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Development of Extruded Shrimp-Corn Snack Using Response Surface Methodology

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Abstract

It is aimed to develop a novel shrimp-corn snack using response surface methodology in this study. Dried shrimp muscle was ground and blended with corn flour at the level of 20% (w:w). The shrimp-corn flour mix was extruded through a co-rotating twin-screw extruder with a screw diameter of 24 mm. The effects of extrusion temperature (110-150 °C), screw speed (200-500 rpm) and feed moisture (17-23 g/100 g) on physicochemical and sensory properties of shrimp-corn snack were investigated using response surface methodology. The extrusion temperature had a significant ($P \leq 0.05$) influence on hardness, omega-3 fatty acids content and sensory properties of shrimp-corn snack. Increasing extrusion temperature from 110 °C to 150 °C, resulted in a snack with higher hardness and lower omega-3 content. While higher overall acceptance scores were obtained at moderate temperature (130 °C), higher omega-3 contents were obtained at lower temperatures combined with higher feed moistures. Predicted optimum condition for extruded shrimp-corn snack production was follows; extrusion temperature: 127.2 ºC, screw speed: 393.4 rpm, feed moisture: 21.6 g/100 g.

Keywords: Shrimp meat, extruded snack, omega-3 fatty acids, hardness, sensory properties.

Cevap Yüzey Metodu Kullanılarak Ekstrüze Karides-Mısır çerezi Geliştirilmesi

Özet

Bu çalışmada cevap yüzey metodu kullanılarak yeni bir karides-mısır çerezi geliştirilmesi amaçlanmıştır. Kurutulmuş karides eti parçalanıp mısır unu ile %20 (w:w) oranında karıştırılmıştır. Elde edilen karışım vida çapı 24 mm olan çift vidalı yarı dönüşlü ekstrüderde pişirilerek çerez elde edilmiştir. Besleme nemi (17-23 g/100 g), ekstrüder vida hızı (200-500 rpm) ve ekstrüzyon sıcaklığı (110-150 °C) parametrelerinin karides-mısır çerezinin fizikokimyasal ve duyusal özelliklerine etkisi cevap yüzey metodu kullanılarak araştırılmıştır. Test edilen parametreler içererisinde sadece ekstrüzyon sıcaklığının karides-mısır çerezinin sertliğine, omega-3 yağ asitleri içeriğine ve duyusal özelliklerine önemli derecede ($P \leq 0.05$) etkisi olduğu saptanmıştır. Karides-mısır çerezi üretimi sırasında ekstrüzyon sıcaklığı 110 °C'den 150 °C'ye arttırıldığında elde edilen çerezlerin daha sert ve omega-3 yağ asitleri içeriği bakımından daha düşük olduğu saptanmıştır. En yüksek duyusal beğeni notları ortalama sıcaklık olan 130 °C'de saptanırken, yüksek omega-3 yağ asitleri içeriği ise düşük derecelerde yüksek ekstrüzyon vida hızında elde edilmiştir.

Cevap yüzey metodu hesaplamaları sonucu ekstrüde karides-mısır çerezi üretiminde 127.2 ºC ekstrüzyon sıcaklığı, 393.4 rpm ekstrüder vida hızı ve 21.6 g/100 g besleme nemi parametreleri optimum üretim koşulları olarak belirlenmiştir.

Anahtar Kelimeler: Karides eti, ekstrüde çerez, omega-3 yağ asitleri, sertlik, duyusal özellikler.

Introductıon

Foods have become an integral part of the eating habits of the majority of the world's population. Basically, they are prepared from natural ingredients or components according to predesigned plans to yield products with specified functional properties (Thakur and Saxena, 2000). Extrusion cooking has been used to develop a wide variety of snack products from different raw materials. It has increasingly been used in the production of breakfast cereals, baby foods, snacks, and modified starch, etc. (Meuser and Van Lengerich, 1984). Extruded snack products are predominantly made from cereal flour or starches and tend to be low in protein and have a low biological value (i.e. low concentration of essential amino acids (Ainsworth *et al*., 2007). To produce a nutritious snack, cereals are usually enriched with protein rich food stuff. Remarkable progress has been made in the utilization of new protein sources such as leguminous seed, single cell proteins (Kinsella and Franzen, 1978), spirulina alga (Joshi, Bera, Panesar, 2014), fish species (Kong *et al*., 2008, Pansawat *et al*., 2008, Shaviklo *et al*., 2011, Shaviklo *et al*., 2014, Singh *et al*., 2014), crab meat (Obatolu *et al*., 2005) and low-commercial shrimp powder (Shaviklo *et al*., 2015).

Successful application of seafood ingredients into cereal based extruded snack products could increase utilization of seafood products and improve the nutritional value of cereal based snacks. Apart from their delicacy, crustacean species such as shrimp, crab and lobster, consist of amino acids, peptides, protein and other useful nutrients (Sriket *et al*., 2007). Shrimp meat is an excellent source of protein and is also a good source of minerals such as calcium. Additionally, shrimp muscle consists of polyunsaturated fatty acids (PUFA) such as eicosapentaenoic (20:5n3, EPA) and docosahexaenoic (22:6n3, DHA) acids, considered as essential. The protein content of shrimp meat typically ranges from 20.44% to 22.46% (Yanar and Çelik, 2006). Shrimp meat combination with other nutrients from cereal sources can provide the basis for a range of highly nutritious extruded snack products.

