Response Surface Methodology Study on Optimization of Fish Tofu as Affected by Dietary Fiber Powder from Pomelo (*Citrus grandis* (L.) Osbeck) Albedo and Tapioca Starch

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ABSTRACT

A Central Composite Rotatable Design (CCRD) was adopted in the optimization of fish tofu with the addition of dietary fiber from pomelo albedo (0-3 g/100 g) and tapioca starch (3-9 g/100 g) on textural (hardness, cohesiveness, springiness, and chewiness), functional (water holding capacity [WHC] and cooking gain) and sensory properties. For each response, a second-order polynomial model was developed using multiple linear regression analysis. Applying desirability function method, optimum conditions for fish tofu were found to be pomelo albedo concentration of 2.98 g/100 g and tapioca starch concentration of 6.46 g/100 g. At this optimum point, hardness, cohesiveness, springiness, chewiness, WHC, and cooking gain were found to be 48.31 N, 0.57, 0.67 mm, 24.50 N mm, 1.39 g/ 100 g and 97.20 g/100 g, respectively. Pomelo albedo and tapioca starch had a notable influence on textural properties, which improved the textural properties at certain levels. Lower addition of pomelo albedo into fish tofu resulted in higher acceptable product with respect to firmness, juiciness and overall quality properties.

Keywords: response surface methodology, optimization, fish tofu, dietary fiber, pomelo albedo, tapioca starch

INTRODUCTION

Relationships between diet and health have led to changes in consumers' dietary habits, resulting in increasing demand for healthier foods. The growing demand by consumers for healthier products is stimulating the development of several fishery products with pleasant texture and taste including reduced fat, cholesterol, calorie contents and altered fatty acid profiles (Pagarkar *et al*., 2011; Ospina-Echeverri *et al*., 2012). The development of restructured fish products and the application of new food ingredients have been used as a way of reaching young and health-conscious consumers, but also as a means to upgrade low-value species and the waste generated by the fish processing industry (Sánchez *et al*., 2004). Simple reduction of fat would apparently be the most efficient method for producing low-fat products; however, product development

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studies on fat reduction should address the possible effects of this reduction on the technological functions such as water holding capacity, texture and sensory qualities after cooking and reheating (Alesón-Carbonell *et al*., 2005; Turhan *et al*., 2005; Sánchez-Zapata *et al*., 2010). In order to avoid the above-mentioned problems, numerous non-meat ingredients have been examined as adjuncts to be incorporated into food products such as starch, soya or whey proteins, seaweeds, carrageenan, konjac or dietary fiber.

Dietary fiber has been used in food products to determine their possible beneficial effects on health because of its technological attributes. Apart from dietary, fiber plays an important role as water binding, gelling, structure building and it can be used as potential fat replacers (O'Shea *et al*., 2012). Some fiber applications had been successful in improving cooking yield, reducing formulation costs and enhancing texture in meat products (Fernández-Ginés, *et al*., 2004; Fernández-López *et al*., 2008). In addition, there is considerable evidence from epidemiological, clinical and biochemical studies that fiber exerts a strong positive influence on human health by decreasing cholesterol level improving glucose tolerance and the insulin response, reducing hyperlipidemia and hypertension, contributing to gastrointestinal health and the prevention of certain cancers (Kaczmarczyk *et al*., 2012; Zhang *et al*., 2013).

