Iranian Journal of Fisheries Sciences 13(3) 748- 760 2014

Puffed corn-fish snack development by extrusion technology

Shahmohammadi H. R.[1,2*]; Bakar J.[2,3]; Russly A. R.[2,3]; Noranizan M. A.[2]; Mirhosseini H.[2]

Received: November 2013 Accepted: June 2014

Abstract

A thermoplastically extruded snack was produced from different blends of corn grits and silver carp minced meat. Response Surface Methodology (RSM) was used to study the effect of fish meat content and to optimize the feed composition. Fourteen treatments from central composite design considering minced fish content (0-3 kg) and corn (7-10 kg) were used as the independent variables. The expansion ratio, protein content, fish odour, and overall acceptability were the dependent variables. Fish odour, linear distance and protein content of puffed corn-fish snack increased significantly with fish content while the expansion ratio significantly decreased ($p<0.05$). The optimum formulation was obtained at 15% of minced fish.

Keywords: Minced fish, Silver carp, Expansion ratio protein content, Extrusion, Response Surface methodology

1-Iranian Fish Research Organization, P. O. Box: 14965 /149. Tehran, Iran
2-Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
3-Institute of Halal Products Research, UPM
Corresponding author's email: h_r_shahmo@yahoo.com

Introduction

Starch-based snacks from corn, rice, and wheat are widely consumed, by children and young people. They are high in fat and carbohydrates and low in protein (Rhee *et al*., 1999). Extrusion processing is widely used in the food industry for restructuring starchy and proteinaceous ingredients (Choudhury and Gogoi, 1996). Several researches have been reported on the incorporation of high protein ingredients including soy (De Mesa *et al*., 2009), whey (Brni *et al*., 2008), legumes (Pastor *et al*., 2011), navy and pinto beans (Gujska and Khan, 1991) into different cereals to enrich the extruded snacks. There are some reports on production of extruded products from blends of meat and non-meat ingredients (Lee *et al.*, 2003; Mittal and Lawrie, 1984). For example Rhee *et al*. (1999) studied blends of corn starch and ground meat from lamb, mutton, hen and beef using a single-screw extruder. However, extrusion of starch containing materials mixed with animal muscle proteins is problematic due to the thermal instability of these formulations and the fundamental thermodynamic difference between protein and starch molecules (Yurjew *et al*., 1989).

The suitability of selected fish and squid for snack food manufactured by indirect extrusion cooking has been evaluated. The results indicated that meat of lean fish showed better extrusion characteristics than that of fat fish, fresh fish being superior to frozen fish. Washing of the fish meat was found to enhance meat utility in extrusion cooking (Wianecki, 2007). The incorporation of fish proteins to starch-rich ingredients such as rice flour significantly reduced expansion and increased hardness. This could be the reason why attempts to develop expanded snack food products from blends of minced fish and starchy ingredients using extruder have met with limited success (Choudhury and Gautam, 2003a). Presently there is no known commercial production of such product.

The extrusion process for snacks is very sensitive to changes in feed composition, extrusion condition and extruder design. Although the addition of fish protein to formulations intended for extrusion puffing is limited by technological constraints, it is extremely desirable from a nutritional viewpoint (Wianecki, 2007). To dateno published report is available on the extruded puffed corn-fish snack using minced meat of silver carp (*Hypophthalmichthys molitrix*). Despite being the most important cultured fish in the world (FAO, 2008), abundance of tiny bones in silver carp makes it unpopular for filleting and direct consumption. The present study was carried out to develop an extruded puffed corn-fish snack from silver carp, to optimize the fish meat content of the puffed snack based on the sensory, textural and protein characteristics of the developed snack.

Materials and Methods

Materials

Freshly-harvested Silver Carp (*H. molitrix*) was obtained from Gilan province on the southern coast of the Caspian Sea. Pre-dried yellow corn grits with 5.2% moisture content (wet basis) and seasoning materials including vegetable oil, cheese powder and salt were purchased from

Golfam Talaei Alborz, Iran. The moisture content of corn grits and fish were measured according to 2.4. The particle size distribution of the corn grits was 2.1% for 0-300 micron, 10.6% for 300-500 micron, 11% for 500-700 micron, 11.1% for 700-800 micron, 54.2% for 800-1200 micron, 6% for 1200-1400 micron and 5% for up to 1400 micron as provided by the supplier. Metalized biaxiallay-oriented polypropylene (BOPP) film with 30µm thickness was used to pack samples.

Sample preparation and process description

The fish was washed, gutted, and filleted manually, which was followed by deboning in a Baader-400 meat separator machine (Baader, Germany). Mixing of ingredients including corn grits and minced fish meat(as in Table1) was carried out in a 60 liter cutter-mixer (Iran steel Co, Iran) for 10 min. Moisture content was adjusted to minimum 16% for all treatments by adding water and mixing for 15 minutes. The mixture was held for 45 minutes at room temperature for moisture equilibration.