On the other hand, deterioration of nutritional quality, owing to high temperature, is a serious problem in most traditional cooking methods. Extrusion cooking technology is preferable to other food-processing techniques in terms of continuous process with high productivity and significant nutrient retention, owing to the high temperature and short time required Sing, Gamalth, & Wakeling, 2007). Extrusion parameters, including feed rate, screw speed, extrusion temperature, retention time, die diameter, etc., are accounted for the quality of finished products. Therefore extrusion parameters which directly affect product quality should be optimized in order to obtain high-quality extruded snack. The overall objective of this study was to develop a novel extruded snack by using corn flour and shrimp meat. The specific objective was to evaluate effects of extrusion parameters including extrusion temperature, screw speed and feed moisture on physicochemical and sensory properties of shrimp-corn snack.

Materials and Methods

Materials

The corn flour (MaizeCor, USA), dried speckled shrimp, *Metapenaeus monoceros*, (VR Foods, Bankong, Tayland) and salt were purchased from a local food market in Helsinki, Finland. The dried shrimp meat was ground to a fine particles size by grinder (Kenwood, model FP 295, Britain) and passed through a 1.5 mm mesh screen. The corn flour (79 g/100 g) was mixed with the shrimp powder (20 g/100 g) and salt (1 g/ 100 g) in plastic container and kept in the dark cabin at 4 °C until utilization.

Extrusion Cooking of Shrimp Meat

Extrusion trials were performed using a twin-screw extruder (PTW-24 Thermo Haake, Dreieich, Germany.) The extruding moisture content was controlled by analyzing the moisture content of the ingredients before extrusion. The barrel consisted of one no temperature controlled zone with the solid feed gate and six temperature controlled zones with the injection gate for the liquid feed at the first zone. A volumetric co-rotating twin-screw (D ¼ 20 mm, L=D of 10) feeder (Brabender, Duisburg, Germany) was used for the solid feed (corn flour and shrimp flour). The temperatures of the six barrel sections were controlled electronically by the extruder control screen system. The feeder of extruder was calibrated to give a feed rate of 67 g min^{-1}. A peristaltic pump (Watson Marlow (505 S), Wilmington, MA, USA) was used for the liquid feed (water), provide a feed moisture content of 17, 20, and 23 (g/100 g). Once the extrusion parameters (extrusion temperature, screw speed and feed moisture) were constant, extruded shrimp snacks were cut (approximately 10 cm long) with a sharp knife as they emerged from the die. The extruded snack samples were left to cool at room temperature for 30 minutes and stored in plastic bags at room temperature (°C) until analyzed. Extrusion trials were conducted in duplicate, and all analyses were done at least in duplicate.

Experiment Design and Statistical Analysis

In order to determine the effect of extrusion temperature (110, 130, 150 °C), screw speed (200, 350, 500 rpm) and feed moisture content (17, 20, 23 g/100 g) on the physicochemical and sensory properties of the shrimp-corn snack, and to optimize extrusion variables Box-Behnken's response surface methodology (RSM) (Box and Behnken, 1960) was performed by generating second-order polynomial equations (Eq. (1):

$$Y = \beta_0 + \sum \beta_i X_i + \beta_{ii} X^2{}_i + \sum \beta_{ij} X_i X_{j,} (1),$$

where Y represents the experimental response $\beta_{0,}$ $\beta_{i,}$ β_{ii} and β_{ij} are constants and regression coefficients of the model, and X_i and X_j are uncoded values of independent variables. RSREG and PROC GLM of the statistical analysis system were used to obtain predictive models. Adequacy of the models was determined by R^2 and model lack of fit tests

(P<0.05). RSM plots were generated as a function of two factors when the third factor was held constant from the models using Design Expert 9.1 Statistical Software (Statease Inc., Minneapolis, USA).

Analyses

Chemical Composition Analyses

The crude protein (6.25xN), moisture and ash content were determined according to the method of AOAC (1990). The moisture content of snack sample was determined by drying the snack samples in laboratory oven at 105 °C until a constant weight was obtained. The crude protein content was calculated by converting the nitrogen content determined using Kjeldahl's method (6.25 N). Ash content was determined by burning the organic content of samples in furnace at 550 °C for 24 hours. The fat content was determined using the method described by the (Bligh and Dyer, 1959). Briefly, 25 g sample was homogenized with 200 ml of a chloroform:methanol:distilled water mixture (50:100:50) at the speed of 3000-4000 rpm for 2 min using homogenizer (IKA T25, Germany). The homogenate was treated with 50 ml of chloroform and homogenized for 1 min. Then, 25 ml of distilled water was added and the homogenized again for 30 sec. The homogenate was centrifuged at 3000 rpm at 4 °C for 15 min using a centrifuge (Thermo, H1650R, Germany) and transferred into a separating flask. The chloroform phase was drained off into a 125 ml flask containing about 2-3 g of anhydrous sodium sulfate, shaken very well, and decanted into a round-bottom flask through a Whatman no. 4 filter paper. The solvent was evaporated at 40 °C using rotary evaporator (Heidolph, Hei-VAP Advantage G5, Germany) and residual solvent was removed by flushing with nitrogen. The total fat content was determined gravimetrically.

Bulk Density (BD) Analysis

Bulk density values of individual dry, cylindrical extruded snack were calculated by dividing the mass of a 10 cm long snack by its volume. Each of samples was weighed using a laboratory balance, accurate to 4 decimal places, and the length and diameter of the sample measured using a digital Vernier caliper as above. BD (g/cm^3) was calculated according to the method of (Ainsworth *et al*., 2007):

$$\text{BD (g/cm}^3\text{)} = \frac{4m}{\pi d^2 l}$$

where m is mass (g) of a length, l (cm) of extruded shrimp snack with a diameter d (cm). The average of 10 extruded samples for each replicate was recorded as the BD.