Pomelo (*Citrus grandis* (L.) Osbeck) is the largest among the citrus fruits and is one of Thailand's economic plants. Pomelo fruit in food industries is used as a fresh fruit and fresh juice. The juice yield of pomelo fruit is less than half of the fruit weight (28.48–38.71 ml per 100 g), very large amounts of by product wastes such as peel are produced in ranged from 30 to 50 g/100 g of the whole fruit (Pichaiyongvongdee and Haruenkit, 2009). The principal component of the pomelo peel is albedo. Albedo is a white, spongy and cellulosic tissue, which could be considered as a potential source of fiber. The albedo obtained from pomelo was characterized by Pichaiyongvongdee and Rattanapun (2015). The Kao Nampheung cultivar was suitable for preparing dietary fiber powder because of its high crude fiber content and low bitter compounds such as limonin and naringin more than other cultivars (Pichaiyongvongdee and Rattanapun, 2015). This could be used as a source of dietary fiber in food processing, due to its high proportion of total dietary fiber and also had a high water holding capacity (Pichaiyongvongdee and Rattanapun, 2015). In addition, pomelo albedo had interesting antioxidant and good color characteristics for its application in food products: the high L* value and the low a* and b* values recorded (Pichaiyongvongdee and Rattanapun, 2015) show that the incorporation of pomelo albedo would not cause great modification of redness or yellowness in fish products.

It is well known that the textural parameters are closely related with sensory properties (Sarıçoban *et al*., 2009). Therefore, finding desired values of texture parameters that optimize sensory properties of product will provide more qualified knowledge to obtain better products that have desired technological properties. Response Surface Methodology (RSM) has been reported to be an effective and powerful tool for optimization of a process when the independent variables have a combined effect on the desired response. RSM is a collection of statistical and mathematical system that has been successfully used for developing, improving and optimizing such processes (Cui *et al*., 1994; Myers and Montgomery, 1995; Wu *et al*., 2007; Sarıçoban *et al*., 2009).

To the best of our knowledge studies regarding the use of pomelo albedo in processed fish products are lacking. In addition, no study has appeared to examine the levels of the processing variables to optimize the texture parameters based on sensory score. Thus, the aim of this work determined the optimization of processing variables such as pomelo albedo (0-6 g/100 g) and tapioca starch (3-9 g/100 g) aiming for improving the quality of fish products (fish tofu) and find the levels of processing variables to optimize the texture parameters based on sensory score.

MATERIALS AND METHODS

Pomelo albedo preparation

Fully matured pomelo (*Citrus grandis* (L.) Osbeck) peels of Kao Nampheung cultivar were collected from orchards in Nakhon Pathom province, Thailand. The albedo layers were manually separated from the rest of the peel and cut into small pieces of approximately 1×1×1 cm before use. Pomelo albedo powders were carried out according to the method described by Pichaiyongvongdee and Rattanapun, 2015. Briefly, samples were washed with the solution adjusted to pH 7 using 0.1 N to reduce bitterness. The ratio of the pomelo albedo and solution was 1:10 (w/v). The samples were left in the solution for 24 hrs and then the liquid was removed and samples were washed with water. After that, samples were steamed for 10 min before centrifugation for 30 min. Debittered pomelo albedo was dehydrated for 2 hrs at 70°C (FDL-115 dehydrator; Binder GmbH; Tuttlingen Germany). Dried sample was milled and sieved so that the separated particles were smaller than 150 µm (mesh 100), producing a product called dietary fiber powder from pomelo albedo.

Fish tofu preparation

Surimi is the main ingredient in the production of fish tofu. Frozen surimi was purchased from Marine Food Product Co., Ltd. (Samutsakorn, Thailand) and partially thawed at room temperature for 1 hr before being cut into about 3 cm cubes. Surimi cubes (45 g/100 g) were chopped at 1800 rpm for 1 min using a silent cutter (GZB 125 Bowl Cutter, Xiaojin, China). Sodium chloride (2 g/100 g) was then added, and chopping continued at 1800 rpm for 1 min. After that, ice water (33 g/100 g), sugar (2 g/100 g), egg white (5 g/100 g), and oil (5 g/100 g) were added into salted surimi and then mixed for 5 min. Finally, pomelo albedo (0-6 g/100 g) and tapioca starch (3-9 g/100 g) were mixed for 1 min until the surimi paste was well mixed. The paste was shaped using aluminium tray blocks (30x30x3 cm) and cooked in water at a temperature of 80-85 ^{o}C for 30 min. After gel setting, surimi gels were cut into cubes of 3x3x3 cm and were then fried in soybean oil at a temperature of 200 ^{o}C for 30 s.

