

Research Article

Effect of Batter Formulation and Pre-drying Time on Qualities of Fried Batter Coatings Prepared with a New Device

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Abstract: The objective of this study was to evaluate the effect of different batter formulation and pre-drying time on qualities and mass transfer during deep fat frying of batters by using a deep-fried crust model. The designed model allow the reproduction of the fried crusts with different batter and core types and made it easier to be separated for further study. The effects of Hydroxy Propyl Methyl Cellulose (HPMC), xanthan gum and fish scale collagen (2%) added to the batters and pre-drying time on mass transfer were determined. Results showed that the most reduction in oil absorption was observed when batter contained HPMC and xanthan gum. The first order kinetic based on the Fick's law were used to describe moisture transfer and oil absorption data, the effective moisture diffusivity ranged between $0.4605 \times 10^{-7} \text{ m}^2/\text{s}$ and $1.4637 \times 10^{-7} \text{ m}^2/\text{s}$ with R^2 from 0.9834 to 0.9985 and fat transfer rate constant was between 0.4387 s^{-1} to 0.6812 s^{-1} with R^2 from 0.9954 to 0.9979. Addition of HPMC or xanthan gum could significantly reduce the effective moisture diffusivity and oil transfer rate constant. Batters treated with pre-drying had lower effective moisture diffusivity and oil transfer rate during the frying process and the longer the pre-drying time was, the lower rate constant would be. Standard Deviation (SD) values showed that the designed deep-dried model system was suitable for fried crusts study.

Keywords: Batter, deep-frying, effective moisture diffusivity, formulation, mass transfer, pre-drying

INTRODUCTION

The market for battered foods has become grown considerably in recent years, particularly in the field of pre-fried products. Frying is a cooking method that can produce the food with a specific flavor, texture and appearance which are globally welcomed especially among the youngs. The crusts formed during deep-fat frying of battered foods is appreciated for its crispness and also batter coatings enhance the goods of the fried food. They act as a barrier against the loss of moisture by protecting the natural juices of goods from the effects of freezing or reheating, thereby ensuring a final product that is tender and juicy on the inside while at the same time crisp on the outside (Fizman and Salvador, 2003), the forming crust is a dominant driving factor for consumer's preference. However, one problem associated with fried batter foods is the considerable amount of oil absorption during frying.

Since the demand of healthier foodstuffs with high quality is getting more among the societies, several approaches have been suggested for decreasing oil absorption during frying of battered foods. In recent years, quite a large number of studies of additive performance in coating systems have been published (Gamonpilas *et al.*, 2013; Primo-Martín, 2012). The use

of Methyl Cellulose (MC) or gums has been the warhorses in experimentation with batters. Based on its reversible heat gelatin ability and surface activity, it can significantly reduce the interfacial tension, together with the good film-forming performance, it can hinder moisture evaporation and oil absorption (Fizman and Salvador, 2003).

Another methods to reduce the oil absorption is pre-drying method. Pre-drying reduces the initial moisture content of the product; and longer pre-drying time results in less free moisture content during frying (Gupta *et al.*, 2000), finally less oil was absorbed. It is important to understand the mechanism involved during the frying process, so that oil migration into the food can be minimized. Fick's law of diffusion are applied to modeling moisture transfer phenomenon during frying with successful agreement between experimental data and calculated values (Troncoso and Pedreschi, 2009). For fat uptake modeling, the first order kinetic model was recommended by Krokida *et al.* (2000). However, properties of the crusts formed during frying are difficult to study for a number of reasons. Core properties (i.e., moisture content, surface roughness and porosity) and batter viscosity can significantly affect the amount of batter adhering to the matrix before frying (batter pickup) (Fizman and Salvador, 2003)

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thus leading to a different crust property. Besides batter pickup, separation of core and crust is difficult and time consuming and the fried product often shows poor reproducibility.

