Journal of Food Engineering 95 (2009) 359–364

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Effect of batter formula on qualities of deep-fat and microwave fried fish nuggets

Su-Der Chen [a,*], Hui-Huang Chen [a], Yu-Chien Chao [a], Rong-Shinn Lin [b]

[a] Department of Food Science, National Ilan University 1, Section 1, Shen Nung Road, Ilan City, Taiwan, ROC
[b] Department of Animal Science, National Ilan University 1, Section 1, Shen Nung Road, Ilan City, Taiwan, ROC

ARTICLE INFO

Article history:
Received 8 January 2009
Received in revised form 7 May 2009
Accepted 16 May 2009
Available online 22 May 2009

Keywords:
Batter
Rheology
Pick-up
Microwave
Frying

ABSTRACT

The crust qualities of fish nuggets by either 5 min deep-fat frying or 3.5 min microwave frying were evaluated by moisture content, oil content, texture, and color. The basic batter formulas contained equal quantity of corn and wheat flours, with different ingredients such as 1% protein, 5% starch or 1% gum. The ratio of solid and water in the batter was 1:0.85, and the flow behaviors of batters were fitted the Herschel–Bulkley model. The highest pick-up values were found in batters containing 1% CMC or 1% HPMC, and they were consistent with their high consistency index. The crusts containing 1% CMC or 1% HPMC showed the highest moisture contents, L^* values and the lowest oil contents than the other crusts. The crust containing 1% HPMC had softer texture than the other crusts. Most crust qualities of fish nuggets showed no significantly difference between the two frying methods.

1. Introduction

Batters are covered on the surface of food products to form the crust during deep-fat frying. The crusts of fried products can provide the crisper texture, golden yellow color and can act as a barrier against the loss of moisture by protecting the natural juices of foods (Mohamed et al., 1998; Dogan et al., 2005a). Therefore the fried products had tender and juicy interior foods and crisper crusts (Fiszman and Salvador, 2003). Batter formula, frying temperature, frying time, heating method, product shape and frying oil will influence the quality of crust (Shih and Daigle, 1999; Baixauli et al., 2003; Altunakar et al., 2004).

Wheat flour and corn flour are the major ingredients in batter formula (Loewe, 1993). Rice flour, starch, soybean meal, gums and leavening agent are also the important batter ingredients (Fiszman and Salvador, 2003). The swelled and gelatinized starch granules in batter can form a protecting layer to decrease the penetration of frying oil into foods and to prevent water evaporation from interior foods (Xue and Ngadi, 2006; Gibney et al., 1999). Gums, proteins or modified starches, including MC or cellulose derivatives, have been used in batters in order to reduce the oil content and increase the moisture retention of fried products (Dziezak, 1991; Balasubramaniam et al., 1997; Llorca et al., 2001, 2005). In general, the pick-up of batter product is 30–50% (Loewe, 1993).

Batter viscosity determines the flow behavior of the product before it fries in the fryer and influences the pick-up ratio (Dogan et al., 2005a,b). Factors influencing the rheological properties of batter are ingredients in formula, solid to water ratio, and temperature (Cunningham and Tiede, 1981). The rheological properties can be measured by the rheometer to understand the changes of hardness, stickiness, elasticity and gelatinization temperature of batter during thermal processing (Sanz et al., 2004, 2005a,b; Salvador et al., 2006; Baixauli et al., 2003, 2007).

Deep-fat frying can be defined as the process of drying and cooking foods through contact with hot oil. Microwaves can interact directly with polar water molecules in food to generate heat throughout the volume of food, so heating time is reduced, and thicker foods are heated more uniformly by microwaves (Venkatesh and Raghavan, 2004; Yeo and Shibamoto, 1991). Microwave frying has two energy sources to heat foods, which can be simultaneously cooked the interior of foods by microwave and the surface of foods by hot oil. It achieves the necessary golden coloration and crispiness of the crusts. Microwave frying significantly shortens frying time, reduces lipid oxidation and minimizes oil content (Chen, 2002; Yang, 2002; Chen et al., 2004).

The objectives of this study were (1) to evaluate the different batter formulas affecting the rheological properties and pick-up ratios of batters, and (2) to analyze moisture content, oil content, texture and color of the crusts by deep-fat frying or microwave frying fish nuggets, in order to obtain the optimal batter formula and frying process for lower oil absorption and reducing frying time.

2. Materials and methods

2.1. Materials

Frozen fish (*Coryphaena hippurus*) was provided by Fuguo Enterprise Co. LTD. (Ilan, Taiwan). Wheat flour and corn starch

* Corresponding author. Tel.: +886 3 9357400x882; fax: +886 3 9310722.
E-mail address: sdchen@niu.edu.tw (S.-D. Chen).

0260-8774/$ - see front matter Crown Copyright © 2009 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2009.05.016

(30% amylose) were purchased from Gi Chan Food Co., Ltd. (Hsin Chu, Taiwan). CMC and HPMC (HPMC300, Taian Ruitai Cellulose Co., Ltd., Feicheng, PRC) were purchased from Toong Yeuan Enterprise Co., Ltd. (Taipei, Taiwan). Modified starch, wheat protein and soy protein were purchased from Yih-Yuan Food Additives Chemical Industrial Co., Ltd. (Taipei, Taiwan). Leavening ($NaHCO_3$) was purchased from Chien Yuan Food Chemicals Co., Ltd. (Taipei, Taiwan). CG excellent frying oil (Code: SP003) was purchased from Chang Guann Co. Ltd. (Kaoshsiung, Taiwan), and it was palm oil.