Determination of textural properties of fish tofu

After cooking and cooling to room temperature (25 °C), three cubic samples of fish tofu (3x3x3 cm) were subjected to texture profile analysis using the texture analyzer AGS-J 500N (Shimadzu, Japan) as described by Bourne (2002). Samples were compressed to 75% of their original height with a cylindrical probe of 6 mm diameter at a compression load of 50 kg, and a cross-head speed of 60 mm/min. The texture profile parameters were interpreted as follows: Hardness (N) is the maximum force required to compress the sample; cohesiveness is the extent to which sample could be deformed prior to rupture (A2/A1), A1 being the total A2 the total energy required for the second compression; springiness (mm) is the ability of the sample to recover to its original shape after the deforming force is removed; and chewiness (N × mm) is the work needed to masticate the sample for swallowing (springiness × gumminess).

Determination of functional properties of fish tofu

Water holding capacity (WHC)

Water holding capacity (WHC) of cooked fish tofu was determined using centrifuge technique with slight modification. About 10 g of fish tofu sample was centrifuged at 12,000 ×g for 30 min at 4 °C. Lower values indicate better WHC (Serdaroglu *et al*., 2005). Values of WHC were based on ratio between weight before centrifuge (W1) and weight after centrifuge (W2) ((W1-W2)/W1) × 100 (Ramírez *et al*., 2007).

Cooking gain

Cooking gain of fish tofu was determined from the known weight of fish tofu before and after cooking (AOAC, 2000).

Sensory evaluation

Fish tofu samples were prepared by warming them in an oven within 2-3 min before testing. Samples were served in random order to an eight membered trained panel who were recruited from the staff and student population of Suan Dusit University's Food Processing Program. Training comprised of presenting the fish tofu treatments in preliminary sessions to the panelists to familiarize them with the attributes to be evaluated. Samples were evaluated using a scaling method of descriptive attributes for appearance (9 = extremely desirable, 1 = extremely undesirable), firmness (9 = extremely firm, 1 = extremely soft), juiciness (9 = juicy, 1 = dry), taste (9 = extremely intense, 1 = imperceptible) flavor (9 = extremely intense, 1 = imperceptible), overall quality (9 = like, 1 = dislike).

Data analysis and modelling

Central Composite Rotatable Design (CCRD) was adopted in the optimization of fish tofu with the addition of pomelo albedo and tapioca starch with various concentrations. CCRD in the experimental design consists of 3^2 factorial points. Albedo concentration (g/100 g, X_1) and starch concentration (g/100 g, X_2) were chosen as independent variables. The range and central point values of these two independent variables were based on the results of preliminary experiments (Table 1).

Table 1. Experimental design matrix used to evaluate the effects of process variables on textural, functional and sensory properties of fish tofu.

Exp no	Albedo concentration (g/100 g) X_1		Starch concentration (g/100 g) X_2	
	Coded	Uncoded	Coded	Uncoded
1	-1	0	-1	3
2	0	3	0	6
3	0	3	0	6
4	0	3	0	6
5	1	6	1	9
6	1	6	-1	3
7	-1	0	1	9
8	0	3	0	6
9	0	3	1.414	10.24
10	-1.414	-1.24	0	6
11	1.414	7.24	0	6
12	0	3	-1.414	1.76
13	0	3	0	6
14	0	3	0	6

Texture, water holding capacity (WHC), cooking gain, and sensory score parameters were selected as the dependent variables (Y) for the combination of the independent variables.

The Response Surface Methodology (RSM) with Central Composite Rotatable Design (CCRD) was analyzed using Design Expert 7 (Stat-Ease Inc., USA). Where Y is the dependent variable, β_0 is the constant, β_i; β_{ii} and β_{ji} are regression coefficients, and X_i, X_j are levels of the independent variables. The R^2 value and the lack of fit value were determined.

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j$$

After the multifactor analysis of variance and the second-order model prediction determinations, the optimal pre-treatment condition was obtained by the desirability function approach and the response surface plots were developed using Design Expert 7 (Stat-Ease Inc., USA).

