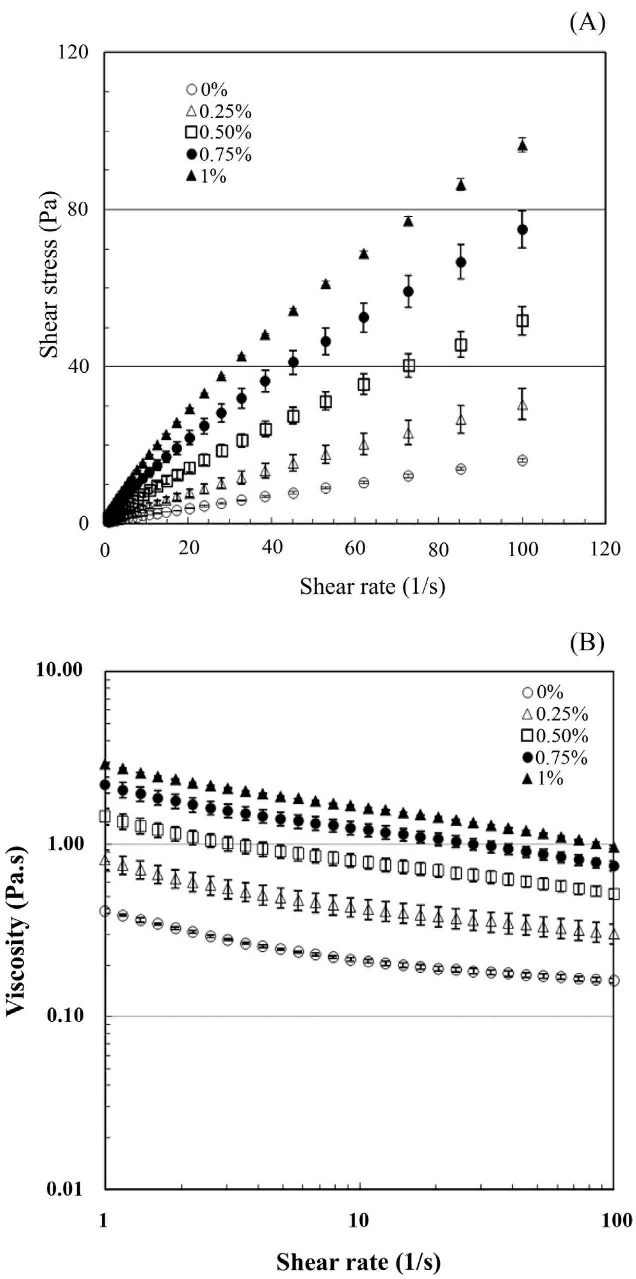

Fig. 1. Rheograms (A) and steady shear viscosity (B) of 39.74% wheat flour (WF)/tapioca starch (TS) batters with and without carboxymethyl cellulose (CMC) in the dry-mix as a function of shear rate at 15 °C, with CMC concentrations in the batters of 0%, 0.109%, 0.217%, 0.326% and 0.435% for 0%, 0.25%, 0.5%, 0.75% and 1% CMC in dry-mix, respectively; WF/TS = 1:1 and details of WF/TS/CMC compositions are shown in Table 1.

with increasing CMC in the dry-mix up to 0.5% (Table 1). Similar results of n values decreasing with increasing CMC were also observed by Cancela et al. (2005).

The yield stress (τ_o) is defined as the stress that must be applied to the batter sample before it starts to flow (Steffe, 1996). Therefore, below τ_o, batter exhibiting a solid-like characteristic will deform elastically, while flowing like a liquid above the τ_o value. The batter stores energy at small strains and does not level out under the gravity force to form a flat surface. At very low shear rates, the suspended particles could remain stationary due to the high viscosity of the solutions containing CMC below the yield point (τ_o). The τ_o increased with increasing CMC content in the batters from 0.18 Pa to 1.16 Pa for the batters containing 0%–0.435% CMC (or 1% CMC in dry-mix). Then, after coating, the batter layer remained stuck on the product surface (Maillard et al., 2016; Tunnarut and Pongsawatmanit, 2018), indicating CMC enhanced the coating performance on chicken wing sticks. This characteristic is important for designing the process and evaluating food quality.