Extrusion

Fourteen runs were carried out as generated by the RSM.A high shear single screw extruder with barrel length to diameter of 3(Tabriz Food Machinery Co., Iran) was used for the extrusion process. The extrusion condition was 130°C for barrel temperature,112 rpm for screw speed, a feed rate of 25kg/hr and die diameter of 3.2 mm. In each run, extrudates were collected in a steady state (5 minutes after the run began). Collected samples were dried at 90°C in a convective air dryer for 20 minutes after which they were seasoned at 33% (w/w) by a roller sprayer (GT-II Jinan Saibainuo Technology Co., China). Pre-mixed seasoning materials consisted of 65% w/w vegetable oil, 30.5% w/w cheese powder and 4.5% w/w edible salt. Approximately 70±5 grams of extrudates from each run were packaged in BOPP pouches (180×300 mm; L×W).

Protein and moisture

The protein analyses were carried out according to the procedure AOAC 988.05. Moisture content was determined as procedure AOAC 930.15. (AOAC, 2000). Data were collected in triplicates.

Expansion Ratio

Expansion ratio (ER) was defined as$D_e/D_d$where $D_e$was the diameter of extrudate and D_d= 3.2 mm was the diameter of the die. The average of 10 measurements of extrudates diameter by a CD-6 CSX vernier digital calliper (Mitutoyo, Japan) was used to calculate expansion ratio (Dileep *et al.* 2010).

Texture Analyses

The textural properties of extrudate were measured using a texture analyser TA-XT2i/50 (Stable Micro Systems Ltd., Godalming, UK). A 5-bladed Kramer Shear cell (DP/KS5) using 50 kg load cell was used. The test speed of 2 mm/s and distance of 48 mm between the two supports was carried out to measure the force-time (distance) curve and peak count. The results were analysed by Texture Exponent 32 (Surrey, UK) software (Meng, *et al.*, 2009). Crispness was taken as the mean linear distance (LD) and also the mean number of major peaks. The reported data were the mean values of three replications.

Sensory Analyses

The sensory analyses of extrudate including overall acceptability (OA) and fish odour (FO), were carried out in the individual booth room at sensory laboratory of National Fish Processing Research Center (NFPRC- Iran) using the 5-Point hedonic scoring scale (Shi *et al*., 2011) at room temperature (25ºC). A group of 10 experienced and competent panellists (Hsu and Chung, 2001) from the researchers and staff of the FPRNC were selected for the test. The panellists were professionals in sensory evaluation with at least three years' experience. The panellists were properly instructed before the test. Overall acceptability 5-point hedonic scale works on grading sale as like very much=5 to dislike very much= 1. The fish odour 5-point intensity works on a scale of none=1 to very high=5. The panellists rinsed their mouths with water in between samples. Ten extrudates of each sample were served on a plastic plate randomly three-digit coded and evaluated.

Experimental design

Response Surface Methodology (RSM) was used to investigate the influences of using different amounts of minced fish meat on texture and acceptability of puffed corn-fish snack in order to optimize the extrusion feed composition. Results from preliminary trials were used to select suitable operating window. A central composite cubic design (CCD) using two factors, one replicate, 14 runs, two blocks, four cube points, three center points in cube, four axial points, three center points in axial and α =1.41421 was employed. Fish (0-3 kg) and corn (7-10 kg) were used as the independent variables. Protein, expansion ratio (ER), overall acceptability (OA) and fish odor (FO) were used as RSM dependant variables (Table 1).

Statistical analysis

A second-order polynomial regression model $y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2$ was established to fit the experimental data for each response (y_i), where the x_1 and x_2 were fish meat and corn content in kg, respectively. $\beta_0, \beta_1, \beta_2, \beta_{11}, \beta_{22}$ *and* β_{12} were the regression coefficients to be determined. The response surface and counter plots for the models were plotted as a function of these two independent variables. The terms which were statistical non-significant ($p>0.05$) were dropped from the initial models and the experimental data were refitted only to significant ($p<0.05$) factors to obtain the final model (Mirhosseini *et al*., 2009). Statistically significant differences between values were evaluated at $p<0.05$ and statistical analyses including 1-sample and 2-sample t-test, Response Surface Methodology (RSM) were evaluated using Minitab-14 (Minitab Inc. USA, 2003) software**.**

Optimization of the ingredients

In order to optimize the ingredients composition, both graphical and numerical multiple optimization procedures were carried out using Minitab software-14 (Minitab Inc. USA). For graphical optimization procedure, three-dimensional (3D) response surface plots and overlaid contour plot were drawn for better visualization of the final reduced models. As for numerical multiple optimizations, response optimizer was used to determine an optimum set level of independent variables that jointly optimized a set of responses by satisfying the requirements for each response.