2.2. Preparation of fish nuggets

The fish nuggets (20 g) were immersed in different batter formulas (Table 1) for 10 s. The major components in batter were wheat flour and corn flour, and other ingredients such as 1% protein, 5% starch or 1% gum were partial instead of flours. The solid to water ratio in batter was controlled at 1:0.85, and each batter contained 1% salt and 0.5% leavening agent. Then the fish nuggets were pre-fried at 180 °C for 30 s in a microwave deep-fat fryer (Chin Ying Fa Mechanical Ind. Co., Ltd., Taiwan). The interior and exterior dimensions of microwave deep-fat fryer were 397 × 397 × 360 mm and 610 × 510 × 630 mm, respectively. The microwave fryer can be controlled by both electric powers 2400 W for heating oil and 2500 W for microwave input. Oil capacity was 16 l. Pre-fried fish nuggets were placed in plastic bags and stored at −18 °C for 1 week in a refrigerator. Finally the frozen fish nuggets were fried by either 180 °C conventional deep-fat frying for 5 min or 180 °C microwave frying for 3.5 min.

2.3. Rheological properties of batter

Rheological properties of different batters were determined in a dynamic rheometer (Rheometer AR-550, TA Instruments, New Castle, Delaware, USA) with a small amplitude oscillatory test (SAOT). The dynamic rheometer was equipped with cone geometry (60 mm diameter with 2° angle). Gap was set at 1.0 mm. Prior to the temperature ramp test, frequency and strain sweeps were conducted to obtain the linear viscoelastic region, after which the frequency and strain were fixed at 1 Hz and 1%, respectively. Temperature sweep involved heating at 2 °C/min from 20 to 80 °C. The frequency was set at a range of 0.01–10 Hz. For viscosity measurements, shear rates were scanned from 0.1 to 100 s^{-1} at 25 °C. Triplicate scans were made, with the storage modulus (G'), loss modulus, (G''), tan δ, and flow property indexes recorded. A non-Newtonian fluid model was utilized to estimate the flow behavior properties of batters.

2.4. Batter pick-up

The fish nugget was immersed in the batters for 10 s, and was then taken out for dripping 30 s. Batter pick-up was analyzed with triplicates and considered to be the amount of batter adhering to a fish nugget, and it is calculated as the ratio of batter weight to the total fish nugget after coating batter (Sanz et al., 2004).

Table 1
Major ingredients and compositions in batter flours.

Item	Wheat flour (%)	Corn flour (%)	Other ingredients (%)
Control	50	50	0
1% Wheat protein	49.5	49.5	1
1% Soy protein	49.5	49.5	1
5% Amylose	47.5	47.5	5
5% Modified starch	47.5	47.5	5
1% CMC	49.5	49.5	1
1% HPMC	49.5	49.5	1

2.5. Water content and oil content

In accordance with AOAC (1984), the crust samples were dried in an oven at 105 °C until constant weights were achieved in order to calculate the weight loss, from which the water content of the sample was obtained. The crude oils of dried crusts were extracted with hexane for 60 min using a Soxtec extraction system HT, to determine the oil content. The moisture content and oil content of fried crusts were analyzed with triplicates.

2.6. Texture analysis

The crust crispness of six replicates was evaluated with a texture analyzer (TA-XT2 Texture Analyzer, stable micro system, England), and the load weight was 25 kg. The crusts were separated from fish nuggets, cut into rectangular (1 cm × 2 cm) strips and immediately subjected to a compression test using a knife adaptor (No. 8). Compression speed was 60 mm/min, with maximum peak force representing cutting force (in Newton, N) and compression distance representing deformation (in mm). Results were used to evaluate the degree of crust crispness.

2.7. Color measurement

The crust sample color with triplicates was measured with a Color Difference Meter (JP7200F, Juki Co. Ltd., Tokyo, Japan) and standardized against a calibration white plate ($X = 82.48$, $Y = 84.23$, $Z = 99.61$; $L^* = 92.93$, $a^* = -1.26$, $b^* = 1.17$). The parameters determined were degrees of lightness (L^*), redness ($+a^*$) or greenness ($-a^*$), and yellowness ($+b^*$) or blueness ($-b^*$). Total color change (ΔE) is defined in the following equation: $\Delta E = \sqrt{(92.93 - L^*)^2 + (-1.26 - a^*)^2 + (1.17 - b^*)^2}$

2.8. Statistical analysis

The experimental results recorded were means ± standard deviation (SD). Results were processed by SPSS 14.0 (SPSS Inc.) analysis. Tests of significant differences were determined by Duncan's multiple range tests at $p < 0.05$.

3. Results and discussion

3.1. Rheological properties and pick-up of batters

Both formula and moisture content of batters significantly affect the rheological properties of batters (Baixauli et al., 2003). Figs. 1–3 show the storage modulus (G''), the loss modulus (G'') and the loss tangent (tan δ) of different batter formulas which were measured under 25 °C and rotation frequency at 0.01–10 Hz. The G' and G'' values of batters containing 1% CMC or 1% HPMC were higher than those of the other batters. The batters containing 1% wheat protein, 5% amylose or 5% modified starch had similar G' and G'' values as the control. Fig. 3 shows tan δ values of different batters. The batters containing 1% CMC or 1% HPMC had smaller values than the other batters, so they had higher visco-elasticity.