The steady shear viscosity at 15 °C decreased as the shear rate increased for all CMC concentrations (Fig. 1B). Increasing the shear rate resulted in a breakdown of the structure formation of the batters at a very low shear rate due to the hydrodynamic forces generated during shear. At a high shear rate, the hydrodynamic interaction dominated the rheological behavior with only a minor influence of the potential interaction (Bergstrom, 1994). The steady shear viscosity values increased with increasing CMC concentration (Fig. 1B). A similar result was also observed in WF-rice flour and WF-corn flour-based batters containing hydroxypropyl methylcellulose (Yılmaz et al., 2017). The current results suggested that CMC could enhance the viscosity and K of the WF/TS batters.

Batter pickup

The batter pickup on the surface of the chicken wing sticks increased with increasing CMC substitution of WF/TS flour blend in dry-mix from 8.1% to 18.5% for 0%–1.0% CMC in dry-mix, respectively ($p < 0.05$, Table 1). However, the batter pickup (18.5%) of WF/TS batters containing 0.435% CMC was lower than that of batter containing WF alone (about 24.9%) according to Ketjarut et al. (2010). The current results suggested that WF plays an important role in enhancing batter viscosity and promoting adhesion through gluten formation in the batter (Mallikarjunan et al., 2010). The viscosity and τ_o of the WF/TS batters also increased with CMC replacement. Since the range in the shear rate used for coating application due to drainage under gravity is suggested to be 0.1–10/s (Steffe, 1996), the viscosity at 10.83/s was used directly from the measurement. A linear relationship between the amount of batter coating and viscosity was obtained as shown in Fig. 2A. Moreover, the batter pickup as a function of yield stress also revealed a linear relationship (Fig. 2B). Therefore, the results confirmed that the higher the viscosity in the batters containing CMC, the stronger the adhesion to the food surface compared to WF/TS batter without CMC, leading to a greater amount of batter coating and reducing the amount of batter dropping from the surface after coating.

Pasting properties from RVA

The pasting properties of each batter were determined using RVA to evaluate the changes in batter viscosity during heating. Since the 39.74% [WF/TS/CMC] in the batter could not be evaluated due to the limitations of the RVA instrument, the batter was diluted with water (1:1) yielding 19.87% w/w before measurement. Then 0%, 0.25%, 0.5%, 0.75% and 1% CMC concentrations in dry-mix were 0%, 0.054%, 0.109%, 0.163% and 0.217% CMC in the diluted batters, respectively. To represent the heating during frying, only the heating profile with the holding time from the pasting profile of the diluted batter (19.87%) was observed. The pasting temperatures of

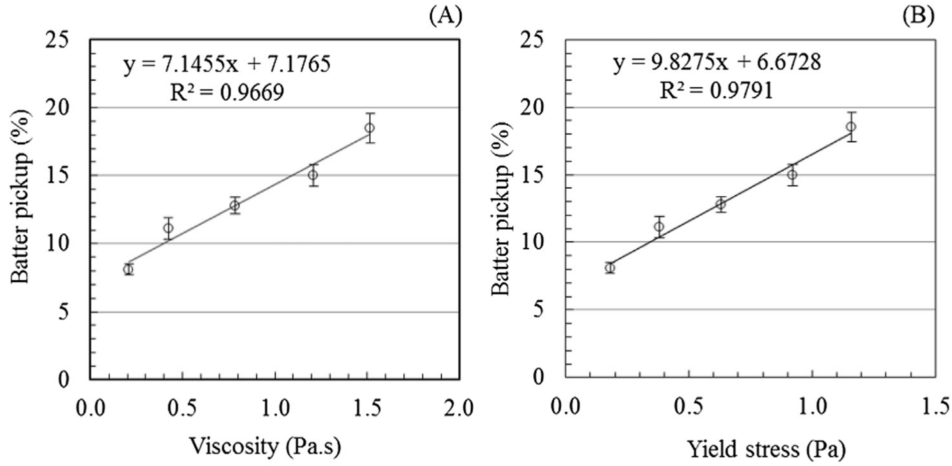

Fig. 2. Relationship between batter pickup and viscosity from steady shear measurement using shear rate at 10.83/s (A) and relationship between batter pickup and yield stress from Herschel-Bulkley model (B). Batter pickup performed at 15 °C with WF/TS/CMC concentration in the batter of 39.74%.