Lateral Expansion (LE) Analysis

Diameter measurement of the extruded shrimp samples were done at the center of each piece with using a digital Vernier caliper accurate to 0.05 mm. Ten measurements were performed for each replication. Lateral expansion (LE, %) was then calculated using the mean of the measured diameters (Ainsworth *et al*., 2007):

LE= (diameter of product – diameter of die hole) / diameter of die hole) x 100.

Texture (Hardness) Analysis

The texture (hardness) property of snacks was assessed by Instron universal testing machine (model 4465, High Wycombe, England) equipped with a 5 kN static load cell and with a small wedge. Extruded snack samples were placed over two supports, 1.5 cm apart, and broken in the middle by a metal wedge (the thickness of contact surface with snack samples was 1 mm^2 and the speed was constant and equal to 0.5 mm/s). The peak force represents the resistance of extruded snack to initial penetration and is believed to give an indication of the hardness of snack sample. Ten randomly collected samples of each snack sample were measured and a mean of measurements was given as Newton (N).

Fatty Acid Composition Analysis

Extraction of lipid from snack sample was performed according to the method of Blig and Dyer (1959). Methyl esters were prepared by transmethylation using 2M KOH in methanol and *n*-heptane according to the method of Özoğul and Özoğul (2007) with minor modification. A lipid sample of 10 mg dissolved in 2 ml *n*-heptane was mixed with 4 ml 2 M methanolic KOH and centrifuged at 4 000 rpm for 10 min. The upper layer was injected into a gas chromatograph (GC; Clarus 500, Perkin Elmer, M, USA).

Gas chromatographic conditions: The fatty acid composition was analyzed by GC equipped with a flame ionization detector and BPX70 fused silica capillary column (50 m x 0.22 mm, film thickness 0.25 µm; SGE Inc., Victoria, Australia). The oven temperature was held at 150 ºC for 5 min, then raised to 200 ºC at 4 ºC/min and without holding, raised to 220 ºC at 1 ºC/min. The injection temperature was set at 220 ºC. Helium was carrier with 1.0 ml/min flow rate. The detector temperature was set at 280 ºC. The split used was 1:50. Fatty acids were identified by comparison with the retention times of standard fatty acid methyl esters (FAME Mix, C4-C24, Supelco PA, USA). The results were expressed as a percentage of the total of the identifiable fatty acids.

Sensory Analysis

The sensory evaluation of shrimp snack was performed by a panel of 10 trained panelists (5 male and 5 female) between 18 and 30 years. The panelists had experience in evaluating of snack and seafood. The sensory evaluations of shrimp snacks were performed in the separated cabin under daylight and ambient temperature according to ISO 11035 international standards (Szymczak, Kolakowski & Felisiak, 2012). Snack samples were coded with three-digit random numbers and served in porcelain dishes to each panelist along with water and piece of bread to clear their palates between samples. The panelists were requested to first evaluate each sample by sniffing alone and then by tasting. They rinsed their mouths with water after tasting each sample.

The sensory evaluation of the snacks was based upon the lowest-highest scores of sensory liking. The intensity for each attribute (appearance, odor, taste and overall acceptability) was rated on a 15-cm unstructured line scale labeled with words showing weak intensities on the left (0 cm) and stronger intensities on the right (15 cm) (Petridis, Raizi & Ritzoulis, 2014). At the end of the sensory evaluation, in order to simplify statistical matters, the 15-cm scale was further divided into five equal segments (very like, adequate like, moderate like, dislike slightly and dislike extremely).

Results and Discussion

Proximate Compositions of Ingredients and Extruded Shrimp-Corn Snacks

The proximate composition of ingredients and snack samples are shown in Table 1. The corn flour was rich in carbohydrate (76.1%), whereas dried shrimp flesh was rich in protein (64.7%), lipid (3.7%) and ash (3.2%). Mixing of corn flour with dried shrimp meat increased the protein, lipid and ash contents of shrimp-corn snacks. Extruded shrimp-corn snack had 14.5 % moisture, 62 % carbohydrate, 18.8 % protein, 2.0 % lipid and 2.2 % ash (Table 1). Extrusion processing removed moisture, and resulted in higher protein, lipid and ash content in final product. The carbohydrate content (62 %) of shrimp-corn snack samples was similar to those (62%) of Shaviklo et al. (2015), who studied extruded puffed corn-shrimp snacks. Higher protein (19.2 %) content was determined in this study compared to those (6.3 g/100 g) of Shaviklo et al. (2015). So all shrimp snack samples could be described as protein rich snack. Other researchers (Maga and Reddy, 1985) have enhanced protein concentrations in cereal flour-based extruded snack with the addition of minced carp meat. They were able to increase the crude protein content from 8.3 to 10.9 g/100g when 20 g/100g raw carp mince was incorporated into the feed mixture. These values are lower than those obtained in this study, since dried shrimp contains a significant amount of protein. After the extrusion process, the mean lipid content of shrimp-corn snacks were 1.3 % which is similar to those (0.47-2.32 %) of Maga and Reddy (1985) and significantly lower than those (28.2 g/100 g) reported by Shaviklo et al. (2015).

Effects of Extrusion Variables On Physical Properties of Extruded Shrimp-Corn Snacks

Effects of extrusion variables on the physicochemical and sensory properties of extruded shrimp snacks are shown in Table 2. The predictive regression models for bulk density, lateral expansion, hardness, ΣPUFA-ω3 and all sensory properties showed high R^2 of 0.921, 0.917, 0.938, 0.684, 0.876, 0.899, 0.916 and 0.908, respectively (Table 3).