Validation of the model

In order to verify the adequacy of final reduced models, 2 sample t-test and 1 sample t-test were carried out to compare the experimental and predicted values for theoretical and practical validation procedures at optimum point, respectively. Close agreement and no significant difference between the experimental and predicted values were needed for validation of the final model.

Results

The expansion ratio, overall acceptability, fish odour, linear distance and protein data are as shown in Table 1. Surface plots were generated in order to visualize the models in Figure 1. The regression coefficients and the equations describing the responses as well as significances are also shown in Table 2. The adequacy of all models was tested for lack-of-fit and coefficient of determination (R^2) in Table 2which expressed the fraction of variation of the response explained by the model. The test of the lack-of-fit was not significant for all responses and R^2 values for equations at the levels of 93-99.3% indicated that the models were suitable with high correlation.

Table 1: Experimental data for protein%, expansion ratio (ER), Overall acceptability (OA), fish odour (FO) and linear distance (LD) from the RSM experiments on extrusion of corn-fish blends.

	Fish (kg)	Corn (kg)	Fish (%)	Protein (%)	ER	OA	FO	LD kg.s
FS1	1.5	8.5	15	8.5±0.2	5.1± 0.2	4.5±0.7	1.4±0.5	172.73±0.10
FS2	1.5	8.5	15	8.2±0.3	5.1±0.3	4.4±0.7	1.3±0.5	172.71±10.86
FS3	3	10	23	9.5±0.3	4.3±0.3	2.8±0.7	3.2±0.6	711.32 *
FS4	0	10	0.0	6.5±0.4	5.2±0.3	4.5±0.7	1.3±0.5	59.88±2.50
FS5	0	7.0	0.0	6.9±0.3	5.3±0.2	4.4±0.5	1.3±0.5	68.10±5.01
FS6	3	7.0	30	10.3±0.3	2.8±0.2	1.6±0.5	4.4±0.7	2065.50*
FS7	1.5	8.5	15	8.6±0.4	5.2±0.2	4.7±0.5	1.5±0.5	188.05±6.25
FS8	1.5	8.5	15	8.7±0.4	4.9±0.4	4.8±0.4	1.5±0.5	172.68±10.83
FS9	1.5	6.4	19	9.0±0.3	4.8±0.4	3.8±0.5	2.7±0.7	342.43±6.26
FS10	1.5	8.5	15	8.3±0.1	4.9±0.3	4.7±0.5	1.4±0.5	172.74±7.67
FS11	1.5	8.5	15	8.6±0.3	5.2±0.3	4.5±0.7	1.7±0.7	172.71±10.83
FS12	3.6	8.5	30	10.0±0.3	2.9±0.1	1.4±0.5	4.5±0.5	2065.50 *
FS13	1.5	10.6	12	7.9±0.2	5.1±0.2	4.5±0.7	1.6±0.7	136.92±11.92
FS14	0	8.5	0	6.7±0.1	5.3±0.1	4.6±0.7	1.1±0.3	61.98±3.54

*Theoritical value obtained by (Equation 1).