Table 2
Pasting properties and differential scanning calorimetry (DSC) gelatinization parameters of wheat flour and tapioca starch based batters containing carboxymethyl cellulose (CMC), with CMC concentrations in batters for rapid visco-analyzer (RVA) experiments of 0%, 0.054%, 0.109%, 0.163% and 0.217%, and 0%, 0.109%, 0.217%, 0.326% and 0.435% corresponding to 0%, 0.25%, 0.5%, 0.75% and 1% weight per weight CMC in the dry-mix, respectively.

Quality parameter	CMC (%) in dry-mix				
	0	0.25	0.50	0.75	1.00
RVA pasting parameter[a]					
Pasting temperature (°C)	73.1 ± 0.1[a]	73.4 ± 0.2[a]	73.1 ± 0.4[a]	73.2 ± 0.0[a]	73.0 ± 0.3[a]
Peak Viscosity (Pa s)	25.6 ± 0.0[a]	25.3 ± 0.2[a]	25.0 ± 0.2[a]	24.9 ± 0.1[a]	24.0 ± 0.3[b]
Viscosity after holding at 95 °C 4 min (Pa s)	3.68 ± 0.59[a]	3.84 ± 0.21[a]	3.42 ± 0.36[a]	3.85 ± 0.04[a]	3.54 ± 0.46[a]
DSC gelatinization[b]					
T_o (°C)	63.4 ± 0.5[a]	63.5 ± 0.3[a]	63.3 ± 0.1[a]	63.1 ± 0.5[a]	63.5 ± 0.4[a]
T_{p1} (°C)	69.4 ± 0.5[a]	69.3 ± 0.6[a]	69.4 ± 0.3[a]	69.2 ± 0.2[a]	69.6 ± 0.1[a]
T_{p2} (°C)	77.8 ± 0.3[a]	77.7 ± 0.5[a]	77.9 ± 0.6[a]	78.3 ± 1.3[a]	77.8 ± 0.9[a]
T_c (°C)	85.5 ± 0.2[a]	86.6 ± 0.7[a]	86.2 ± 0.2[a]	86.1 ± 0.2[a]	86.1 ± 0.5[a]
Δ*H* (J/g dry starch)	12.0 ± 0.7[a]	12.4 ± 0.4[a]	12.2 ± 0.5[a]	12.3 ± 0.6[a]	11.8 ± 0.8[a]

T_o = onset temperature; T_p = peak temperature; T_c = conclusion temperature; ΔH = gelatinized enthalpy.
Mean ± SD values (n = 3) of parameters of RVA pasting properties and DSC gelatinization followed by different lowercase letters within the same row are significantly ($p < 0.05$) different using Duncan's multiple range test.
[a] For RVA measurement, batter was diluted with water (1:1) yielding 19.87% (WF/TS/CMC).
[b] For DSC measurement, batter contained 39.7% (WF/TS/CMC).

diluted WF/TS batters with and without CMC were about 73.0–73.4 °C ($p > 0.05$, Table 2) whereas the peak viscosity decreased highly significantly in the batter prepared from 1% CMC in dry-mix from 25.6 Pa s (batter without CMC) to 24.0 Pa s (Table 2, $p < 0.05$). Adding CMC in the WF/TS flour blend did not alter the peak time (6.8–6.9 min, data not shown) or the viscosity holding at 95 °C for 4 min (heating process, 3.42–3.85 Pa s, $p > 0.05$, Table 2), indicating that batters containing less than 0.163% CMC (0.75% CMC in dry-mix) did not alter the pasting properties.