Bulk Density of Extruded Shrimp-Corn Snacks

Effect of extrusion variables including temperature, screw speed and feed moisture on the bulk density of shrimp-corn snacks are given in Table 2. The bulk density of extruded snack samples ranged from 0.62 to 1.41 g/cm^3 (Table 2). The shrimp-corn snack sample with the highest bulk density (1.41 g/cm3) was obtained at moderate temperature (130

C), moderate screw speed (350 rpm) and moderate feed moisture (20 g/100 g). The bulk density values of shrimp-corn snack samples were found significantly lower than those reported by Shaviklo *et al*. (2015). They have reported that the bulk density values of puffed corn-shrimp ranged between 56.4 to 69.6 g/lt. Lower bulk density values of shrimp-corn snack could be resulted from high protein content of dried shrimp meat. Bulk density of snacks were significantly affected ($P \leq 0.05$) by extrusion temperature, although feed moisture and screw speed had no significant effect on bulk density (Table 3).

Lateral Expansion of Extruded Shrimp-Corn Snacks

Effect of extrusion temperature, screw speed and feed moisture on the lateral expansion of shrimp-corn snacks are given in Table 2. The lateral expansion of extruded snack samples ranged from 4.4 to 69.6 %. The product with the highest lateral expansion ratio (69.6 %) was produced at moderate temperature (130 °C), high screw speed (500 rpm) and low feed moisture (17 g/100 g) (Table 2). These results were found lower than those reported by Ainsworth *et al*. (2007). Only extrusion temperature had significantly ($P \leq 0.05$) effect on the lateral expansion of snack samples (Table 3). Higher lateral expansion values of snack samples could be stemmed from high extrusion temperature since extrusion temperature had a significantly effect on the lateral expansion of snack samples.

Hardness of Extruded Shrimp-Corn Snacks

Effect of extrusion temperature, screw speed and feed moisture on the hardness of shrimp-corn snacks are given in Table 2. The hardness of extruded snack was determined by measuring the maximum force required to break off the extruded snack. The hardness values of extruded shrimp snack samples varied between 158.1 and 358.3 Newton (N) (Table 2). Only extrusion temperature had significant ($P \leq 0.05$) effect on hardness of shrimp snack samples (Table 3). Highest hardness value (358.3 N) was observed at high temperature, high screw speed and moderate feed moisture, whereas lowest hardness value (158.1 N) was observed at moderate temperature (110 °C), lowest screw speed (200 rpm) and lowest feed moisture (20 g/100 g) (Table 2). These results were found tenfold higher than those reported by Ainsworth *et al.* (2007). They have reported that the hardness of brewers spent grain added corn snacks ranged between 11.18 and 22.12 N.

Figure 1a presents the effect of feed moisture and screw speed on the hardness of shrimp-corn snacks. Increasing feed moisture and screw speed at moderate extrusion temperature increased the hardness of the shrimp-corn snacks (Fig. 1a). Figure 2a presents the effect of feed moisture and extrusion temperature on the hardness of shrimp-corn snacks. Increasing extrusion temperature at lowest feed moistures and moderate screw speed significantly increased the hardness of shrimp snacks (Fig. 2a). Figure 3a presents the effect of screw speed and extrusion temperature on the hardness of shrimp-corn snacks. Increasing of extrusion temperature and screw speed at moderate feed moisture significantly increased the hardness of extruded shrimp snack samples (Fig.3a). The cross-linking of proteins and development of a protein network has increased the maximum force or hardness of extruded shrimp snack (Giri and Bandyopadhyay, 200). Increase in protein content with addition of shrimp meat to corn snacks probably caused starch-protein interaction and cross-linking of shrimp-corn proteins. Thus it might have made the shrimp-corn snacks tenfold harder compared to corn snacks.

Effects of Extrusion Variables on Fatty Acid Composition of Extruded Shrimp-Corn Snacks

PUFA-ω3 fatty acids content of oils extracted from shrimp meat, corn flour and snack samples are shown in Table 2. Compared to corn flour, oil shrimp meat contains high proportion (23.74 %) of ΣPUFA-ω3 (Table 2). The ΣPUFA-ω of extruded shrimp snack samples varied between 9.03 and 14.57 %. Highest ΣPUFA-ω fatty acids value was obtained at lowest extrusion temperature, lowest screw speed and moderate feed moisture, whereas lowest ΣPUFA-ω fatty acids value was obtained at highest extrusion temperature, highest screw speed and moderate feed moisture.

Blending of corn flour with shrimp meat increased ΣPUFA-ω3 content of extruded snacks. Figure 1b presents the effect of feed moisture and screw speed on the ΣPUFA-ω3 content of shrimp-corn snacks. Although increasing feed moisture and screw speed at moderate extrusion temperature tended to decrease ΣPUFA-ω3 content (Fig. 1b), feed moisture and screw speed had no significant effect on ΣPUFA-ω3 content of shrimp snack samples (Table 3). Only extrusion temperature had significant ($P \leq 0.05$) effect on ΣPUFA-ω3 of shrimp snack samples (Table 3). Figure 2b presents the effect of feed moisture and extrusion temperature on the ΣPUFA-ω3 of shrimp-corn snacks. Decreasing extrusion temperature and feed moisture at moderate screw speed significantly increased ΣPUFA-ω3 content of shrimp snack samples (Fig. 2b). Figure 3b presents the effect of screw speed and extrusion temperature on the ΣPUFA-ω3 of shrimp-corn snacks. Decreasing both screw speed and extrusion temperature of extruder significantly increased ΣPUFA-ω3 content of shrimp-corn snack samples (Fig. 3b). In last decades polyunsaturated fatty acids (PUFA) of ω3 family namely eicosapentaenoic (EPA) and docosahexaenoic (DHA) has gained attention because of the prevention of human coronary artery disease and improvement of retina and brain development, and also decreased incidence of breast cancer, rheumatoid arthritis, multiple sclerosis, psoriasis and inflammation (Özoğul and Özoğul, 2007).