To overcome these problems in studying the properties of fried crusts, some researchers have fried a fixed amount of batter on a stainless steel plate or immersed fixed amount of batter in frying oil. Although valuable results can be obtained, their applicability in research on crust formation is limited, because the water evaporating from the core during frying is an important factor that cannot be neglected when studying properties of batter coatings. A Deep-Fried Crust Model (DFCM) system was designed by Visser *et al.* (2008) for making deep-fried crusts, but still meet several difficulties, since the device holds four cups, size of the fryer needs bigger, thus more oil used in the study; besides this, the device was not such flexible, so a device derived from DFCM was used.

The aim of this research was to study the effect of several additives added to the batters and pre-drying time on properties of the fried batter coatings which prepared by a designed deep-fried model system allowing the reproduction of crusts with a flexibility of adapting to different batter and core properties. The knowledge generated by this study could be helpful in the future study of fried battered food.

MATERIALS AND METHODS

Batter ingredients and formulations: The batter formulation consisted of wheat flour (Wei-fang Kite flour Co., Shandong, China), leavening (Gan-zhiyuan

sugar Co., Nanjing, China), salt (Mo-dun salt Co., Shanghai, China), tilapia scale collagen (<1000 D) (Jindong Biotech Co., Haikou, China), xanthan gum (Jing-ye food additives Co., Henan, China), HPMC (Guang-da Technological Development Co., Jiangxi, China) and the composition of batter was shown in Table 1.

The thoroughly pre-blended powders were mixed with cold tap water in ratios of 1/1 (w/w) in a stirring apparatus (Star ST-906CS, Qingdao Bang and Lufsen Electrical Appliance Co., Shandong, China) for 2 min. Batter prepared from wheat flour alone was considered the control batter. Batters used for pre-drying study were placed in the hot air drier at 85°C for 15 min and 30 min before frying.

Development of deep-fried device: A new deep-fried model device (Fig. 1) was obtained using a device that consisted of a aluminum cup, which was covered by a Teflon wire to prevent the crust from caking to the wire during frying. The small mesh size and the hydrophobic

Table 1: Ingredients in batter

Ingredients (%) ^a	Patterns			
	Wheat flour	Fish scale collagen	Xanthan gum	HPMC
Wheat flour	91.4	89.4	89.4	89.4
Leavening	3.1	3.1	3.1	3.1
Salt	5.5	5.5	5.5	5.5
Fish scale collagen	-	2	-	-
Xanthan gum	-	-	2	-
HPMC	-	-	-	2

^a: All ingredient percentages are given on a weight basis

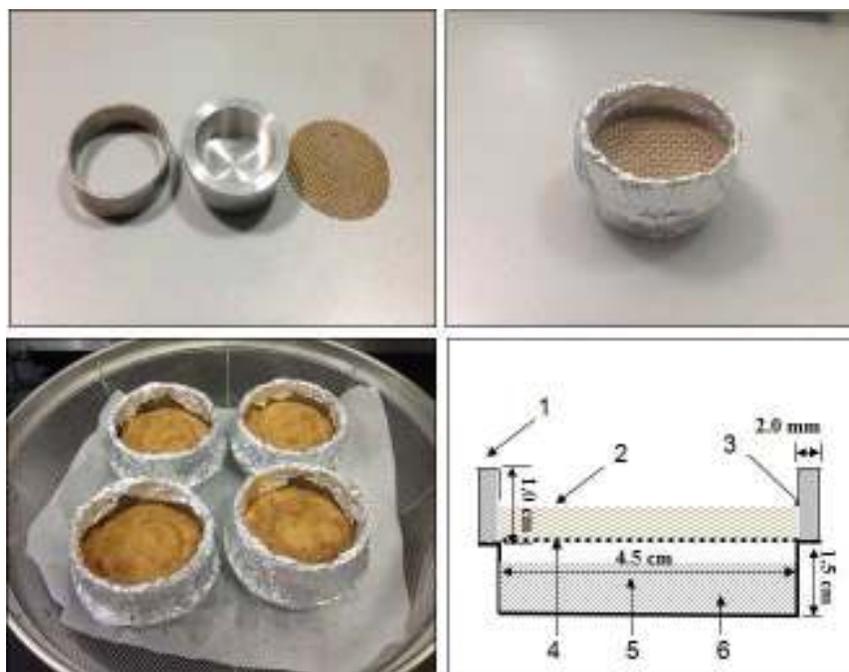


Fig. 1: Schematic presentation of deep-fried model system; (1: Tinfoil; 2: Batter; 3: Stainless steel ring; 4: Teflon wires; 5: Silica; 6: Aluminum cup)