The G'' and G'' values of batters increased with rotation frequency and the Herschel–Bulkley model provided a good fitting for the flow behaviors of the batters (Table 2). The batters containing 1% CMC or 1% HPMC had higher consistency than other batters, so they exhibited the strong adhesion to fish nugget and had significantly higher pick-up values over 40% than other batters. The HPMC-enhanced batter demonstrated strong coating performance at a temperature range between 5 and 25 °C (Chen et al., 2008). Moreover, the batters with 1% soy protein, 1% CMC or 1% HPMC had higher yield stresses than other batters. The batters containing

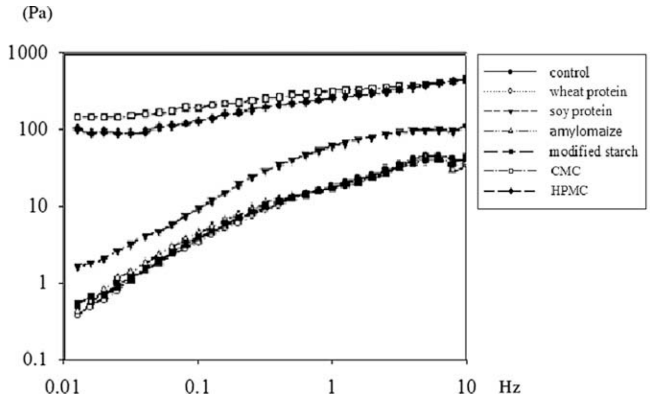

Fig. 1. The G' (storage modulus) values of different batters at 25 °C.

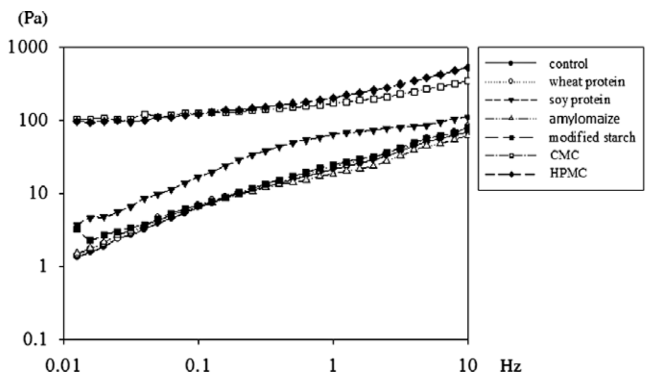

Fig. 2. The G'' (loss modulus) values of different batters at 25 °C.

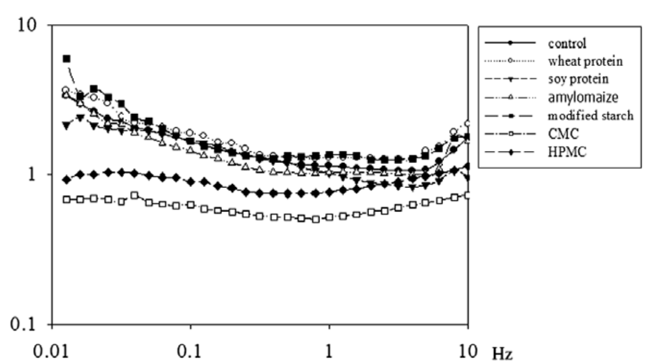

Fig. 3. The tan δ values of different batters at 25 °C.

Table 2
Effect of different batter viscosity on pick-up of fish nuggets.

Item	Flow behavior	r^2	Pick-up (%)
Control	$\tau = 72 + 0.204\gamma^{1.065}$	0.978	29.85 ± 1.85^{c}
1% Wheat protein	$\tau = 86 + 0.898\gamma^{0.956}$	0.950	22.40 ± 1.32^{d}
1% Soy protein	$\tau = 240 + 7.585\gamma^{0.904}$	0.983	23.75 ± 4.81^{d}
5% Amylose	$\tau = 54 + 12.079\gamma^{0.500}$	0.941	28.56 ± 4.11^{c}
5% Modified starch	$\tau = 24 + 2.844\gamma^{0.814}$	0.949	29.25 ± 1.55^{c}
1% CMC	$\tau = 201 + 16.158\gamma^{0.466}$	0.969	48.82 ± 1.12^{a}
1% HPMC	$\tau = 179 + 47.035\gamma^{0.495}$	0.998	43.18 ± 1.57^{b}

[a–d]Means in the same column followed by different letters are significantly different ($p < 0.05$).

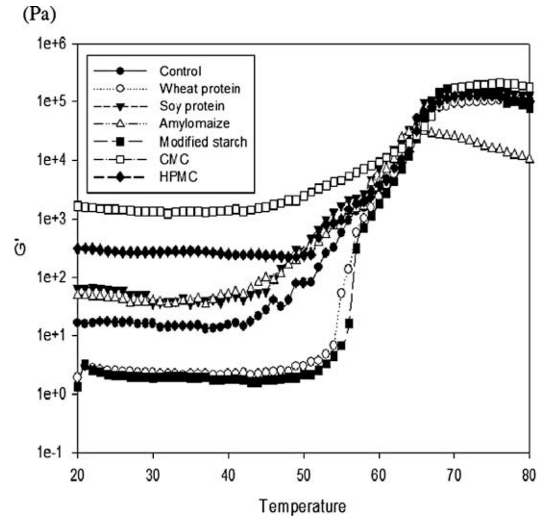

Fig. 4. Effect of temperature gradient on G' values for different batters.