PUFA-ω3/ω6 ratio of oils extracted from shrimp meat, corn flour and snack samples are shown in Table 2. PUFA-ω3/ω6 ratio of shrimp oil (1.26) was significantly higher than corn oil's PUFA-ω3/ω6 ratio (0.02). After the production of shrimp snacks, the ω3/ω6 ratios of snacks varied from 0.28 to 0.44 (Table 2). Highest PUFA-ω3/ω6 ratio (0.44) was observed at low extrusion temperature (110 °C), low screw speed (200 rpm) and moderate feed moisture (20 g/100 g), whereas lowest PUFA-ω3/ω6 ratio (0.28) was observed at high temperature (150 °C), high screw speed (500 rpm) and moderate feed moisture (20 g/100 g). All snack samples could be named as healthy snack since their PUFA-ω3/ω6 ratio were significantly higher than WHO/FAO recommendation value (0.2). Generally a high ω3/ω6 ratio is desirable, although the WHO/FAO (Clough, 1993) recommendations is that in total diet the ω3/ω6 ratio should be no higher than 1:5, i.e., 0.2 (Vujkovic *et al*., 1999).

Effects of Extrusion Variables on Sensory Properties of Extruded Shrimp-Corn Snacks

Effects of extrusion temperature, screw speed and feed moisture on the sensory properties of shrimp-corn snacks are shown in Table 2. Odor scores of snacks ranged between 10.25 and 13.92; appearance scores ranged between 8.59 and

13.00; taste scores ranged between 9.59 and 13.42; and the overall acceptance scores ranged between 9.75 and 13.25 (Table 2). The lower odor scores were obtained at lowest extrusion temperature (110 °C), whereas higher odor scores were obtained at moderate extrusion temperature (130 °C). Increasing extrusion temperature from 110 to 130 °C yielded the shrimp snack with good odor, but further incerese in temperature up to 150 °C decreased the sensory odor scores. As odor scores, the appearance scores of snack samples produced moderateand higher extrusion temperature (130-150 °C) was higher than snack samples produced at minimum (110 ºC) extrusion temperature. Increasing extrusion temperature positively contributed to appearance. Taste of shrimp snack samples also increased when the extrusion temperature was increased. Extrusion temperature positively contributed the sensory properties including odor, appearance and taste of shrimp snack. It is probably stemmed from the reddish-brown color development via Maillard reaction took place between in shrim snack sample during cooking. Carbohydrate and protein derivatives such as glucose-6-phosphate and free amino acids present in the metabolic pathways can act as reactants to initiate the Maillard reaction (Kawashima and Yamanaka, 1996). Maximum overall acceptance score (13.25) was obtained at moderate temperature (130 ºC), highest screw speed (500 rpm) and highest feed moisture (23 g/100 g), whereas minimum overall acceptance score (9.75) was obtained at lowest temperature (110 ºC), lowest screw speed (200 rpm) and moderate feed moisture (20 g/100 g). As well as physicochemical changes, all sensory properties including odor, appearance, taste and overall acceptance of snack samples were found to be significantly ($P≤0.05$) affected by changes in extrusion temperature (Table 3).

Figure 1c presents the effect of feed moisture and screw speed on the overall acceptance scores of shrimp-corn snacks. The response surface plots, shows that increasing feed moisture and screw speed at moderate extrusion temperature increased the overall acceptance scores from 9.75 to 13.25 (Fig. 1c). Figure 2c presents the effect of feed moisture and extrusion temperature on the overall acceptance scores of shrimp-corn snacks. Increasing extrusion temperature from lowest (110 ºC) to moderate temperature (130 ºC) significantly increased ($P≤0.05$) the sensory overall acceptance scores, whereas increasing extrusion temperature from moderate (130 ºC) to highest temperature (150 ºC) decreased the sensory overall acceptance scores (Fig. 2c). Figure 3c shows the effect of screw speed and extrusion temperature on the overall acceptance scores of shrimp-corn snacks. Increasing extrusion temperature from lowest to moderate temperature at all screw speed, increased the overall acceptance scores, whereas further increase in extrusion temperature decreased the overall acceptance scores of shrimp-corn snacks (Fig. 3c). Higher overall acceptance scores were obtained at higher screw speed at moderate extrusion temperature (Fig. 3c).

Ooptimization of Extrusion Conditions for Shrimp-Corn Snack Production

A three-variable, three-level Box and Behnken design (Box & Behnken, 1960) was applied to optimize the extrusion cooking in order to obtain the maximum and combined response values. Three-level variables of extrusion cooking were extrusion temperature (110, 130 and 150 ºC), screw speed of extruder (200, 350 and 500 rpm) and feed moisture (17, 20 and 23 g/100g), whereas the responses were PUFA-ω3 fatty acids content and sensory overall acceptance score. In order to obtain shrimp snack containing high amount PUFA-ω3 fatty acids and liking by consumers, the optimum extrusion conditions were determined for calculating the predicted values of response variables using the prediction equations derived by RSM. Verification experiments performed at the predicted conditions derived from ridge analysis of RSM demonstrated that experimental values were reasonably close to the predicted values, confirming the validity and adequacy of the predicted models. The optimization of extrusion conditions including extrusion temperature, extruder screw speed and feed moisture of ingredients was based on the highest level of the PUFA-ω3 fatty acids and sensory overall acceptance score. The predicted optimum condition obtained using computer program (Design Expert 9.1, Stat-Ease Lnc, Minneapolis, USA) for the extruded shrimp snack production was follows; extrusion temperature: 127.2 ºC, screw speed: 393.4 rpm, feed moisture: 21.6 g/100 g (Table 4). At this optimum conditions the hardness, PUFA-ω3 fatty acids and overall acceptance score of shrimp snack were found to be as 232.42, 13.76 and 12.56, respectively. In order to show the optimum area, an overlay plot was obtain using the values of PUFA-ω3 fatty acids and overall acceptance responses (Fig. 4). The optimum point obtained from the software calculation is placed on left-upper side of the yellow area in the Fig. 3. At the optimum point the overall acceptance score of snack was 13.76. It means that the snack produced at optimum point was liked very much by sensory panelist since ‘13-15 points’ corresponds to ‘very like’ in 15-cm unstructured line sensory evaluation scale.Considering the optimum conditions, it is concluded that the shrimp snack containing high amount PUFA-ω3 fatty acids and liking by consumers could be produced at moderate extrusion temperature, screw speed and feed moisture.