teflon coating prevent penetration of the batter into the mesh. Stainless steel rings are placed on the top of the wire, acting as a reservoir for the batter. Silica (keep in the temperature and humidity chamber for 24 h) with 60% water content was placed into the aluminum cup. During frying, water evaporated from the silica into the batter, thus making it possible to simulate the process of frying and study the quality of crusts for a wide variety of batters and cores. Finally, the whole device was secured by covering a tinfoil on the outside. Four device were used once time to ensure the result of the study more accurate.

A circular aluminum cell of dimension Φ 50 mm was used to hold around 5 g batter. The advantages of using this device are:

- The amount of batter pick up is constant for all formulation
- Reproducibility of the data obtained is better than traditional methods. Visser *et al.* (2008) used a similar device to study the properties of crusts during deep fat frying of a Deep-Fried Model (DFCM) system and reported that the resulted crusts were comparable to commercial products. Model designed in this study was an improved version, which would be more flexible to have the crusts out of device after frying and properties of the upper side of the batter which was directly connected to the oil were more consistent with the reality.

Preparation of kibbeling: Frozen parts of tilapia fillet were cut in blocks $3 \times 2.5 \times 4$ cm. The frozen blocks were defrosting at 5°C for at least 2 h and placed into the temperature and humidity chamber (5°C , 60% humidity) for 24 h. Subsequently, the blocks were dipped in the laboratory-prepared batter and subsequently fried in soybean oil at 180°C for 2 min. Crusts separated from kibbeling are set as the conventional sample.

Frying: The entire device is immersed in the frying medium (soybean oil at 180°C) and fried for 2 min and temperature was measured using a thermocouple. A commercial deep-fat fryer (Verly HY-81R, Gang Yang Machine and Electric Equipment Co., Guangzhou, China) was used, the fresh oil was preheated and maintained at $180 \pm 2^\circ\text{C}$ for half an hour before frying. Fried coatings were separated from the gauze 3 min after frying and immediately for the later experiments. 5 g batters were pipetted onto the Teflon gauze and immersed into the hot oil, the forming crusts were prepared without device.

Color measurements: Colors of the coatings after the frying operation were measured instrumentally using a

chroma meter (CR-400, Konica minolta Inc., Tokyo, Japan) using the CIE Lab L^* , a^* and b^* color scale. Triplicate readings were carried out at room temperature on three different sections of each sample. Chroma (C^*) is the attribute that allows the degree of difference in comparison to a grey color with the same lightness to be determined for each hue, so it is considered the quantitative attribute of colorfulness:

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad (1)$$

Hue (h°) is the attribute according to which colors have been traditionally defined as reddish, greenish, etc. and hue angle were calculated from the parameters (Albert *et al.*, 2009):

$$h^\circ = \arctan(b^*/a^*) \quad (2)$$

Moisture and fat analysis: The water content was determined using a dry oven method. Samples were cut into pieces and placed at 105°C in an oven until constant weights were arrived. The crude oils of dried crusts were extracted with petroleum ether for 3 h using a Soxhlet extraction system (SZF-06, Xinjia electronics Co., Shanghai, China).