Thermal properties determined using differential scanning calorimetry

The gelatinization behavior of each 39.74% (WF/TS/CMC) batter was investigated. The DSC thermograms of all batters with and without CMC had two similar endothermic peaks without complete separation that were attributed to the WF and TS fractions in the batter. The first peak at the lower temperature was attributed to the WF fraction and the second peak at a higher temperature was attributed to the TS fraction (Ketjarut and Pongsawatmanit, 2015). There were no significant parameters of DSC gelatinization among the batters with and without CMC (Table 2). The T_o and T_c values of the batters based on the heating DSC thermograms were 63.1–63.5 °C and 85.5–86.6 °C, respectively ($p > 0.05$). T_{p1} and T_{p2} were used to explain the fractions of WF and TS, respectively (Fig. 3) according to Ketjarut and Pongsawatmanit (2015). The T_{p1} and T_{p2} values of all (WF/TS/CMC) batters were about 69.2–69.6 °C and 77.7–78.3 °C, respectively ($p > 0.05$, Table 2). The gelatinized enthalpy (Δ*H*), indicating the energy required to gelatinize starch granules, was determined based on the area under the endothermic peak. Since the T_o, T_p and T_c values of the peaks from each (WF/TS/CMC) batter were not significantly different, and the mixing ratio of WF and TS = 1:1 was constant for all dry-mix of (WF/TS/CMC), Δ*H* was reported as the sum of ΔH_1 and ΔH_2 (Fig. 3) contributed from the WF and TS fractions, respectively. The Δ*H* values were 11.8–12.4 J/g dry starch ($p > 0.05$). The results suggested that the gelatinization behavior of the WF/TS-based batter did not alter with CMC addition and the constant mixing ratio of the WF/TS flour blend. However, the gelatinization of the batters depended on the flour types and their composition in the formulation (Ketjarut and Pongsawatmanit, 2015).

Quality of fried battered product from wheat flour/tapioca starch batters with and without carboxymethyl cellulose

Pre-frying was used for storing in a frozen state and for final frying before consumption. After dipping into each (WF/TS/CMC) batter, the wing sticks were pre-fried at 180 ± 7 °C for 4 min and

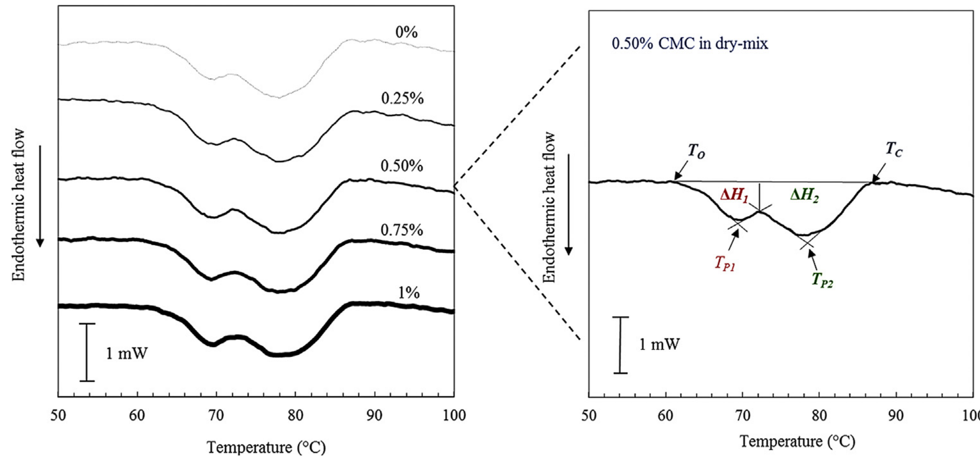

Fig. 3. Typical heating differential scanning calorimetry thermograms of batters containing 39.74% (WF/TS/CMC) batters, with carboxymethyl cellulose (CMC) concentrations in the batters of 0%, 0.109%, 0.217%, 0.326% and 0.435% for 0%, 0.25%, 0.5%, 0.75% and 1% CMC in dry-mix, respectively, at a heating rate of 2 °C/min.

Table 3
Moisture and oil contents of pre-fried crusts on chicken wing sticks and texture parameters obtained from force-deformation curves of fried battered pieces of thin dried squid (1 mm thickness) prepared from 39.7% [WF/TS/CMC] batters[a].