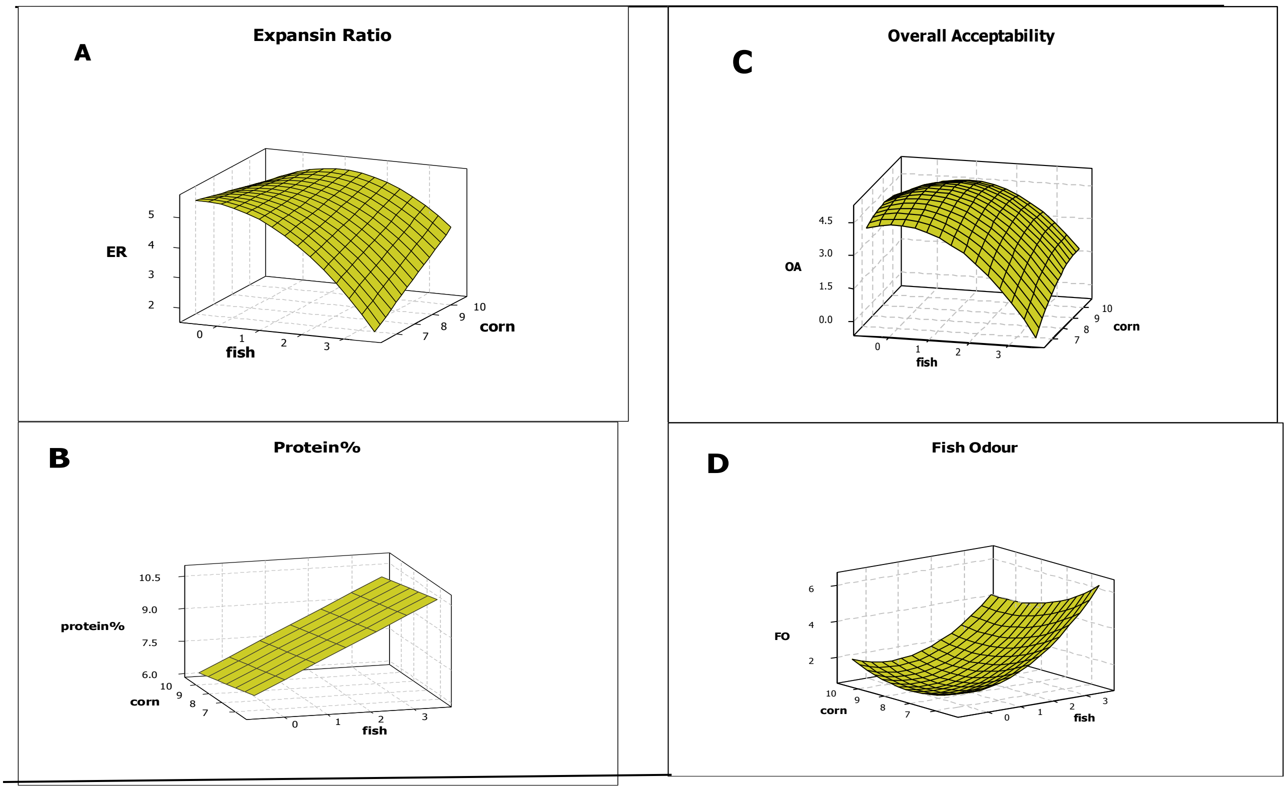

Figure 1: Surface plot of A) expansion ratio and B) protein% C) Overall Acceptability and D) Fish odour versus ingredients (kg).

Table 2: Regression equations coefficients and p-value (p) of the predicted reduced models[a] for response variables including protein, expansion ratio, overall acceptability and fish odour.

	Protein		Expansion Ratio		Overall acceptability		Fish Odour	
Coefficients	Coefficients	p	Coefficients	p	Coefficients	p	Coefficients	p
Linear								
β_0	8.4090	0.000	5.9000	0.000	-4.0050	0.032	12.7513	0.000
β_1	0.9222	0.000	-1.2115	0.013	-0.8299	0.011	1.0368	0.003
β_2	-0.1630	0.059	-0.0646	0.447	2.1297	0.000	-2.7528	0.000
Quadratic								
β_{11}	_	0.461*	-0.2256	0.000	-0.3833	0.000	0.3046	0.000
β_{22}	_	0.734*	_	0.276*	-0.1278	0.000	0.1602	0.000
Interaction								
β_{12}	_	0.103*	0.1556	0.007	0.1444	0.001	-0.1333	0.001
R^2 %	93		96.1		99.4		99.3	
p Lack-of-fit		0.063*		0.100*		0.898*		0.661*

[a] $y= \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2$, x_1=fish (kg) , x_2=corn (kg).

*Not significant at $p>0$

As in Table 2 both independent variables affected all product responses significantly ($p \leq 0.05$) except for corn percentage which was non-significant in protein. This was the reason that related coefficients (β_{11}, β_{22} and β_{12}) for protein were assumed to be zero inTable3.Fish content had linear effect on protein and quadratic effect on ER, OA and FO. The regression equation of linear distance versus fish% is shown in Equation 1.A good correlation (R^2=99.6%) and suitable cubic model was illustrated by $p \leq 0.001$. The LD of run number of 3, 6 and 13 (23, 30 and 30% fish respectively) were obtained by extrapolation of the available data using (Equation 1), because the samples were too hard and thus could not be mesured by the Texture Analyzer in maximum load (50kg). The expansion ratio was low and sensory texture was too hard and quite unacceptable for these extrudates.

LD = 63.31+35.87 fish% - 4.815 fish%**2 + 0.1948 fish%**3 (Equation 1)

The lack of expermental data for linear distance (LD) and peakscount in aforementioned 3 points was the reason that they were ignored in optimization modeling.

The regression equation indicated a high negative correlation (R^2= 99.4%) between linear distance and expansion ratio ($p \leq 0.001$).

LD=6778-2103ER+157.9ER**2 (Equation 2)

Optimization using Response Surface Methodology

The relationship between the independent and dependent variables is shown in Fig.1 and in Equation1. The optimization module in an overlaid plot investigated the combination of parameters levels that satisified the requirments placed on each of the responses. The bright area in Fig.2 showes the feasible response values in the factor space graphically. Regions that did not meet the proposed critria were shaded. Fig. 3 indicated the ingredients amount at the optimum point. Predicted optimum levels of ingredients based on maximal protein percentage and OA, minimizing the fish odour and targeting the expansion ratio at 5,was obtained at 1.6 kg minced fish and 8.7 kg corn content. This composition (15% minced fish) will result in the best combination of four defined responses.