Based on the experimental design suggested by Design-Expert® Software version 7, 14 runs with 2 blocks of experiments were conducted. The response surface regression (RSREG) procedure for Design-Expert® software was employed to fit the quadratic polynomial equation to the experimental data.

RESULTS AND DISCUSSION

The R^2 values of models for this study were higher than 0.70, indicating a good fit, as shown in Table 2. All the lacks of fit tests were not significant, which also showed a good fit between the experimental data and the model. The R^2 value reflects the suitability of the model to represent the real relationship between the selected reaction parameters. Many statistical analyses were used for fitting the model, to judge the experimental error, the statistical significance of the terms in the model, and the suitability of the model (Sanaei *et al*., 2013). However, there is no reference value stating that higher R^2 suggests a good model and lower R^2 suggests a poor model.

Textural properties of fish tofu

Fig. 1 illustrates the effects of pomelo albedo and starch concentrations as three-dimensional graphs where direction of the effects of processing variables on textural properties can be seen. Fig. 1(A) indicates that increasing pomelo albedo and starch concentrations level increased ($P \leq 0.05$) hardness because their addition would involve incorporating particles in the protein matrix that would strengthen the binding (Viuda-Martos *et al*., 2009). These results were in agreement with reports by Cardoso *et al*. (2008) in low-fat fish sausage with added pea fiber or Yilmaz (2004) in low-fat meatballs added with rye bran. However, Alesón-Carbonell *et al*. (2005) or Sánchez-Zapata *et al*. (2010) indicated that the hardness was not modified by the addition of lemon albedo or tiger nut fiber in beef and pork burgers, respectively. Cohesiveness increased when concentration of pomelo albedo increased up to optimum at each of starch concentration and then decreased after addition of pomelo albedo at high level (Fig. 1B). These results were in concordance with the results of Viuda-Martos *et al*. (2010) who reported that orange fiber decreased cohesiveness of *mortadella* (cooked meat product). Choi *et al*. (2010) also reported that addition of rice bran fiber in reduced-fat meat emulsion systems caused a reduction in cohesiveness. Springiness values were related to the elastic properties of fish tofu, so increasing springiness value indicates that elasticity of fish is adequate. Fig. 1(C) showed that pomelo albedo and starch increased the springiness of fish tofu; however, the springiness decreased when concentration of pomelo albedo and starch increased. Chewiness was influenced by pomelo albedo and starch concentration. The results were similar on springiness, where chewiness increased when concentration of pomelo albedo and starch increased up to optimum levels and the value slightly decreased with increased concentration (Fig. 1D). These results were supported by the study of Cardoso *et al*. (2008) on the incorporation of pea starch in fish sausage formulations.

Functional properties of fish tofu

Water holding capacity (WHC)

Water holding capacity (WHC) plays an important role in maintaining the quality of food products as it influences the formation of texture in food (Zayas, 1997). Fiber has high hydration capacity can decrease the percentage of water loss indicating that they improved water retention of food gels (Figuerola *et al*., 2005). The formulations containing pomelo albedo has interior