Conclusion

In this study, the shrimp meat was not only used as an enrichment ingredient to increase the nutrition value, but it also helped to increase sensory properties of corn flour based snack because of its desirable flavor and taste. Shrimp meat was successfully incorporated with corn flour for the production of novel shrimp-corn snack. Although feed moisture of ingredients and screw speed of extruder didn’t affect the physicochemical and sensory properties of extruded shrimp-corn snack, the changes in the extrusion temperature significantly affected. Increasing extrusion temperature yielded the decrease in ΣPUFA-ω3 content and increase in hardness of snacks. Shrimp-corn snacks produced at moderate extrusion temperature, highest screw speed and moderate feed moisture had highest preference levels for parameters of overall acceptability. The findings of this study indicate the feasibility of developing new value added products from aquatic sources and corn flour by extrusion cooking.

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Table 1. Proximate composition of ingredients and extruded corn-shrimp snack.

Samples	Moisture (%)	Carbohydrate (%)	Protein (%)	Lipid (%)	Ash (%)
Corn flour (defatted)	11.9±0.7	76.1±0.8	9.5±0.2	1.9±0.2	0.6±0.1
Dried shrimp flesh	17.5±0.6	16.5±0.6	64.7±1.1	3.7±0.3	3.2±0.2
Extruded shrimp snack**	14.5±0.8	62.5±0.7	18.8±0.5	2.0±0.4	2.2±0.2

*The values represent mean score± standard errors; *n*:3 per experimental replicate.
** Mean values of ingredients and extruded snacks

Table 2. Effects of extrusion conditions on physicochemical and sensory properties of extruded shrimp-corn snack

Samples	Extrusion conditions*			Physicochemical properties					Sensory properties			
	X_1	X_2	X_3	Bulk density (g/cm^3)	Lateral expansion (%)	Hardness (N)**	Σ PUFA-ω3 (%)	PUFA-ω3/ω6 (%) ratio **	Odor	Appearance	Taste	Overall acceptance
Shrimp oil	-	-	-	-	-	-	23.74±0.16	1.26	-	-	-	-
Corn oil	-	-	-	-	-	-	0.79±0.03	0.02	-	-	-	-
E1	110	350	23	1.34±0.05	08.0±2.6	167.3±21.1	14.25±1.06	0.43	10.25±0.86	8.59±1.02	9.75±0.63	9.84±0.81
E2	110	350	17	1.16±0.13	21.6±6.2	186.3±10.3	13.93±1.44	0.42	10.42±0.74	9.59±0.82	9.84±0.77	10.42±0.66
E3	110	200	20	1.38±0.06	04.4±2.2	158.1±16.3	14.57±0.73	0.44	10.34±0.94	8.84±0.53	9.59±0.83	9.75±0.87
E4	110	500	20	0.98±0.10	34.4 ±8.3	211.5±17.9	13.92±0.86	0.41	10.59±0.85	10.09±1.03	9.67±0.67	10.50±0.69
E5	130	200	23	1.26±0.04	*08.4±2.6*	219.6±18.5	13.15±1.77	0.39	13.42±1.03	11.34±0.92	12.92±0.75	12.67±0.78
E6	*130*	*350*	*20*	*1.41±0.10*	*14.8±4.1*	*232.6±12.4*	*13.73±1.29*	*0.39*	12.67±0.97	11.17±0.86	13.00±1.11	12.42±0.85
E7	130	500	23	1.24±0.12	24.8±8.8	290.2±13.6	12.92±1.32	0.38	13.92±0.92	12.42±0.82	13.42±0.75	13.25±0.94
E8	130	200	17	1.26±0.04	14.8±1.8	266.9±28.0	13.05±1.34	0.38	12.25±0.89	11.50±0.34	13.07±0.86	12.34±1.072
E9	130	500	17	0.6±0.04	69.6±5.0	298.4±20.1	12.55±1.74	0.35	11.25±1.02	9.75±0.78	12.25±1.07	11.42±1.10
E10	*130*	*350*	*20*	*1.03±0.07*	*25.6±4.8*	*245.7±15.7*	*13.80±1.75*	*0.38*	12.89±1.03	11.09±0.98	13.09±0.44	12.59±1.06
E11	*130*	*350*	*20*	*1.16±0.08*	*16.8±3.9*	*251.1±13.9*	*13.86±1.66*	*0.39*	12.75±1.10	11.00±1.02	13.17±0.93	12.50±0.94
E12	150	200	20	1.18±0.05	17.6±2.6	306.3±14.6	12.06±1.94	0.38	12.00±0.81	12.09±0.84	11.59±0.75	10.92±0.97
E13	150	350	23	0.90±0.06	24.4±3.3	317.7±18.2	10.24±1.39	0.30	11.84±0.79	13.00±0.96	11.34±0.95	11.25±0.1.03
E14	150	500	20	0.79±0.13	38.1±2.0	358.3±11.4	09.03±1.46	0.28	12.09±0.88	12.17±0.78	11.75±1.08	11.75±0.93
E15	150	350	17	0.86±0.06	30.0±4.7	319.6±12.3	10.98±1.28	0.32	11.25±0.73	12.42±0.87	10.75±1.05	11.34±0.78

* X_1: Temperature (ºC) of barrel zones 6-8, X_2: Screw speed (rpm) and X_3: Feed moisture (g/100 g db).