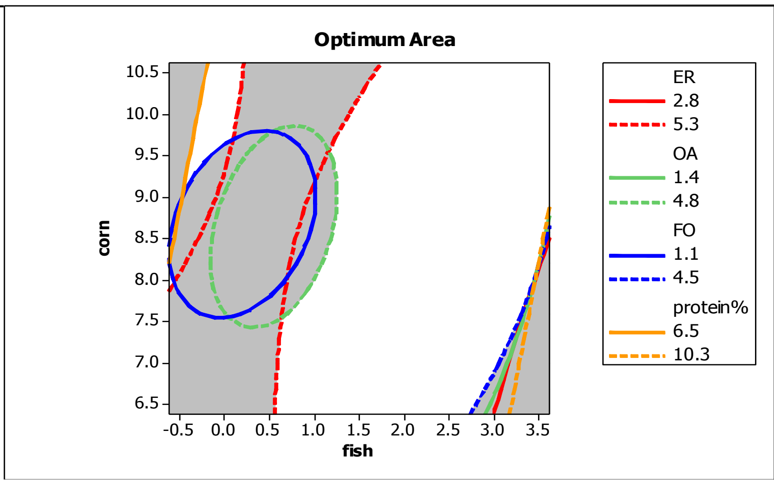

Figure2: The optimal working conditions illustrated in bright region of overlaid contour plot of Protein%, ER, OA and FO vs ingredients (kg) from RSM runs.

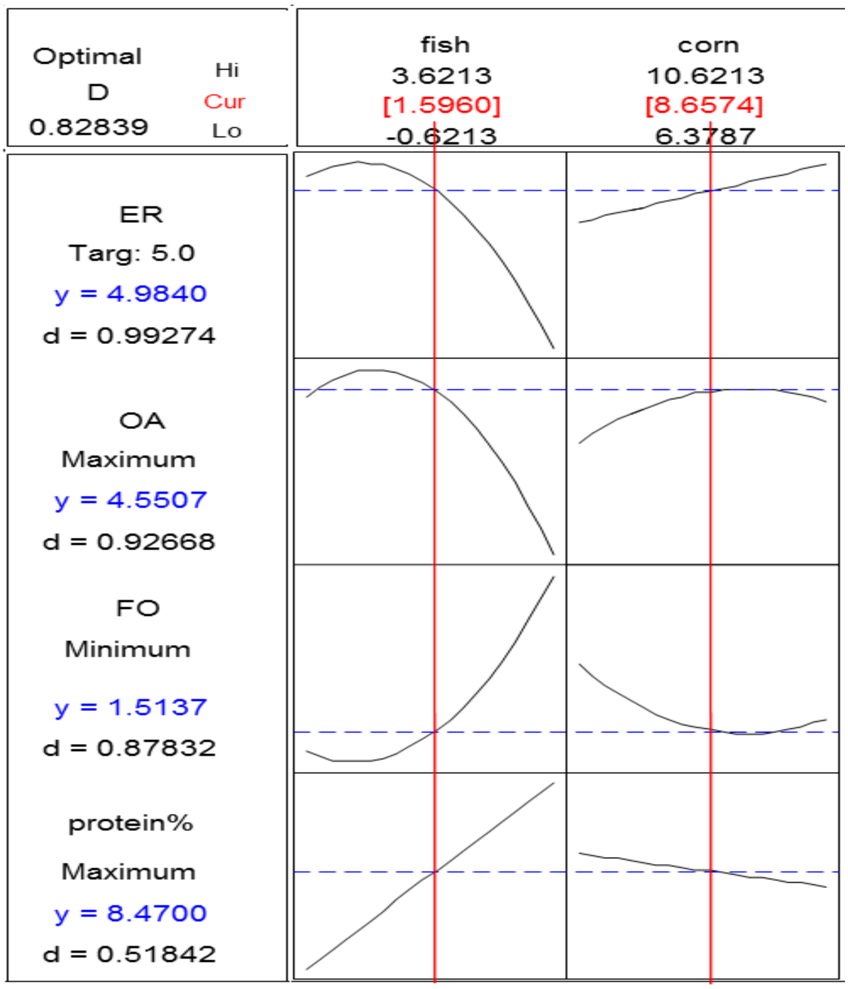

Figure 3: Predicted optimum point according to RSM multiple response optimizer.