Modeling: Frying is a dehydration process and it involves heat and mass transfer simultaneously (Yildiz *et al.*, 2007). Effective diffusion coefficient in the fried batters can be modeled using the solution to the Fick's second law of diffusion equation (Nasiri *et al.*, 2011) as presented in Eq. (3):

$$M_r = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[(-2n+1)^2 \frac{\pi^2 D_{eff} t}{4L^2}\right] \quad (3)$$

Equation (3) can be simplified as follows when M_e is very small:

$$M_r = \frac{M}{M_0} = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) = \frac{8}{\pi^2} \exp(-kt) \quad (4)$$

where, M_r is moisture content ratio, M_0 , M and M_e are respectively initial moisture content (g/g, dry basis), moisture content at time t (g/g, dry basis) and equilibrium moisture content (g/g, dry basis), D_{eff} is the effective moisture diffusion coefficient (m^2/min) and d is the thickness (m) of the batter coating.

For oil uptake modeling, a first order kinetic model proposed by Krokida *et al.* (2000) was considered:

$$FC = O_{eq}[1 - \exp(-kt)] \quad (5)$$

where,

FC = Oil content (g/g, dry basis)
 O_{eq} = Equilibrium fat content (g/g, dry basis)
 k = Rate constant (s^{-1})
 Standard Deviation (SD) is defined as followed:

$$SD = \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1}} \quad (6)$$

where, \bar{X} is the average value of the samples

Statistical analysis: An Analysis of Variance (ANOVA) was performed to compare the effects of the different batters. Least significant differences were calculated by the Duncan's multiple range t -test. The analysis was performed using SPSS for Windows Version 21 (SPSS Inc., Chicago, USA). All the data and graphs were treated with Origin 8.50 software (Origin Lab Corporation, Northampton, USA).

RESULTS AND DISCUSSION

Color changes: The influence of the different ingredients studied on the parameter values for clarity (L^*), green-red component (a^*) and blue-yellow component (b^*) obtained after frying are showed in

Fig. 2. With respect to the color comparison after frying, fish scale collagen was the ingredient that provided the lowest L^* and showed a higher a^* value. Visually, the increase in parameter a^* and the decrease in parameter L^* translated into a slightly more intense golden color which was perfectly acceptable in the batter formulations studied (Baixauli *et al.*, 2003).

The C^* and h° values of fried crusts as shown in Table 2 were distributing from 32.01 (68.83) to 40.01 (75.28). $h^\circ = 0$ and 90 represent the red-purple and yellow color of the sample, fish scale collagen could significantly improve the golden color of the crust.

Prepared without the new device, water vapor on both sides of the crust would be more easy to evaporated and as a result of high temperature accompanied by dehydration, Maillard reaction and caramelization of sugars produced a typical golden color.

Table 2: Chroma and hue angle of different formula coatings fried for 2 min under 180°C

Batter formula	Chroma	Hue angle
Wheat flour	36.23 ^b (0.53)	74.01 ^b (0.85)
Fish scale collagen	36.49 ^b (0.27)	75.28 ^a (0.55)
Xanthan gum	40.01 ^a (0.69)	68.83 ^c (0.76)
HPMC	32.01 ^c (0.46)	75.03 ^a (0.32)

Different small letters within the same column, showed significant differences, $p < 0.05$

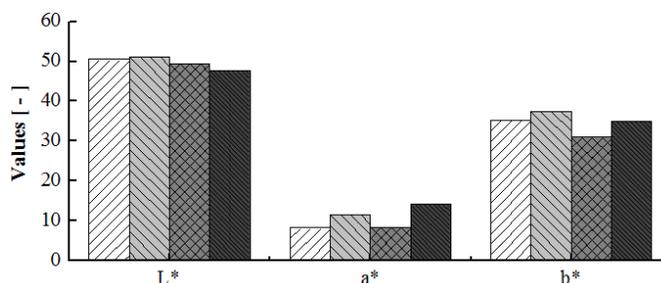


Fig. 2: L^* , a^* , b^* values of fried batter coatings prepared with a new device;
 ▨ Wheat flour; ▩ xanthan gum; ▧ HPMC; ▦ fish scale collagen