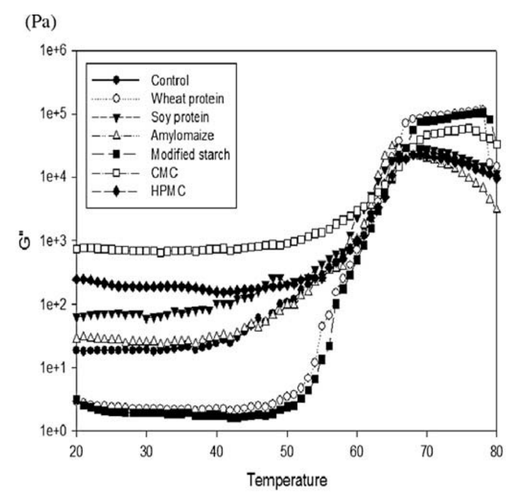

Fig. 5. Effect of temperature gradient on G'' values for different batters.

1% protein did not have higher pick-up values, which were different from Dogan et al.'s results (2005a), they may be due to different moisture contents in batter formulas. The batters containing 5% amylose or 5% modified starch had similar pick-up values as the control, and the results were coincidence with Altunakar et al. (2004) and Salvador et al. (2005).

The changes of G' values (Fig. 4) and G'' values (Fig. 5) of different batters during 20–80 °C heating were measured. The batters containing 1% CMC or 1% HPMC had higher G' and G'' values than the control, and the batters containing 1% wheat protein or 5% modified starch had the lowest G' and G'' values. The batters containing 1% soy protein or 5% amylose increased G' and G'' values during 40–45 °C, and they were as similar as the control. However, the other batters must be heated over 50 °C to change the rheological properties. Therefore, batters containing 1% HPMC decreased pasting temperature and increased viscosity, thus enhancing batter setting and adherence properties (Altunakar et al., 2004; Naruenartwongsakul et al., 2004; Sanz et al., 2004; Chen et al., 2008).

3.2. Effects of batter formula and frying process on crust qualities of fish nuggets

The pre-fried fish nuggets were finally fried by either 180 °C conventional frying for 5 min or 180 °C microwave frying for

3.5 min, respectively; therefore, the center temperature of fish nuggets could increase from −18 °C to over 90 °C. The volumetric heat generation in the fish nuggets by microwave could overcome the slow heat conduction by conventional hot oil alone and significantly shorten the frying time (Chen, 2002; Yang, 2002; Chen et al., 2004).

Moisture contents in the pre-fried crusts were 48.61–51.53%, and moisture contents in the final fried crusts decreased to 31.60–45.27% due to further frying and heating (Table 3). The moisture content in the crust of chicken nugget significantly decreased with frying time. However the rate of moisture loss in the crust was much faster than that in the core of chicken nuggets; the crust could retain much juiciness in chicken (Adedeji et al., 2009). The oil contents in the pre-fried crusts were 4.96–10.06%, and as expected the oil contents of the final fried crusts increased to 8.07–18.92% (Table 4). The temperature of the interior food increases to cause water evaporation and form pores on the crust during frying. Therefore, oil diffuses to the porous crust leading to higher oil content and lower moisture content in the crusts of fried foods (Gamble et al., 1987; Sahin et al., 2005). Although frying time for microwave frying was shorter than that for conventional frying, the microwave fried crust did not have lower oil content compared to the conventional deep-fat fried crusts. This may due to oil adhered to the surface of the crust during frying, and frying time difference between conventional frying and microwave frying does not matter. In addition, the fat content of the crust suddenly increased after 30 s of frying and then had litter changes for further frying (Adedeji et al., 2009). Both crusts and foods simultaneously absorb oil during frying to increase oil contents (Llorca et al., 2001); therefore, batter containing thermogelation ingredients or other pre-heating treatments instead of pre-frying process were further studied to decrease the oil content of fired foods (Sanz et al., 2004, 2005a,b; Llorca et al., 2005; Salvador et al., 2006; Baixauli et al., 2003, 2007).

Moisture contents in the crusts containing 1% CMC or 1% HPMC were 42.72–45.27%, and they were significantly higher than the other batters (Table 3). Oil contents in the crusts containing 1% CMC or 1% HPMC were significantly lower than the control group

Table 3
Effect of 180 °C conventional frying and microwave frying on the moisture content of fish nugget crusts.