Table 2. Response surface model for processing condition of fish tofu

Response	Model equation	Model significance	Lack of fit	R^2
Hardness	Coded equation $45.16+2.95X_1+5.19X_2–1.09X_{12}–0.36X_1^2$ $-2.06X_2^2$ Actual equation $21.05+3.90X_1+4.84X_2–0.24X_{12}–0.16X_1^2$ $-2.23X_2^2$	0.0002[a]	0.4224[b]	0.9189
Cohesiveness	Coded equation $0.56+0.014X_1+0.026X_2–6.250E\text{-}003X_{12}–6.881E\text{-}003X_1^2$ $-0.010X_2^2$ Actual equation $0.43+0.03X_1+0.02X_2–1.389E\text{-}003X_{12}–3.058E\text{-}003X_1^2$ $-1.111E\text{-}003X_2^2$	0.0002[a]	0.8019[b]	0.9156
Springiness	Coded equation $0.64+0.044X_1+0.042X_2–0.016X_{12}–0.015X_1^2$ $-0.050X_2^2$ Actual equation $0.27+0.07X_1+0.09X_2–3.611E\text{-}003X_{12}–6.694E\text{-}003X_1^2$ $-5.582E\text{-}003X_2^2$	0.0007[a]	0.8995[b]	0.8774
Chewiness	Coded equation $22.26+2.78X_1+3.19X_2–1.04X_{12}–0.77X_1^2$ $-3.39X_2^2$ Actual equation $-3.30+4.28X_1+5.93X_2–0.23X_{12}–0.34X_1^2$ $-0.38X_2^2$	0.0009[a]	0.5001[b]	0.8662
WHC	Coded equation $2.17\text{-}0.79X_1\text{-}0.86X_2+0.32X_{12}+0.068X_1^2$ $-0.69X_2^2$ Actual equation $8.16\text{-}1.05X_1\text{-}1.32X_2+0.07X_{12}+0.33X_1^2$ $+0.08X_2^2$	0.0006[a]	0.3830[b]	0.8836
Cooking gain	Coded equation $100.51\text{-}3.28X_1\text{-}3.09X_2+0.76X_{12}+0.25X_1^2$ $+2.19X_2^2$ Actual equation $120.50\text{-}3.53X_1\text{-}4.20X_2+0.17X_{12}+0.11X_1^2$ $+0.24X_2^2$	<0.0001[a]	0.4518[b]	0.9468
Appearance	Coded equation $6.63+\text{-}0.42X_1\text{-}0.44X_2\text{-}0.14X_{12}\text{-}0.22X_1^2$ $-0.72X_2^2$ Actual equation $1.95+0.76X_1+1.16X_2\text{-}0.03X_{12}\text{-}0.10X_1^2$ $+0.08X_2^2$	0.0647[b]	0.5410[b]	0.7838
Firmness	Coded equation $6.27+\text{-}0.40X_1\text{-}0.58X_2\text{-}0.22X_{12}\text{-}0.23X_1^2$ $-0.81X_2^2$ Actual equation $0.78+0.88X_1+1.35X_2\text{-}0.05X_{12}\text{-}0.10X_1^2$ $+0.09X_2^2$	0.0005[a]	0.2416[b]	0.8915
Juiciness	Coded equation $6.25+\text{-}0.39X_1\text{-}0.78X_2\text{-}0.29X_{12}\text{-}0.21X_1^2$ $-0.68X_2^2$ Actual equation $0.80+0.93X_1+1.26X_2\text{-}0.06X_{12}\text{-}0.09X_1^2$ $+0.08X_2^2$	0.0001[a]	0.4340[b]	0.9240
Taste	Coded equation $6.31+\text{-}0.37X_1\text{-}0.70X_2\text{-}0.17_{12}\text{-}0.21X_1^2$ $-0.87X_2^2$ Actual equation $0.52+0.76X_1+1.44X_2\text{-}0.04X_{12}\text{-}0.09X_1^2$ $+0.10X_2^2$	0.0601[b]	0.3451[b]	0.8318
Flavor	Coded equation $6.35+\text{-}0.48X_1\text{-}0.70X_2\text{-}0.20_{12}\text{-}0.26X_1^2$ $-0.78X_2^2$ Actual equation $0.69+0.94X_1+1.34X_2\text{-}0.04X_{12}\text{-}0.12X_1^2$ $+0.09X_2^2$	0.0831[b]	0.4795[b]	0.8087
Overall quality	Coded equation $6.40+\text{-}0.45X_1\text{-}0.73X_2\text{-}0.41_{12}\text{-}0.26X_1^2$ $-0.82X_2^2$ Actual equation $0.14+1.20X_1+1.47X_2\text{-}0.09X_{12}\text{-}0.12X_1^2$ $+0.09X_2^2$	0.0004[a]	0.5923[b]	0.8969

[a] Significant ($p \leq 0.05$).
[b] Not significant ($p \geq 0.05$).