Validation

The adequacy of the response surface equation was checked by the comparison of experimental and predicted values. The oretical validation of the models was tested by two sample t-test as shown in Table 3 and no significant difference was found between those values for all responses [Protein ($p=0.931$), ER ($p=0.946$), OA ($p=0.948$) and FO ($p=0.987$)].

Table 3: Comparison between experimental (Exp.) and predicted (Pre.) values based on the final reduced models.

Factors(kg)		Protein[a]%		Expansion Ratio[a]		Overall Acceptability[a]		Fish Odour[a]	
Fish	**Corn**	**Pre.**	**Exp.**	**Pre.**	**Exp.**	**Pre.**	**Exp.**	**Pre.**	**Exp.**
1.5	8.5	8.4	8.5	5.0	5.1	4.6	4.5	1.5	1.4
1.5	8.5	8.4	8.2	5.0	5.1	4.6	4.4	1.5	1.3
3	10	9.5	9.5	4.3	4.3	2.9	2.8	3.1	3.2
0	10	6.8	6.5	5.3	5.2	4.5	4.5	1.2	1.3
0	7	7.3	6.9	5.4	5.3	4.6	4.4	1.3	1.3
3	7	10.0	10.3	3.1	2.8	1.7	1.6	4.4	4.4
1.5	8.5	8.4	8.6	5.0	5.2	4.6	4.7	1.5	1.5
1.5	8.5	8.4	8.7	5.0	4.9	4.6	4.8	1.5	1.5
1.5	6.4	8.8	9	4.7	4.8	3.7	3.8	2.7	2.7
1.5	8.5	8.4	8.3	5.0	4.9	4.6	4.7	1.5	1.4
1.5	8.5	8.4	8.6	5.0	5.2	4.6	4.5	1.5	1.7
3.6	8.5	10.3	10	2.8	2.9	1.3	1.4	4.5	4.5
1.5	10.62	8.1	7.9	5.4	5.1	4.4	4.5	1.7	1.6
0	8.5	7.0	6.7	5.4	5.3	4.9	4.6	0.9	1.1

[a]No significant ($p>0.05$) difference between predicted and experimental value.

These observations verified the adequacy of the corresponding response surface model employed for predicting the variation of extrudate properties as a function of the independent variables. Practical validation of the models at optimum point was also tested by one sample t-test. Results are as shown in Table 4which indicates there was no significant difference ($p\geq0.05$) between the predicted and experimental data for all responses at optimum point. Therefore, the developed models were theoretically and practically valid.

Table 4: Comparison between practical and predicted values based on the final reduced models at the optimum point (fish= 15% and corn=85%) for responses.

	Overall Acceptability[a]	Expantion Ratio[a]	Protein%[a]	Fish Odour[a]
Predicted value	4.5	5.0	8.5	1.6
Actual value	4.4±0.5	4.9±0.3	8.4±0.3	1.6±0.3
p-Value *	0.601	0.634	0.446	0.667

**p*- value from 1-sample t-test.

[a] No significant (p>0.05) difference between predicted and experimental value.

Discussion

The high negative correlation between linear distance and expansion ratio (as in Equation 2) indicated that extrudates with high expansion were found to be less hard, is in agreement with studies reported by Faller *et al*. (1998). Expansion ratio was negatively correlated (R^2= 96.1) with fish content, mostly due to the high moisture content of the fish meat (Table2). The inverse relationship between moisture in extrusion feed and ER was also indicated by previous studies (Falcone and Phillips 1988; Rhee *et al*. 1999a; Thymi *et al*. 2005; Pansawat *et al*. 2008; Stojceska *et al*. 2009;).On the contrary, Rehrah *et al*. (2009) reported that increasing moisture level significantly increased the expansion of the exrtudate. Increasing hardness by reduction of feed moisture was also reported by Lin *et al*.(2000) and Rehrah *et al*. (2009). The disagreement may be explained by different ranges of moisture content of the feed. In previous report of literatures feed moisture content was remarkably high (40-60%, 60-70% and 40-90%, respectively) while the present research studied moisture of the feed was in the range from 16 to 27% of the formulation.

By using high fish content in the blend (30%) burning and die blockage were observed as were also reported by previous studies (BA-Jaber *et al*., 1993; Rhee *et al*., 1999b). When the fish content was >19% at which point the moisture was out of target level (16%), the ER decreased. The extrudates were so dense and hard that measurment could not be made by the texture anaylzer. This was expected as high fish content contrbuted to the higher moisture content. Previous reported studies also indicated that the hardness of extrudates increases as the feed moisture content increases(Ding *et al*., 2005;Altan *et al*., 2008; Meng *et al*., 2009). Reduction of ER with increasing bulk density and hardness of extrudates due to the addition of muscle and fish protein were also reported(Gogoi *et al*. 1996; Gautam *et al*. 1997; Choudhury and Gautamb 2003; Curic *et al*. 2009;). Rehrah *et al*. (2009) reported a negative relation between protein amount and expansion ratio of extrudate. They indicated that the reason was probably the strong bonding between protein molecules. The addition of protein increases the firmness of plasticized extrudates, thereby preventing their expansion. On the contrary, an increase of the expansion index with increasing protein content was also reported by Boye *et al*. (2010). Moraruand Kokini (2003) reported that soy protein isolate (1-8%) increased the