Item	Pre-frying	Conventional frying	Microwave frying
Control	48.64 ± 0.81^{a,x}	35.90 ± 1.10^{bc,y}	33.53 ± 1.42^{d,z}
1% Wheat protein	48.61 ± 1.78^{a,x}	33.21 ± 2.02^{d,y}	31.60 ± 0.85^{e,y}
1% Soy protein	48.81 ± 1.71^{a,x}	34.61 ± 0.59^{cd,y}	34.90 ± 1.05^{d,y}
5% Amylose	51.47 ± 0.31^{a,x}	37.11 ± 0.51^{b,z}	38.52 ± 0.53^{c,y}
5% Modified starch	49.61 ± 0.92^{a,x}	34.43 ± 0.13^{cd,z}	38.04 ± 0.29^{c,y}
1% CMC	51.53 ± 1.22^{a,x}	44.47 ± 0.29^{a,y}	42.72 ± 0.77^{b,z}
1% HPMC	49.01 ± 3.03^{a,x}	44.54 ± 1.85^{a,y}	45.27 ± 1.09^{a,xy}

$^{x–z}$Means in the same row followed by different letters are significantly different ($p < 0.05$).
$^{a–e}$Means in the same column followed by different letters are significantly different ($p < 0.05$).

Table 4
Effect of 180 °C conventional frying and microwave frying on the oil content of fish nugget crusts.

Item	Pre-frying	Conventional frying	Microwave Frying
Control	10.06 ± 0.32^{a,z}	14.79 ± 0.72^{c,y}	16.47 ± 0.27^{b,x}
1% Wheat protein	9.14 ± 0.53^{a,y}	18.92 ± 0.67^{a,x}	18.76 ± 0.66^{a,x}
1% Soy protein	9.66 ± 0.81^{a,y}	17.69 ± 0.08^{b,x}	17.95 ± 0.57^{a,x}
5% Amylose	8.99 ± 0.32^{a,z}	12.84 ± 0.59^{d,y}	14.47 ± 0.26^{c,x}
5% Modified starch	9.93 ± 0.57^{a,y}	13.89 ± 0.94^{cd,x}	12.58 ± 0.56^{d,x}
1% CMC	4.96 ± 1.23^{c,y}	9.92 ± 0.67^{e,x}	11.46 ± 0.50^{e,x}
1% HPMC	6.22 ± 0.16^{b,y}	8.07 ± 0.87^{f,x}	8.36 ± 0.55^{f,x}

$^{x–z}$Means in the same row followed by different letters are significantly different ($p < 0.05$).
$^{a–f}$Means in the same column followed by different letters are significantly different ($p < 0.05$).

Table 6
Effect of 180ºC conventional frying and microwave frying on the L^* value of fish nugget crusts.

Item	Pre-frying	Conventional frying	Microwave frying
Control	73.39 ± 0.42^{ab,x}	59.44 ± 0.21^{d,z}	60.65 ± 0.64^{d,y}
1% Wheat protein	70.28 ± 4.35^{b,x}	57.93 ± 0.80^{e,y}	59.90 ± 0.57^{d,y}
1% Soy protein	71.13 ± 3.95^{b,x}	61.50 ± 0.32^{c,y}	61.07 ± 0.36^{d,y}
5% Amylose	73.79 ± 0.27^{ab,x}	58.97 ± 0.20^{de,z}	63.44 ± 0.87^{c,y}
5% Modified starch	72.58 ± 1.78^{b,x}	62.47 ± 0.44^{c,y}	60.21 ± 1.00^{d,y}
1% CMC	77.99 ± 1.23^{a,x}	68.30 ± 0.77^{a,y}	67.20 ± 0.59^{b,y}
1% HPMC	77.72 ± 2.60^{a,x}	66.64 ± 1.37^{b,z}	70.44 ± 0.21^{a,y}

$^{x–z}$Means in the same row followed by different letters are significantly different ($p < 0.05$).
$^{a–e}$Means in the same column followed by different letters are significantly different ($p < 0.05$).

Table 7
Effect of 180 °C conventional frying and microwave frying on the a^* value of fish nugget crusts.

Item	Pre-frying	Conventional frying	Microwave frying
Control	−0.51 ± 0.16^{b,z}	6.20 ± 0.41^{c,x}	5.00 ± 0.82^{ab,y}
1% Wheat protein	−0.58 ± 0.13^{b,z}	7.15 ± 0.32^{b,x}	5.65 ± 1.24^{a,y}
1% Soy protein	−0.51 ± 0.10^{b,z}	5.22 ± 0.23^{d,x}	4.57 ± 0.33^{abc,y}
5% Amylose	−0.82 ± 0.62^{b,z}	8.79 ± 0.21^{a,x}	3.49 ± 0.18^{bcd,y}
5% Modified starch	−0.53 ± 0.09^{b,y}	4.59 ± 0.52^{e,x}	4.16 ± 0.42^{abc,x}
1% CMC	0.20 ± 0.34^{a,y}	2.64 ± 0.13^{f,x}	3.38 ± 0.92^{cd,x}
1% HPMC	0.32 ± 0.48^{a,z}	4.61 ± 0.34^{e,x}	2.21 ± 1.07^{d,y}

$^{x–z}$Means in the same row followed by different letters are significantly different ($p < 0.05$).
$^{a–f}$Means in the same column followed by different letters are significantly different ($p < 0.05$).

Table 5
Effect of 180 °C conventional frying and microwave frying on the cutting force (kg) and deformation (mm) of fish nugget crusts.