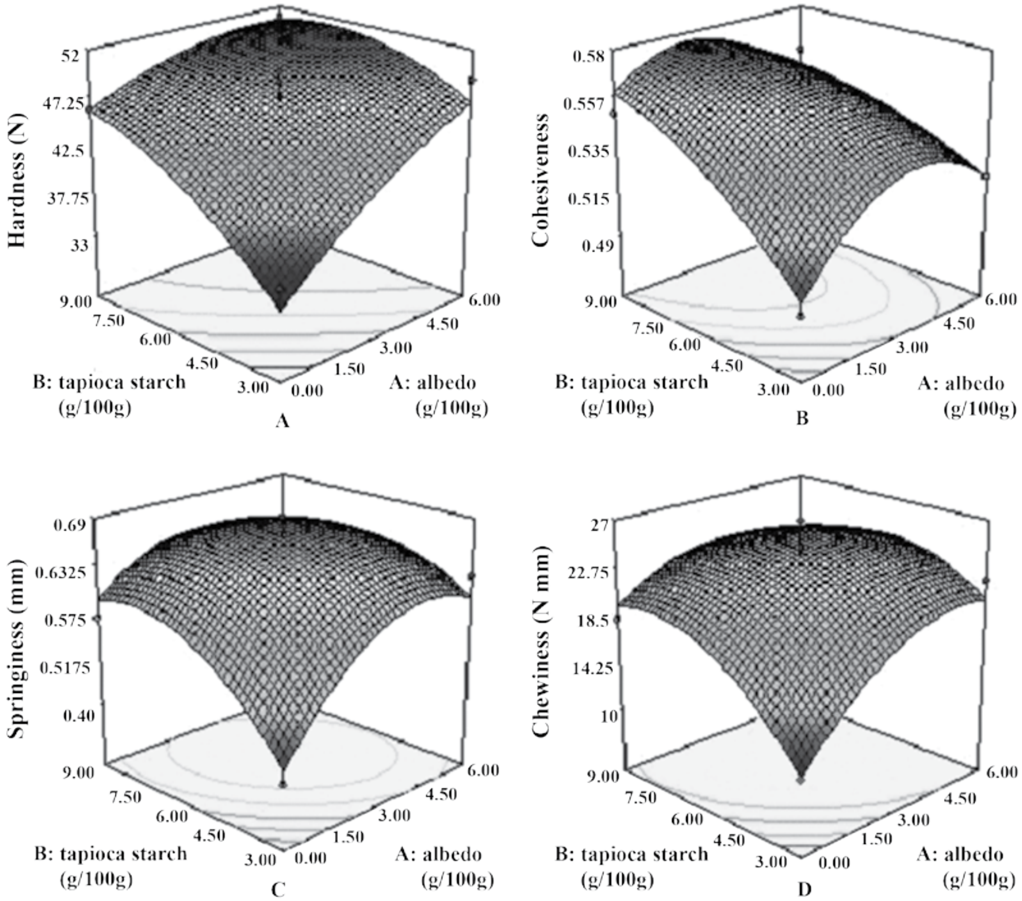

Figure 1. Effect of pomelo albedo and starch concentration on: (A) hardness; (B) cohesiveness; (C) springiness; and (D) chewiness of fish tofu.

micelles in the fish tofu that can hold water and maintain the juiciness of fish tofu. As seen in Fig. 2(A), WHC decreased when pomelo albedo concentration increased up to optimum point at each starch concentration. But subsequently, decreased in pomelo albedo and tapioca starch showed a high increased in WHC.

Cooking gain

Cooking gain is the most important factor for the meat industry in predicting the behavior of products during cooking due to nonmeat ingredients or other factors (Pietrasik and Li-Chan, 2002). In this study, the results have high cooking gain (due to the weight after cooking was more than the weight before cooking, cooking gain results then multiply with 100). The average results of cooking gain (g/100 g) are presented in Fig. 2(B). For Fig. 2(B), cooking gain decreased when pomelo albedo and tapioca starch concentrations. The highest cooking gain value in this study occurred at the lowest concentration of pomelo albedo and tapioca starch (0 g/100 g pomelo albedo and 3 g/100 g tapioca starch concentration).