Quality parameter	CMC (%) in dry-mix				
	0	0.25	0.50	0.75	1.00
Pre-fried crusts					
Moisture content (%, dry basis)	36.4 ± 2.4[c]	37.5 ± 6.4[c]	42.0 ± 2.3[bc]	47.6 ± 1.8[ab]	53.0 ± 5.1[a]
Oil content (%, dry basis)	47.2 ± 2.3[a]	45.2 ± 0.7[ab]	44.1 ± 1.5[b]	43.1 ± 1.5[b]	38.3 ± 1.1[c]
Texture of fried, battered pieces[b]					
Area (N mm)	1280 ± 304[a]	1491 ± 280[a]	1909 ± 481[a]	1874 ± 437[a]	1519 ± 340[a]
Count peaks	57±2[b]	66±3[ab]	73±4[a]	70±8[a]	56 ± 10[b]

[a] Mean ± standard deviation values (n = 3) of qualities followed by different lowercase letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same row.
[b] Area = the area under the force-distance curves indicating the toughness; Count peak = the number of major positive peaks (>200 g force threshold) indicating the crispness from force-distance curves under the compression test.

further heated in the oven at 195 ± 3 °C for 8 min. Considering the changes in the coating layer of the batter during deep-fat frying process, heating induced starch gelatinization, protein denaturation (in the WF fraction) and vaporization of water in the batter leading to a crust layer forming (Ketjarut and Pongsawatmanit, 2015). The moisture content of the pre-fried crust after oven heating increased with increasing CMC content from 36.4% to 53.0% (db) for 0–1% CMC in dry-mix, respectively ($p < 0.05$, Table 3). CMC could form a three-dimensional network and hold water molecules within the system (Andrew, 2004). The oil content in the pre-fried crust prepared from WF/TS batter without CMC had the highest oil content (47.2%) as expected from the thermoset network of the gluten protein which caused the frying oil to easily penetrate into the crust layer during frying. A significant decrease in the oil content (38.3%) in the sample prepared from 1% CMC in dry-mix was observed in the pre-fried samples containing CMC ($p < 0.05$, Table 3). A similar result of oil content reduction was also observed in doughnut samples containing CMC reported by Funami et al. (1999) because cellulose derivatives reduced oil absorption through film formation at temperatures above their incipient gelation temperature. Generally, the oil uptake is largely determined by the moisture content in the food (Mellema, 2003). The mechanism of oil penetration during frying could be explained as follows. The temperature of the battered food increased rapidly leading to water loss because of the conversion of the water molecules into vapor along with the starch gelatinization and protein denaturation occurring simultaneously and creating a crust layer (Ketjarut and Pongsawatmanit, 2015). Therefore, the CMC addition into WF/TS batters may have created a network providing a barrier to prevent oil uptake during heating (frying), leading to a reduction in oil pickup (Akdeniz et al., 2006; Xue and Ngadi, 2009; Chen et al., 2009). The results suggested that CMC in the batter formed a network or solid-like structure to increase moisture retention and reduce oil uptake.

The final fried crust layers were too thin to peel off and resulted in nonhomogeneous samples for texture measurement. Therefore, to evaluate the texture of the fried batter layer, the dried squid sheet was used as a base for battering into each (WF/TS/CMC) batter and frying at 180 ± 7 °C for 4 min. Since the thickness of dried squid (1 mm) was very thin, the texture of the fried, battered squid sheet was used to compare the texture of fried crust layers from different mixing ratios of (WF/TS/CMC) batters. After the fried samples filled the Ottawa cell and were compressed as bulk compression (Bourne, 2002), the toughness and crispness could be determined from the area under the force-deformation curve (not shown) and a number of major peaks (in excess of 200 g force threshold), respectively. The areas under the curves (indicating toughness) of all fried crust samples were 1280–1909 N mm with no significant differences ($p > 0.05$, Table 3) due to the high standard deviation of the mean values expected from the homogeneous problem of tested samples. However, the fried crust prepared from the WF/TS batters without CMC had the lowest values, suggesting the work required to compress the sample increased with CMC addition. In general, a porous product that is crispier requires less force to break. Subsequently, the crispness was evaluated from the number of major positive peaks (in excess of 200 g force threshold) that occurred due to the breakage of the samples from force-distance curves under the compression test. A higher number of major peaks (above 70) exhibited more crispness of the food pieces and was observed in the samples prepared from WF/TS batters with 0.5% and 0.75% CMC in dry-mix whereas the lowest number of major peaks (about 57 peaks) was found in the fried samples without CMC and with 1% CMC. The 0.5% CMC in dry-mix enhanced the crispness and porosity of the fried product. The results indicated that the crispness of the fried, battered food depended on the CMC concentration.