Item	Cutting force (kg)		Deformation (mm)	
	Conventional frying	Microwave frying	Conventional frying	Microwave frying
Control	0.83 ± 0.01^{c,x}	0.83 ± 0.01^{c,y}	3.00 ± 0.16^{c,x}	3.01 ± 0.44^{bc,x}
1% Wheat protein	0.98 ± 0.01^{a,x}	0.94 ± 0.01^{a,y}	2.07 ± 0.13^{e,x}	2.46 ± 0.63^{c,x}
1% Soy protein	0.83 ± 0.01^{c,y}	0.94 ± 0.01^{a,x}	2.61 ± 0.10^{d,y}	3.32 ± 0.14^{b,x}
5% Amylose	0.88 ± 0.01^{b,x}	0.73 ± 0.01^{d,y}	2.98 ± 0.02^{c,x}	2.61 ± 0.29^{c,x}
5% Modified starch	0.82 ± 0.01^{c,y}	0.93 ± 0.01^{b,x}	2.97 ± 0.08^{c,x}	2.46 ± 0.17^{c,y}
1% CMC	0.82 ± 0.02^{c,x}	0.83 ± 0.01^{c,x}	3.65 ± 0.20^{b,x}	3.42 ± 0.37^{b,x}
1% HPMC	0.38 ± 0.01^{d,y}	0.83 ± 0.01^{c,x}	5.15 ± 0.25^{a,x}	4.56 ± 0.09^{a,y}

$^{x–z}$Means in the same row followed by different letters are significantly different ($p < 0.05$).
$^{a–e}$Means in the same column followed by different letters are significantly different ($p < 0.05$).

and other batters ($p < 0.05$) (Table 4). The crust of fish nuggets containing methylcellulose had low oiliness by sensory evaluation (Albert et al., 2009). Because CMC and HPMC in batters can form thermal gel structures to increase moisture retention and reduce oil pick-up; they are suitable for a barrier ingredient in fried foods (Dziezak, 1991). HPMC is a hydrocolloid that gels when heated and returns to its original liquid consistency when cooled. Therefore, the HPMC–starch or CMC–starch crusts are rather than simply changing the diffusion characteristics of water and oil across the barrier (Collar et al., 1998; Kuntz, 1997; Pryia et al., 1996), these gels also alter the flow properties of batters. In addition, the batters containing CMC or HPMC decreased pasting temperature and increased viscosity, thus enhancing batter setting and adherence properties (Altunakar et al., 2004; Naruenartwongsakul et al., 2004; Sanz et al., 2004; Chen et al., 2008).

The crusts containing 5% amylose or 5% modified starch had higher moisture contents (33.53–35.90%) (Table 3) and lower oil contents (12.58–14.47%) than the control group (Table 4). The swelled starch granules were heated by frying to resist moisture loss and decrease oil diffusing to the crusts (Chen et al., 2008). The final fried crusts containing 1% wheat protein and 1% soy protein had less moisture contents (Table 3) and higher oil contents (Table 4) due to low pick-up values than other fried crusts (Table 2). Therefore, enough batter provided coating and film structure outside the fish nuggets to avoid too much water evaporation during frying.

Crunchiness is a very important and a desirable texture of the fried product (Albert et al., 2009). Cutting force may represent crust hardness, and compression distance to cut-off crust may represent deformation to evaluate fracturability, with deformation values correlation negatively with crust crispness (Chen et al., 2008). The hardness and crispness of fried crusts containing 1% wheat protein or 1% soy protein were higher than the control group (Table 5). The fried crusts containing HPMC had softer and elasticity texture, because HPMC gel absorbing water molecules in the crusts resulted in inferior crispness and increased elasticity of crust (Chen et al., 2008; Sahin et al., 2005).

The crust color of fried fish nugget affects consumers' purchasing. The golden color of fried crusts appeared due to Maillard reaction and caramelization of sugars in the higher temperature frying treatment (Albert et al., 2009). Table 6 shows that L^* values of the pre-fried crusts were between 70.28 and 77.99. The crusts containing wheat protein, soy protein or modified starch obtained darker color, because Maillard reaction occurred during frying. The L^* values of both conventional fried and microwave fried crusts significantly decreased than pre-fried crusts. The L^* values of crusts containing 1% CMC or 1% HPMC were 66.64–70.44, which were significantly lighter than the other batters. Batter added dextrin achieved the darker crust by Maillard reaction, but batter containing methylcellulose had much lighter color crust (Albert et al., 2009). Because the crusts containing 1% CMC or 1% HPMC had high water holding capacity and less Maillard reaction occurrence during frying (Akdeniz et al., 2006).

Both conventional fried and microwave fried crusts increased the redness a^* (Table 7) and yellowness b^* values (Table 8) than pre-fried crusts. Redness a^* values of pre-fried crusts containing 1% CMC or 1% HPMC were higher than other pre-fried crusts. But a^* values of both conventional fried and microwave fried crusts containing 1% CMC or 1% HPMC were lower than other final crusts. The b^* values of pre-fried crusts were 15.99–21.79. The pre-fried crust containing 5% amylose had the lowest b^* value; and there was no significant difference in b^* values among other pre-fried crusts (Table 8). There was no significant difference in b^* values between conventional fried and microwave fried crusts except for crusts containing 1% soy protein or 5% amylose. Therefore, the golden color of final fried fish nugget crusts was accomplished by both conventional frying and microwave frying.

Table 8
Effect of 180 °C conventional frying and microwave frying on the b^* value of fish nugget crusts.