**N: Newton; PUFA-ω3: polyunsaturated fatty acids (C16:3, C18:3, C18:4, C20:3, C20:4, C20:5, C22:5, and C226), PUFA-ω6: (C18:3, C18:2, C20:4, and C22:5).

Table 3. Predictive regression models coefficients of physicochemical and sensory properties of extruded shrimp-corn snack.

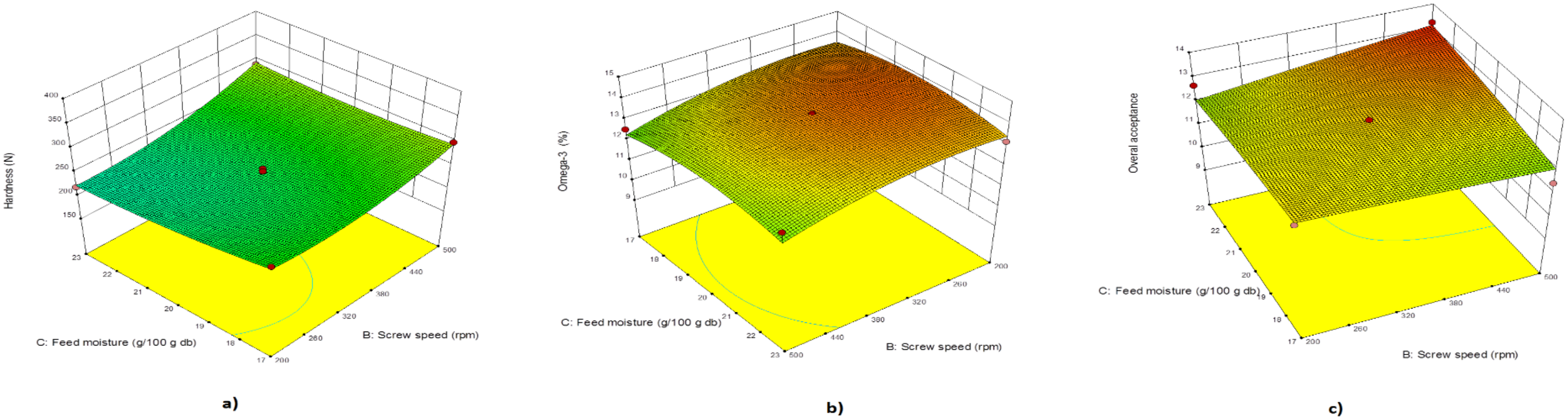
	Physicochemical coefficients				Sensory coefficients			
	Bulk density (g/cm^3)	Lateral expansion (%)	Hardness (N)	ΣPUFA-ω3	Odor	Appearance	Taste	Overall acceptance
Intercept	1.19	17.83	254.57	12.84	11.86	11.00	11.68	11.53
Temperature (X_1)	-0.26*	15.54*	72.34*	-0.88	0.53*	0.96*	0.67*	0.48*
Screw speed (X_2)	7.500E-003	-3.16	-20.44	-0.34	0.24	0.055	0.019	0.36
Feed moisture (X_3)	0.040	3.38	2.70	0.91	0.046	0.073	0.28	-0.087
X_1X_2	0.038	0.075	5.83	-0.56	0.19	0.17	-0.049	0.086
X_1X_3	0.018	4.85	15.30	0.58	-0.034	0.041	-0.053	0.045
(X_2X_3)	0.047	-0.60	-1.20	-1.02	0.36	-0.18	-0.063	0.0.050
X_1^2	-0.065	2.37	-4.25	-0.34	-0.82	-0.25	-1.56	-1.14
X_2^2	0.035	1.12	8.45	-0.46	0.25	0.036	-0.19	0.27
X_3^2	-0.075	1.25	-2.82	0.69	0.31	0.38	0.069	-0.17
R^2	0.921	0.917	0.938	0.684	0.876	0.899	0.916	0.908
Lack of fit	0.014	3.22	8.92	46.70	0.01	0.82	121.13	11.75

*Parameter is significant to the predictive regression model ($P \leq 0.05$).

Table 4. Responses at optimum conditions for extruded corn-shrimp snack production.