ER of wheat starch while wheat gluten (up to 11%) reduced it. Perhaps this was best explained by Wianecki (2007) who stated that in addition to the role of fat content of protein source, water-soluble-proteins both of plant and animal origin reduce extrudat expansion, while myofibrilar protein of animal meat and vital gluten are highly extrudable materials.

It was concluded that silver carp minced fish can be used to produce a nutritious puffed corn-fish snack with desirable expansion ratio, texture and sensory attributes by direct extrusion technology. The optimal combination of ingredients was determined to be at 1.6 kg fish and 8.7 kg corn content (i.e. 15% minced fish). The incorporation of fish content >19% highly improved the protein content but provided a higher amount of moisture content (19-27%) which resulted in the hardness undesirable fish odour. Burning and die blockage problems were also observed at 30% fish content blend of the extrusion feed which were technical problems in developing corn-fish snack with higher amount of fish content.

Acknowledgements

Authors would like to acknowledge their appreciation to Iranian Fisheries Research Organization (IFRO),Universiti Putra Malaysia (UPM) andto Golfalm Talaei Alborz Co. (Puffish) for all their supports.

References

Altan, A., McCarthy, K. L. and Maskan, M. ,2008. Evaluation of snack foods from barley-tomato pomace blends by extrusion processing. *Journal of Food Engineering*,84(**2**), 231-242.

AOAC, 2000.Method 965.33. In W. Horwitz (Ed.), Official methods of analysis of AOAC international. 2, 12-41. AOAC international USA.

BA-Jaber, A., Sofos, J., Schmidt, G. and Maga, J., 1993.Cohesion and hardness of extrusion-cooked mechanically and hand-deboned poultry meat with soy protein isolate and kappa-carrageenan *Journal of Muscle Foods*,4(**1**), 27-39.

Boye, J., Zare, F. and Pletch, A. ,2010. Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International*,43(**2**), 414-431.

Brni , M., Karlovi , S., Bosiljkov, T., Tripalo, B., Jeek, D. and Cugelj, I., 2008. Enrichment of extruded snack products with whey proteins. *Mljekarstvo*, 58(**3**), 275-295.

Choudhury, G. S. and Gautam, A. ,2003a. Effects of hydrolysed fish muscle on intermediate process variables during twin-screw extrusion of rice flour. *LWT - Food Science and Technology,* 36(**7**), 667-678.

Choudhury, G. and Gautam, A. ,2003b.Hydrolyzed fish muscle as a modifier of rice flour extrudate characteristics. *Journal of Food Science,* 68(**5**), 1713-1721.

Choudhury, G. S. and Gogoi, B. K. ,1996.Extrusion Processing of Fish Muscle.*Journal of aquatic food product technology*,4(**4**), 37-67.

Curic, D., Novotni, D., Bauman, I., Kricka, T. and Dugum, J. ,2009.Optimization of extrusion cooking of cornmeal as raw material for bakery products. *Journal of Food Process Engineering*,32(**2**), 294-317.

De Mesa, N. J. E., Alavi, S., Singh, N., Shi, Y.-C., Dogan, H. and Sang, Y. ,2009. Soy protein-fortified expanded extrudates: Baseline study using normal corn starch. *Journal of Food Engineering,* 90(**2**), 262-270.

Dileep, A., Shamasundar, B., Binsi, P. and Howell, N. ,2010.Composion and quality of rice flour-fish mince based extruded products with emphasis on thermal properties of rice flour .*Journal of Texture Studies,*41(**2**), 190-207.

Ding, Q. B., Ainsworth, P., Tucker, G. andMarson, H., 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *Journal of Food Engineering,* 66(**3**), 283-289.

Falcone, R. G. and Phillips, R. D. ,1988. Effects of feed composition, feed moisture, and barrel temperature on the physical and rheological properties of snack like products prepared from cowpea and sorghum flours by extrusion. *Journal of Food Science,* 53(**5**), 1464-1469.

Faller, J., Klein, B., and Faller, J. , 1998. Characterization of corn-soy breakfast cereals by generalized procrustes analyses. *Cereal Chemistry,* 75(**6**), 904-908.

FAO,2008. World aquaculture production of fish, crustaceans, molluscs, etc., by principal species in 2008. From ftp://ftp.fao.org/FI/CDrom/CD_yearbook_2008/root/aquaculture/a6.pdf.