Item	Pre-frying	Conventional frying	Microwave frying
Control	$19.19 \pm 1.67^{ab,y}$	$32.85 \pm 1.74^{cd,x}$	$30.93 \pm 0.86^{ab,x}$
1% Wheat protein	$17.96 \pm 0.42^{bc,y}$	$34.02 \pm 0.86^{bc,x}$	$31.88 \pm 2.03^{a,x}$
1% Soy protein	$20.08 \pm 0.65^{ab,z}$	$32.33 \pm 0.30^{cd,x}$	$29.51 \pm 1.36^{ab,y}$
5% Amylose	$15.99 \pm 0.55^{c,z}$	$37.27 \pm 0.20^{a,x}$	$28.45 \pm 1.19^{b,y}$
5% Modified starch	$20.46 \pm 1.05^{ab,y}$	$31.49 \pm 0.39^{de,x}$	$30.94 \pm 1.52^{b,x}$
1% CMC	$21.79 \pm 2.06^{a,y}$	$30.44 \pm 0.69^{e,x}$	$31.88 \pm 1.75^{a,x}$
1% HPMC	$21.12 \pm 2.66^{a,y}$	$35.61 \pm 1.23^{b,x}$	$31.61 \pm 2.16^{a,x}$

$^{x–z}$Means in the same row followed by different letters are significantly different ($p < 0.05$).
$^{a–e}$Means in the same column followed by different letters are significantly different ($p < 0.05$).

Table 9
Effect of 180 °C conventional frying and microwave frying on the ΔE value of fish nugget crusts.

Item	Pre-frying	Conventional frying	Microwave frying
Control	$26.61 \pm 0.91^{abc,z}$	$46.71 \pm 1.33^{c,x}$	$44.36 \pm 1.16^{ab,y}$
1% Wheat protein	$28.31 \pm 3.14^{ab,y}$	$48.73 \pm 0.72^{b,x}$	$45.66 \pm 1.22^{a,x}$
1% Soy protein	$28.97 \pm 2.65^{a,y}$	$44.73 \pm 0.30^{d,x}$	$43.05 \pm 0.84^{b,x}$
5% Amylose	$24.22 \pm 0.22^{c,z}$	$50.57 \pm 0.18^{a,x}$	$40.46 \pm 0.95^{c,y}$
5% Modified starch	$28.09 \pm 0.61^{ab,z}$	$43.38 \pm 0.32^{e,y}$	$44.59 \pm 0.34^{ab,x}$
1% CMC	$25.52 \pm 2.11^{abc,y}$	$38.45 \pm 1.03^{f,x}$	$40.35 \pm 1.58^{c,x}$
1% HPMC	$25.32 \pm 0.53^{bc,z}$	$43.75 \pm 0.23^{de,x}$	$38.02 \pm 1.91^{d,y}$

$^{x–z}$Means in the same row followed by different letters are significantly different ($p < 0.05$).
$^{a–e}$Means in the same column followed by different letters are significantly different ($p < 0.05$).

The total color change of pre-fried crusts did not have significant difference among the batters adding protein, starch or gum (Table 9). Conventional deep-fat fried crusts except containing 5% modified starch had higher total color changes than microwave fried crusts, and they may be due to shorter frying time.

4. Conclusion

The Herschel–Bulkley model provided a good fitting for flow behavior of the batters. Batters containing 1% CMC or 1% HPMC had higher viscosity to obtain high pick-up values, higher water contents, and lower oil contents, but smaller total color changes. The less oily quality was obtained in CMC or HPMC added fried fish nuggets no matter with traditional deep frying or microwave frying. Nevertheless, microwave frying reduced frying time and accelerated frying process.

References

Albert, A., Varela, P., Salvador, A., 2009. Improvement of crunchiness of battered fish nuggets. European Food Research and Technology 228, 923–930.
Adedeji, A.A., Ngadi, M.O., Raghavan, G.S.V., 2009. Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. Journal of Food Engineering 91, 146–153.
Akdeniz, N., Sahin, S., Summu, G., 2006. Functionality of batters containing different gums for deep-fat frying of carrot slices. Journal of Food Engineering 75 (4), 522–526.
Altunakar, B., Sahin, S., Sumnu, G., 2004. Functionality of batters containing different starch types for deep-fat frying of chicken nuggets. European Food Research and Technology 218 (4), 318–322.
AOAC, 1984. Official Methods of Analysis of the Association of Official Analytical Chemists, 14th ed. AOAC, Arlington, VA.
Baixauli, R., Sanz, T., Salvador, A., Fiszman, S.M., 2003. Effect of the addition of dextrin or dried egg on the rheological and textural properties of batters for fried food. Food Hydrocolloids 17, 305–310.
Baixauli, R., Sanz, T., Salvador, A., Fiszman, S.M., 2007. Influence of the dosing process on the rheological and microstructural properties of a bakery product. Food Hydrocolloids 21, 230–236.

Balasubramaniam, V.M., Chinnan, M.S., Mallikarjunan, P., Phillips, R.D., 1997. The effect of edible film on oil uptake and moisture retention of a deep-fat fried poultry product. Journal of Food Process Engineering 20, 17–29.

Chen, C.-J., 2002. The application of microwave hybrid heating technology. Food Industries 34 (7), 4–13.

Chen, S.-D., Pao, A.-C., Chen, H.-H., 2004. Studies on gracilar mackerel steak using microwave frying. Ilan University Journal of Bioresources 1 (1), 53–63.