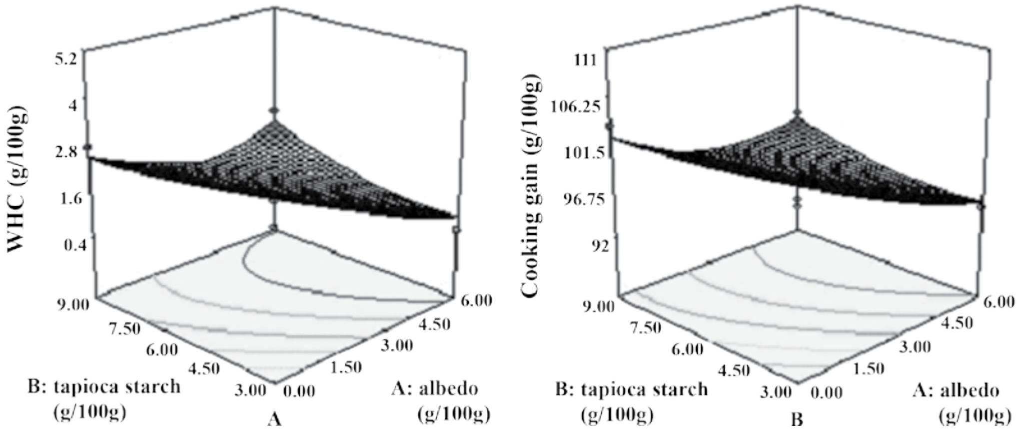

Figure 2. Effect of pomelo albedo and starch concentration on: (A) WHC and (B) cooking gain.

This study showed that there was high cooking gain. This result indicates that during cooking, some of the moisture was lost, but due to the ability of pomelo albedo and starch to absorb water during cooking, it has resulted in high cooking gain in fish tofu. This result is consistent with Serdaroglu *et al*. (2005) who reported increased moisture retention in meatballs with added legume flours. Moreover, this cooking gain was also higher when compared with the cooking gain of minced hake and horse mackerel muscle restructured using wheat fiber, as reported by Sánchez-Alonso *et al*. (2007).

Sensory evaluation

Sensory evaluation results are given in Table 2. The second-order polynomial models for firmness, juiciness and overall quality were significant. The effect of pomelo albedo and starch to increase hardness as seen in TPA results (Fig. 1A) could be perceived by the panelists who scored the firmness. Increase in the pomelo albedo and starch concentration resulted in increased firmness, which was consistent with hardness values measured by TPA analysis (Figs. 1A and 3A). However, addition of pomelo albedo at high level (6 g/100 g) caused firmness reduction. Similar results were found in juiciness. Pomelo albedo and starch resulted in an increase in juiciness, which was in accordance with WHC and cooking gain (Fig. 2A, B and 3B); however, the increase in pomelo albedo showed a slight decrease in juiciness of fish tofu. Increasing levels of pomelo albedo and starch had a negative effect on overall quality of fish tofu. Fig. 3C indicates that an increase in pomelo albedo and starch concentration resulted in lower overall quality scores. In this study, the objective was also to find the optimum TPA, WHC and cooking gain indices based on the sensory characteristics of fish tofu. Therefore, the processing variables that brought about the patties with maximum overall quality were considered as optimum. The analysis indicated that optimum value for the responses of fish tofu processing with the addition of pomelo albedo and tapioca starch can be achieved using a pomelo albedo concentration of 2.98 g/100 g and tapioca starch concentration of 6.46 g/100 g. The responses for hardness, cohesiveness, springiness, chewiness, WHC, and cooking gain in the fish tofu samples with high overall