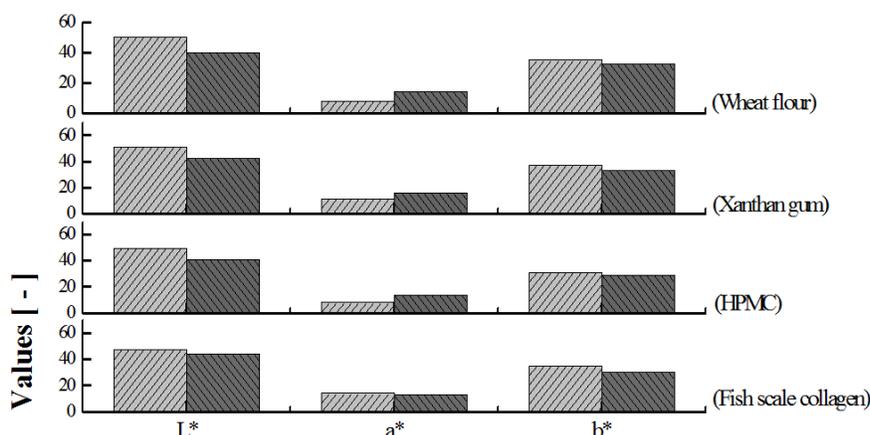


Fig. 3: L^* , a^* , b^* values of fried batter coatings prepared with and without a new device;
 ▨ Prepared without new device; ▩ Prepared with new device

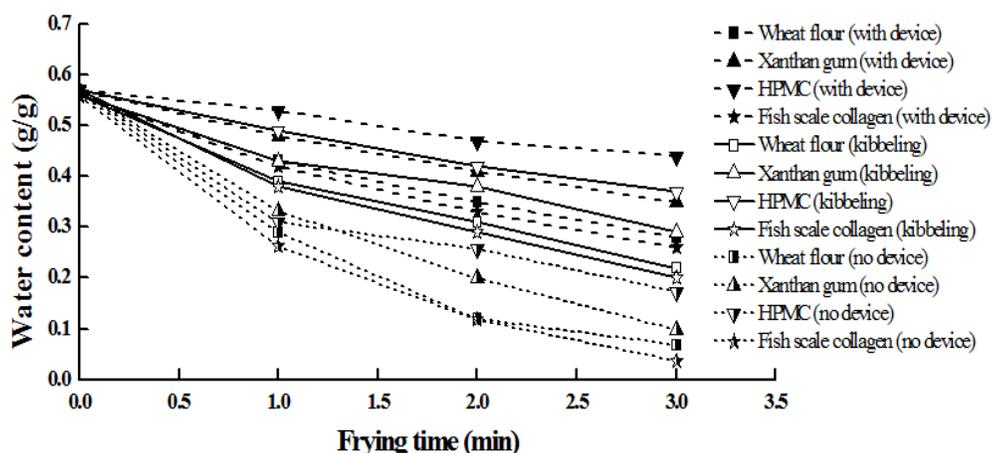


Fig. 4: Effect of different batter formulation on water content of fried crusts prepared with and without device