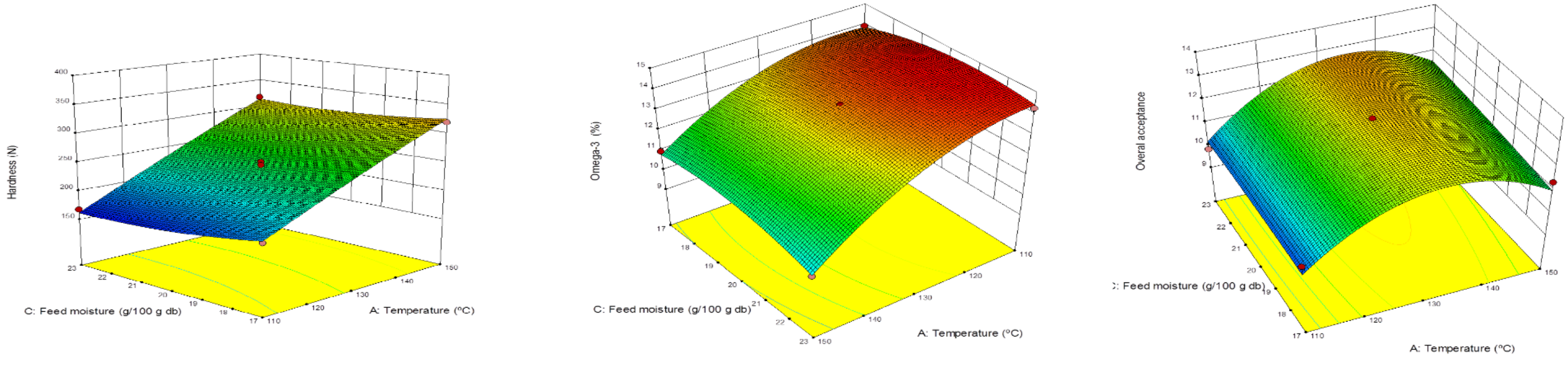
Optimum conditions			Responses at optimum conditions		
X_1*	X_2*	X_3*	Hardness (N)	PUFA-ω3 fatty acids (%)	Overall acceptance score
127.2	393.4	21.6	232.42	13.76	12.56

*X_1: Temperature (ºC) of barrel zones 6-8, X_2: Screw speed (rpm) and X_3: Feed moisture (g/100 g db).



*Extrusion temperature is fixed at 130 ºC.

Figure 1. Effect of feed moisture and screw speed on the hardness (a) omega-3 fatty acids content (b) and overall acceptance scores (c) of shrimp snack samples.



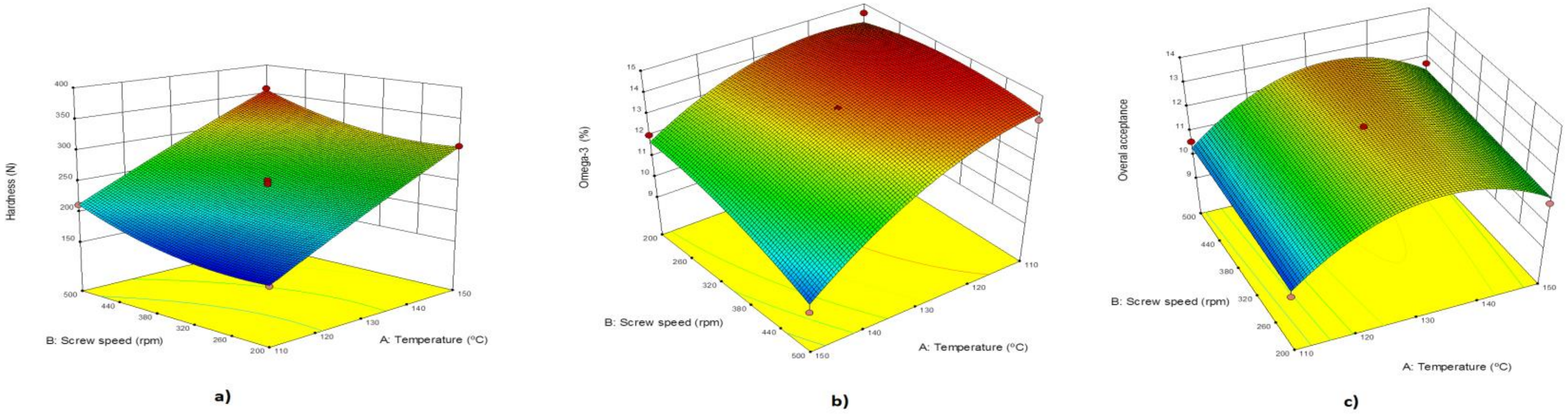
a)

b)

c)

*Screw speed is fixed at 350 rpm.

Figure 2. Effect of feed moisture and temperature on the hardness (a) omega-3 fatty acids content (b) and overall acceptance scores (c) of shrimp snack samples.



*Feed moisture is fixed at 20 g/100 g.

Figure 3. Effect of screw speed and temperature on the hardness (a) omega-3 fatty acids content (b) and overall acceptance scores (c) of shrimp snack sample.

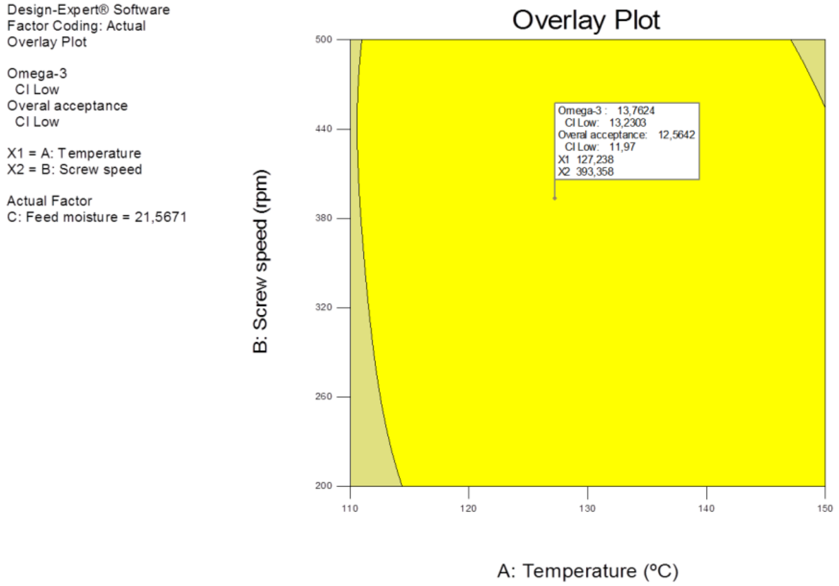


Figure 4. Overlay plot used for graphical optimization of multiple responses.