Chen, H.-H., Kang, H.-Y., Chen, S.-D., 2008. The effects of ingredients and content on the rheological properties of batters and physical properties of crusts in fried foods. Journal of Food Engineering 88, 45–54.

Collar, C., Armero, E., Artinez, Z., 1998. Lipid binding of formula bread dough. Food Research and Technology 207 (2), 110–121.

Cunningham, F.E., Tiede, L.M., 1981. Influence of batter viscosity on breading of chicken drumsticks. Journal of Food Science 46, 1950–1952.

Dogan, S.F., Sahin, S., Sumnu, G., 2005a. Effect of containing different protein types on the quality of deep-fat-fried chicken nuggets. European Food Research and Technology 220, 502–508.

Dogan, S.F., Sahin, S., Sumnu, G., 2005b. Effect of soy and rice flour addition on batter rheology and quality of deep-fat chicken nuggets. Journal of Food Engineering 71, 127–132.

Dziezak, J.D., 1991. A focus on gums. Food Technology 45, 116–132.

Fiszman, S.M., Salvador, A., 2003. Recent developments in coating batters. Trends in Food Science 14, 399–407.

Gamble, M.H., Rice, P., Selman, J.D., 1987. Relationship between oil uptake and moisture loss during frying of potato slices from c.v. Record UK tubers. International Journal of Food Science and Technology 22, 233–241.

Gibney, A., Butler, F., Dwyer, E., 1999. Rheology and adhesion of fish batter coating made from flour from Irish grown wheat varieties. Irish Journal of Agriculture and Food Research 38, 241–249.

Kuntz, L.A., 1997. The Great Cover-up: Batters, Breadings and Coatings. Food Product Design. Weeks Publishing Co., Northbrook, IL, USA.

Llorca, E., Hernando, I., Perez-Munuera, I., Fiszman, S.M., Lluch, M.A., 2001. Effect of frying on the microstructure of frozen batter coated squid rings. European Food Research and Technology 213 (6), 448–455.

Llorca, E., Hernando, I., Perez-Munuera, I., Quiles, A., Larrea, V., Fiszman, S.M., Lluch, M.A., 2005. Microstructural study of frozen batter-coated squid rings prepared by an innovative process with a pre-frying step. Food Hydrocolloids 19, 297–302.

Loewe, R., 1993. Role of ingredients in batter systems. Cereal Foods World 38, 673–677.

Mohamed, S., Hamid, N.A., Hamid, M.A., 1998. Food components affecting the oil absorption and crispness of fried batter. Journal of Science Food Agriculture 78, 39–45.

Naruenartwongsakul, S., Chinnan, M.S., Bhumiratana, S., Yoovidhya, T., 2004. Pasting characteristics of wheat flour-based batters containing cellulose ethers. Lebenesmittel-Wissenschaft Und-Technologie 37, 489–495.

Pryia, R., Singhal, R.S., Kulkarni, P.R., 1996. Carboxylmethylcellulose and hydroxylpropylmethylcellulose as additives in reduction of oil content in batter based deep-fat fried boondis. Carbohydrate Polymers 29 (4), 333–335.

Sahin, S., Sumnu, G., Bilge, A., 2005. Effect of batters containing different gum types on the quality of deep-fat fried chicken nuggets. Journal of the Science and Food Agriculture 85, 2375–2379.

Salvador, A., Sanz, T., Fiszman, S.M., 2005. Effect of the addition of different ingredients on the characteristics of a batter coating for fried seafood prepared without a pre-frying step. Food Hydrocolloids 19, 703–708.

Salvador, A., Sanz, T., Fiszman, S.M., 2006. Dynamic rheological characteristics of wheat flour-water doughs. Effect of adding NaCl, sucrose and yeast. Food Hydrocolloids 20, 780–786.

Sanz, T., Salvador, A., Fiszman, S.M., 2004. Effect of concentration and temperature on properties of methylcellulose-added batters application to battered, fried seafood. Food Hydrocolloids 18, 127–131.

Sanz, T., Salvador, A., Velez, G., Munoz, J., Fiszman, S.M., 2005a. Thermogelation properties of methylcellulose (MC) and their effect on a batter formula. Food Hydrocolloids 19, 141–147.

Sanz, T., Salvador, A., Velez, G., Munoz, J., Fiszman, S.M., 2005b. Influence of ingredients on the thermo-rheological behaviour of batter containing methylcellulose. Food Hydrocolloids 19, 869–877.

Shih, F.E., Daigle, K., 1999. Oil uptake properties of fried batters from rice flour. Journal of Agricultural and Food Chemistry 47, 1611–1615.

Venkatesh, M.S., Raghavan, G.S.V., 2004. An overview of microwave processing and dielectric properties of agri-food materials. Biosystems Engineering 88 (1), 1–18.

Xue, J., Ngadi, M., 2006. Rheological properties of batter systems formulated using different flour combination. Journal of Food Engineering 77, 334–341.

Yang, B.B., 2002. An overview of microwave and conventional energy hybridized processing. Food Industries 36 (7), 1–7.

Yeo, H.C.H., Shibamoto, T., 1991. Chemical comparison of flavors in microwave and conventionally heated foods. Trends in Food Science and Technology 2, 329–332.