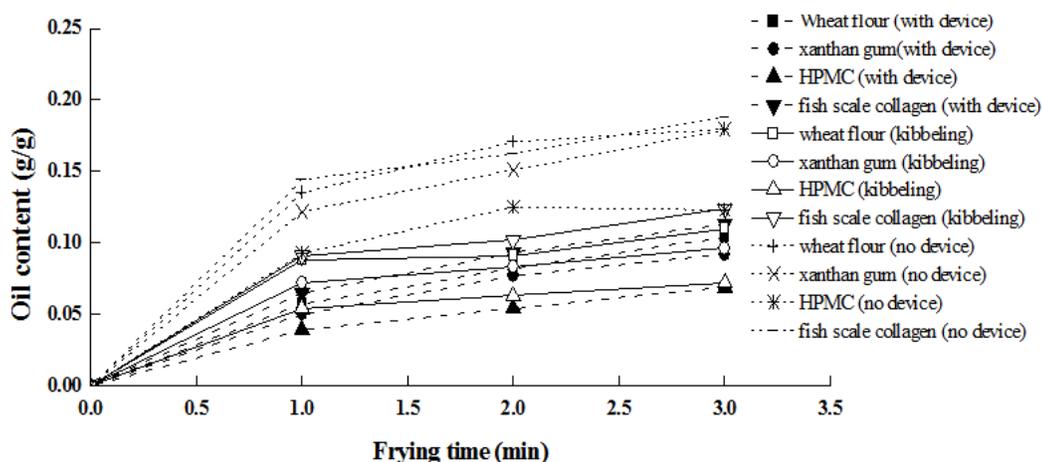


Fig. 5: Effect of different batter formulation on oil content of fried crusts prepared with and without device

Figure 3, batters prepared with the deep-fried model device which concerning the effect of water evaporated from the core to the crusts showed a lower L^* , a higher a^* and a lower b^* , which could lead to a more intense golden color than the crusts prepared without the new device.

Moisture and oil content: Figure 4 and 5 showed the water content and oil content of the several fried crusts prepared with, without the deep-fried device and crusts separated from kibbeling. The higher the frying time, the higher the moisture loss and oil content was observed. Compared to the crusts separated from kibbeling, crusts prepared with device had a little higher water content, but lower oil content, whereas crusts prepared without device showed a much lower water content but higher oil content, quality of crust prepared with device was more closer to the conventional sample. That's because without device, both sides of the crusts immersed to the hot oil, large amount of water evaporated, leaving large holes on the crusts surface and more oil was sucked into crusts. But

when with the device, moisture from the core evaporated into the sublayer of the crusts, only the upper of the crusts occurred water loss, so amount of evaporated water became less and the phenomenon of oil absorption which caused by water replacement decreased. As we can see from Fig. 1 there is a space between the silica and batter, high temperature together with the evaporated water accelerated the process of gelatinization of the batter, the forming film on the sublayer of the crust stop water from evaporating, so the water content of the crusts prepared with device was a little higher than the conventional sample. Water evaporating from the core plays an important role in the mechanism determining oil uptake during and after frying (Mellema, 2003).

The three kinds of crusts had a same result that crusts added with HPMC and xanthan gum had a higher water content and a lower oil content. HPMC and xanthan gum showed the effectiveness in reducing the amount of oil allowed to permeate into the crust and in acting as an oil barrier during frying. HPMC is a hydrocolloid that gels when heated and reverses to its

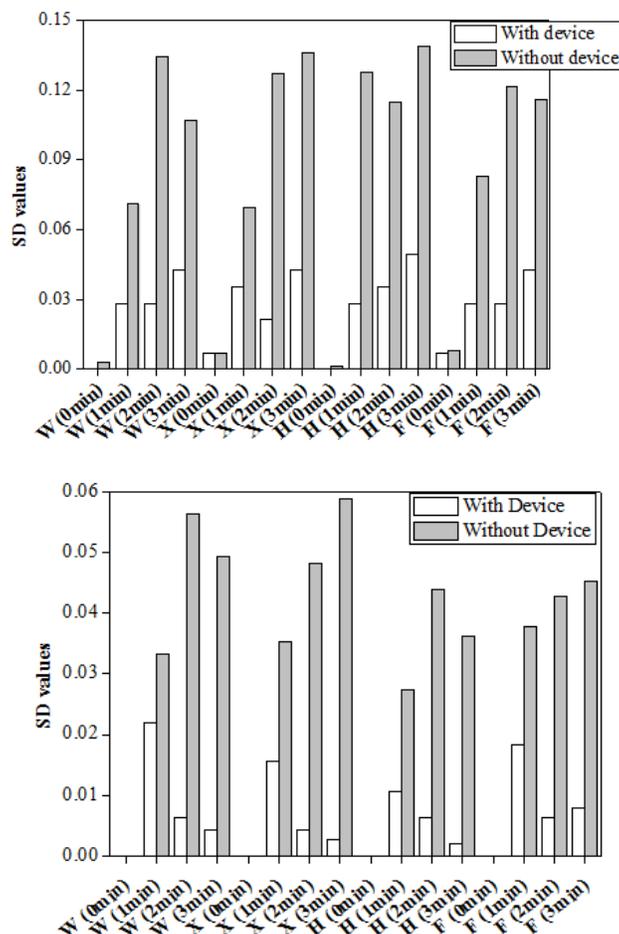


Fig. 6: SD (standard deviation) values of water content; (a) and oil content; (b) between crusts of kibbeling and crusts prepared with or without device; W: Wheat flour; X: Xanthan gum; H: HPMC; F: Fish scale collagen; Frying time is 0, 1, 2, 3 min, respectively