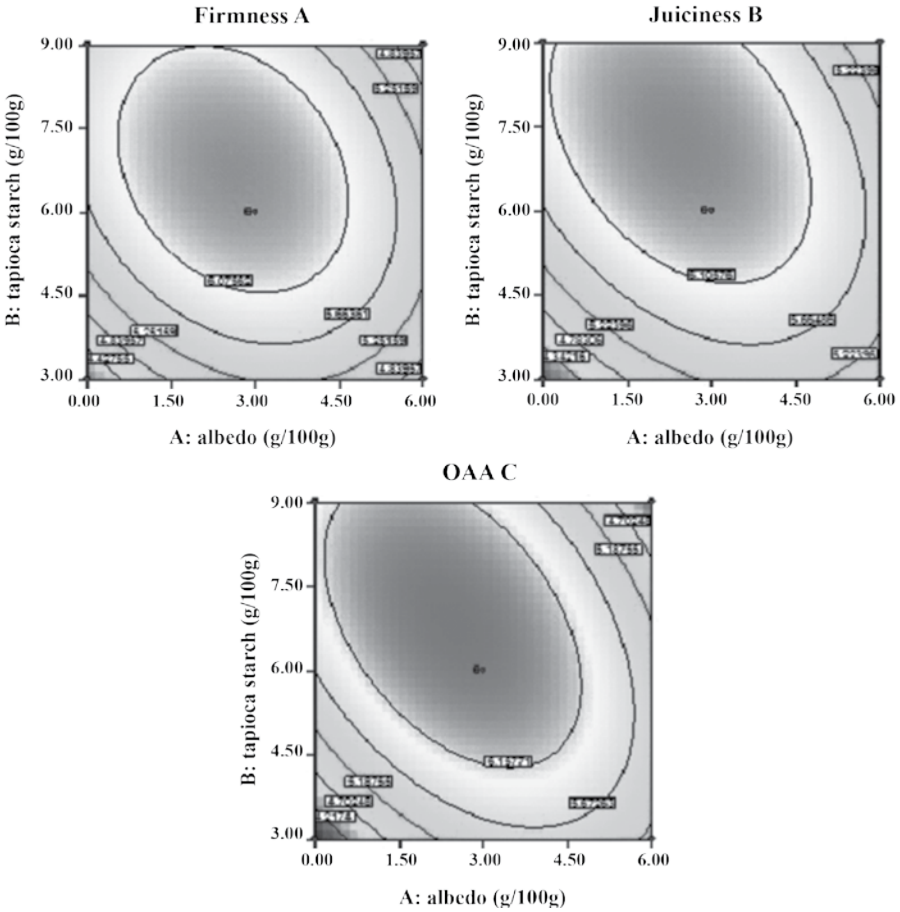

Figure 3. Effect of pomelo albedo and starch concentration on: (A) firmness; (B) juiciness and (C) overall quality attributes.

quality score were predicted at 48.31 N; 0.57; 0.67 mm; 24.50 N mm; 1.39 g/ 100 g; and 97.20 g/100 g respectively, with a desirability value of 1. The desirability value of 1 or close to 1 indicates that the setting seems to achieve favorable results for all responses as a whole.

CONCLUSION

It was found that the addition of pomelo albedo and starch to fish tofu favoured better textural, functional and sensory properties. However, pomelo albedo and starch could be added only up to some extent for improvement of these qualities in the processed fish product. Results in this study showed that the effects of pomelo albedo and starch were statistically significant for optimization of fish tofu. Second-order polynomial models were obtained for predicting texture profile analysis (hardness, cohesiveness, springiness, and chewiness), WHC, cooking gain and sensory properties. Optimum conditions for fish tofu with addition of pomelo albedo and starch would be as follows: pomelo albedo concentration 2.98 g/100 g and starch concentration 6.46 g/100 g. Therefore, it is possible to produce a texturally acceptable fish product combining multiple health promoting factors, namely, higher dietary fiber intake, lower fat intake and fish nutrients without sacrificing the quality of food product.

ACKNOWLEDGEMENT

This research was funded by Suan Dusit University, Bangkok, Thailand. The first author is deeply grateful to her advisor, Asst. Prof. Dr. Wanwimol Klaypradit for valuable guidance and encouragement.

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