Based on the results in Table 3, the 0.5% and 1.0% CMC in dry-mix were selected to investigate final frying compared with the sample without CMC (control). The frozen, pre-fried, battered chicken wing sticks were deep-fried at 180 ± 7 °C for 3 min without thawing prior to determining the moisture and oil contents. After final frying, the crust layers were drier, thinner and crispier due to water evaporation during heating. Because of the difficulty in peeling the crust layer prepared from the (WF/TS/CMC) batters without the skin of the wing sticks, the moisture and oil contents were evaluated using the all parts of the wing sticks (except bone). The moisture contents (49.0–53.5% wb or 96.0–115.0% db) increased and the oil contents (31.6–35.0%) of the samples decreased with increasing CMC content (Table 4). Adding 0.5% CMC in the dry-mix resulted in a moisture content (49.6% wb) comparable to that of the control ($p > 0.05$, Table 4) but provided a lower oil content (31.7%) ($p < 0.05$, Table 4) than that without CMC (35.0%).

The liking scores of the final fried wing sticks with and without CMC in the fried crust layer were evaluated (Table 4). The overall liking scores of the products with the crust layer prepared from 0% to 0.5% CMC in dry-mix were 7.6 and 6.9, respectively ($p > 0.05$, Table 4). Liking scores above 5 were acceptable (Sanz et al., 2008). However, the liking scores of the product prepared from 1% CMC in dry-mix were the lowest for all attributes. Considering the sensory scores and the physicochemical properties, the results suggested that 0.5% CMC in dry-mix could be used to prepare the (WF/TS/CMC) batter for coating to obtain a final fried, battered sample with a lower oil content and an overall liking score of about 7.

In conclusion, the addition of CMC could enhance the viscosity and batter pickup on the food surface without changing the gelatinization behavior of the WF/TS-based batters. Fried chicken wing sticks prepared from the batters containing CMC had a lower oil content than those without CMC. However, 0.5% CMC in dry-mix could be applied to prepare the (WF/TS/CMC) batter and the final fried, battered sample with an overall liking score of about 7. The information gained in this study could be used for product development in the fried, battered industry to enhance the quality of the product in terms of oil reduction using CMC in the flour blend of WF and TS.

Table 4
Moisture content, oil content and liking scores of final fried battered chicken wing sticks prepared from 39.7% [WF/TS/CMC] batters[a].

Quality parameter[b]	CMC (%) in dry-mix		
	0	0.5	1.0
Moisture content (%, wet basis)	49.0 ± 0.5^b	49.6 ± 0.3^b	53.5 ± 0.0^a
Moisture content (%, dry basis)	96.0 ± 1.9^b	98.4 ± 1.0^b	115.0 ± 0.2^a
Oil content (%, dry basis)	35.0 ± 0.5^a	31.7 ± 0.5^b	31.6 ± 0.5^b
Sensory liking scores			
Appearance	7.7 ± 0.7^a	7.3 ± 1.1^{ab}	6.8 ± 1.1^b
Color	7.6 ± 0.8^a	7.5 ± 1.2^a	7.0 ± 1.2^a
Thickness of the crust	7.3 ± 1.2^a	7.1 ± 1.3^{ab}	6.4 ± 1.6^b
Adhesion	7.4 ± 1.1^a	7.2 ± 1.1^a	6.0 ± 1.9^b
Oil absorption	6.6 ± 1.4^a	5.4 ± 1.9^b	3.8 ± 1.8^c
Crispness	7.5 ± 0.8^a	7.3 ± 1.0^{ab}	6.7 ± 1.6^b
Overall liking	7.6 ± 0.8^a	6.9 ± 1.2^a	5.8 ± 1.8^b

[a] Mean ± standard deviation values (n = 3 and 50) for physicochemical and sensory parameters, respectively followed by different lowercase letters within the same row are significantly different ($p < 0.05$) by Duncan's multiple range test.
[b] Battered wing sticks were pre-fried (180 °C for 4 min) with further oven heating and final frying at 180 °C for 3 min without thawing.

Conflict of interest

The authors declare that there are no conflicts of interest.

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