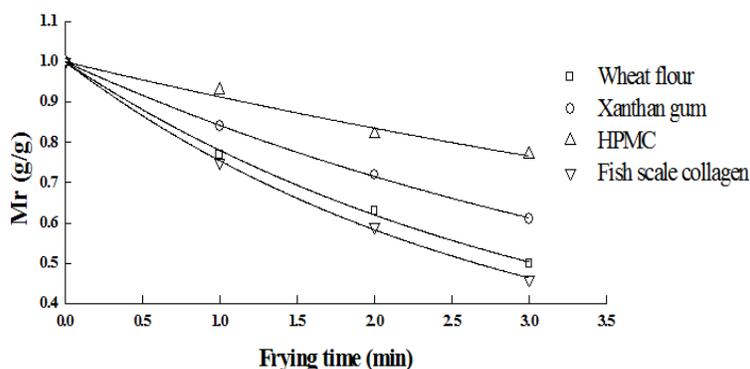


Fig. 7: Moisture content during frying of batter coating with different formulations prepared with deep-fried device

origin liquid consistency when cooled. It is high water retention capacity protects against moisture loss and reduced the oil content (Chen *et al.*, 2008). Xanthan gum can change the surface intensity between crust and oil and suddenly sealed off the holes caused by water evaporation, hinder oil from sucked into crust (Akdeniz *et al.*, 2006).

Figure 6 shows the SD values of water content and oil content between the crusts of kibbeling and crusts prepared with new device and between the crusts of kibbeling and crusts prepared without new device. Results shows that SD values of water and oil content between crusts prepared with device and crusts separated from kibbeling are smaller than the values

between crusts prepared without device and crusts separated from kibbeling, properties of crusts prepared by the new device are more similar to the commercial ones.

Diffusion modeling: A good knowledge of the mechanisms involved during frying process is essential to control oil absorption. Figure 7 shows the experimental and predicted values of moisture content ratio of batters prepared by the device. The model parameters for moisture diffusion in fried batters are presented in Table 3. As we can see from Table 3, HPMC and xanthan gum presented a positive effect on the effective moisture diffusivities. Adding HPMC and xanthan gum into the batter could reduce the D_{eff} during frying since its good water binding capacity hinder the evaporation of water. The moisture diffusivity of shrimp nuggets, coated with batters that were prepared from mixture of wheat and soy flours was reported to

be between $1.23 \times 10^{-6} \text{ m}^2/\text{min}$ and $3.42 \times 10^{-6} \text{ m}^2/\text{min}$ (Nasiri *et al.*, 2011).

Figure 8 shows the experimental and predicted values of oil content ratio during frying of batters. Data on oil absorption rate constants for fried batters are shown in Table 3. The rate constant of xanthan gum and HPMC added crust was lower than the control sample, while addition of fish scale collagen increasing the rate constant. The results may be attributed to the good film-forming abilities of gums that can alter batter flow properties besides changing the intensity of water and oil finally reduce the rate constant of oil absorption. The high R^2 values showed that, kinetic models were appropriate for predicting D_{eff} and k .