Gautam, A., Choudhury, G. S.andGogoi, B. K.,1997. Twin screw extrusion of pink salmon muscle: effect of mixing elements and feed composition *Journal of Muscle Food,* .8(**3**), 265-285.

Gogoi, B. K., Oswalt, A. J. and Choudhury, G. S. ,1996. Reverse screw element(s) and feed composition effects during twin-screw extrusion of rice flour and fish muscle blends. *Journal of Food Scienc,*.61(**3**), 590-595.

Gujska, E. and Khan, K., 1991. Functional properties of extrudates from high starch fractions of navy and pinto beans and corn meal blended with legume high protein fractions. *Journal of Food Science,* 56(**2**), 431-435.

Hsu, S. and Chung, H. Y., 2001.Effects of [kappa]-carrageenan, salt, phosphates and fat on qualities of low fat emulsified meatballs. *Journal of Food Engineering,* 47(**2**), 115-121.

Lee, S. O., Min, J. S., Kim, I. S., and Lee, M. ,2003. Physical evaluation of popped cereal snacks with spent hen meat. *Meat scienc,* .64(**4**), 383-390.

Lin, S., Huff, H. and Hsieh, F., 2000. Texture and chemical characteristics of soy protein meat analog extruded at high moisture. *Journal of Food Science,* 65(**2**), 264-269.

Meng, X., Threinen, D., Hansen, M. andDriedger, D.,2009. Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack. *Food Research International,* 43(**2**), 650-658.

Mirhosseini, H., Tan, C. P., Hamid, N. S. A., Yusof, S., andChern, B. H. ,2009. Characterization of the influence of main emulsion components on the physicochemical properties of orange beverage emulsion using response surface methodology. *Food Hydrocolloids,* 23(**2**), 271-280.

Mittal, P. and Lawrie, R. ,1984. Extrusion studies of mixtures containing certain meat offals: Part 1-Objective properties. *Meat science*, 10(**2**), 101-116.

Moraru, C. I. andKokini, J. L. ,2003. Nucleation and Expansion During Extrusion and Microwave Heating of Cereal Foods. *Comprehensive Reviews in Food Science and Food Safety,* 2(**4**), 147-165.

Pansawat, N., Jangchud, K., Jangchud, A., Wuttijumnong, P., Saalia, F. K. and Eitenmiller, R. R., 2008. Effects of extrusion conditions on secondary extrusion variables and physical properties of fish, rice-based snacks.*LWT - Food Science and Technology,* 41(**4**), 632-641.

Pastor, C. E., Drago, S. R., Gonzalez, R. J., Juan, R., Pastor, J. E. and Alaiz, M., 2011. Effects of the addition of wild legumes (*Lathyrus annuus* and *Lathyruscly menum*) on the physical and nutritional properties of extruded products based on whole corn and brown rice. *Food Chemistry*. 117, 466-469

Rehrah, D., Ahmedna, M., Goktepe, I. and Yu, J., 2009. Extrusion parameters and consumer acceptability of a peanut-based meat analogue. *International Journal of Food Science and Technology*.44(**10**), 2075-2084.

Rhee, K., Cho, S.H. and Pradahn, A. M.,1999a. Composition, storage stability and sensory properties of expanded extrudates from blends of corn starch and goat meat, lamb, mutton, spent fowl meat, or beef.*Meat Science*,52(**2**), 135-141.

Rhee, K. S., Cho, SH. And Pradahn, A. M. ,1999 b. Expanded extrudates from corn starch-lamb blends: process optimization using response surface methodology. *Meat science*, 52(**2**), 127-134.

Shi, C., Wang, L., Wu, M., Adhikari, B. and Li, L., 2011. Optimization of Twin-Screw Extrusion Process to Produce Okara-Maize Snack Foods Using Response Surface Methodology. *International Journal of Food Engineering*,7(**2**), 9.

Stojceska, V., Ainsworth, P., Plunkett, A. and Ibanoglu, S., 2009. The effect of extrusion cooking using different water feed rates on the quality of ready-to-eat snacks made from food by-products. *Food Chemistry,* 114(**1**), 226-232.

Thymi, S., Krokida, M., Pappa, A. and Maroulis, Z., 2005. Structural properties of extruded corn starch. *Journal of Food Engineering,* 68(**4**), 519-526.

Wianecki, M. 2007. Evaluation of fish and squid meat applicability for snack food manufacture by indirect extrusion cooking. *Acta Scientiarum Polonorum: Technologia Alimentaria,* 6P.

Yurjew, V., Likhodziewskaya, I., Zasypkin, D., Alekseev, V., Grinberg, V. Y. and Polyakow, V., 1989. Investigation of the microstructure of textured proteins produced by thermoplastic extrusion. *Die Nahrung,* 33, 823-830.