Pre-drying: Table 4 shows the model parameters for moisture transfer and oil migration of batters during frying after pre-dried for different times. With the time of pre-drying being longer, the D_{eff} values and k values

Table 3: Model parameters for moisture transfer and oil uptake in fried crusts with different batter formulation

	Batter formula	$k \text{ (s}^{-1}\text{)}$	$D_{eff} \times 10^{-7} \text{ (m}^2\text{/s)}$	R^2
Moisture transfer	Wheat flour	0.3163	1.2832	0.9974
	Xanthan gum	0.2163	0.8775	0.9965
	HPMC	0.1135	0.4605	0.9834
	Fish scale collagen	0.3608	1.4637	0.9985
Oil uptake	Wheat flour	0.5822	0.1241	0.9954
	Xanthan gum	0.4387	0.1142	0.9964
	HPMC	0.5104	0.0871	0.9973
	Fish scale collagen	0.6812	0.1284	0.9979

Table 4: Model parameters for moisture transfer and oil uptake in wheat and xanthan gum added batters with different pre-drying times

	Batter formulation	Pre-drying (min)	$k \text{ (s}^{-1}\text{)}$	$D_{eff} \times 10^{-7} \text{ (m}^2\text{/s)}$	R^2
Moisture transfer	Wheat flour	0	0.3163	1.2832	0.9974
		15	0.2921	0.9873	0.9773
		30	0.2023	0.8145	0.9851
	Xanthan gum	0	0.2163	0.8775	0.9965
		15	0.2003	0.6820	0.9647
		30	0.1978	0.5460	0.9785
Oil uptake	Wheat flour	0	0.5822	0.1241	0.9854
		15	0.5008	0.1224	0.9757
		30	0.4983	0.1138	0.8914
	Xanthan gum	0	0.4387	0.1142	0.9864
		15	0.3978	0.1089	0.9699
		30	0.3710	0.1037	0.9810

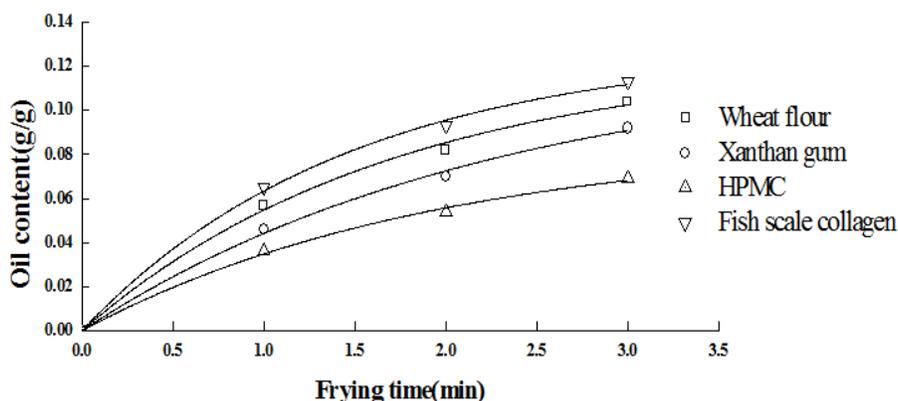


Fig. 8: Oil content during frying of batter coating with different formulations prepared with deep-fried device

of the crusts which only contain wheat flour and with xanthan gum added decreasing. From the results we can see pre-drying could be an effective method to reduce the water diffusion and oil absorption of batters during frying, since pre-drying reduced the D_{eff} and oil uptake rate and less moisture content causes less inner vacuum pressure after taking out the food from the fryer, less oil is sucked in to the food (Debnath *et al.*, 2003). The model shows a good fit as indicated the high R^2 values.

CONCLUSION

Physical properties of fried batter coatings are influenced to several extents by the type of additives added and the time of pre-drying operation. Addition of tilapia scale collagen could significantly improve the pale color of the control samples, producing crusts with a brighter golden color after frying. Adding HPMC or xanthan gum into the batters could significantly decrease the oil absorption rate constant, finally reduce the oil absorption of the crusts during frying. Pre-drying was an effective method to reduce the oil uptake during frying, since it could make the structure more condensed. The kinetic models gave a good fit for moisture diffusion and oil transfer of batters with different formulation during frying. Compared to the conventional samples, the designed deep-fried model device is convenient for studying the properties of fried crusts.

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