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Optimization of puffed corn-fish snack extrusion conditions using response surface methodology

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Abstract

To optimize the extrusion conditions of novelty developed puffed corn-fish snack, Response Surface Methodology was performed. Feed rate (810-1206 g/min), temperature (105-125ºC) and screw speed (146- 208 rpm)were considered as 3 independent variables. Expansion ratio, density, sensory texture, overall acceptability, linear distance and count peak were used as dependent variables. Density and expansion ratio were significantly ($p < 0.05$) correlated with the factors ($R^2 > 0.94$). Optimum condition was found at 116ºC, feed rate at1107 g/min and screw speed at 148 rpm, where the expansion ratio of 5.5 and density of 41.92 kg/m^3 were obtained. Besides, the effect of feed rate (0.5-1.5 kg/min) on textural properties was individually studied. A quadratic model (R^2>0.95) was found for expansion ratio versus feed rate while density showed a cubic regression model (R2>0.80) verses feed rate.

Introduction

Fish are known to contain important constituents for the human diet such as nutritional and readily-digestive proteins, lipid-soluble vitamins, micro elements and polyunsaturated fatty acids (Friedman, 1996). The incorporation of fish proteins in starch-rich ingredients such as rice flour significantly reduced expansion and increased hardness. This may 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, 2003).

To overcome the aforementioned problem many variables such as feed composition, feed rate (FR), barrel temperature, screw speed (SS), screw configuration and the die geometry should be controlled (Meng *et al*., 2009). The combination parameters of feed rate and screw speed are important, since they determine the filling level in the extruder. This is critical to the process because it governs the balance between the weak and strong mass transfer mode which influences the shear stress and resistance time (Chokshi *et al.*, 2004). Moreover, physical characteristics such as expansion, density and hardness are important parameters to evaluate the consumer acceptability of the final product (Patil *et al*., 2007).

Response surface methodology (RSM) is a well-known method to study extrusion conditions. RSM was employed to study the effects of extrusion conditions on secondary extrusion variables and physical properties of the extrudates of a formulation containing rice flour, fish powder, menhaden oil and vitamin E (Pansawat *et al*., 2008). The effect of various extrusion parameters (barrel temperature (T) , screw speed (SS), feed rate (FR), moisture content and fish mince percentage) on the properties (density, expansion ratio, water solubility index and water absorption index) of extruded snacks was studied. The results showed that temperature was the most significant parameter followed by moisture content. Screw speed and feed rate were found to have least influence on extrudate properties (Rao and Parhar, 2009).

The effect of extrusion conditions including FR (1.16-6.44 kg/h), SS (150-250 rpm), and product temperature (100-260ºC) on physical properties of extrudates including density, expansion ratio (ER) and porosity were investigated. The extrudate's physical properties were found to be dependent on feed moisture content, residence time and temperature while they were not affected by screw speed (Thymi *et al*., 2005).

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Genetic algorithm was employed to optimize process variables during single screw extrusion of a fish and rice flour blend. The optimum process conditions were reported at high fish content of 41-45% and medium moisture content of about 40% (Shankar and Bandyopadhyay, 2004). High screw compression ratio, high barrel temperature and low die temperature were reported to provide a good texture in extrusion of textured soya protein (Frazier *et al*., 1983).

Many other studies have reported effects of different process variables and extruder configuration on properties of different blends of extrudates (Reyes-Moreno *et al*., 2003; Zhou and Hanna, 2004; Hagenimana *et al*., 2006; Altan *et al*.,2008; De Pilli, *et al*., 2008;Perez *et al*., 2008; Pushpadass *et al.,* 2008;Bueno *et al*., 2009; Curic *et al*., 2009; Shi *et al*., 2011; Chakraborty and Bhattacharya, 2011; Liu *et al*.,2011).

Since the extrusion process is very sensitive to every change of feed composition, extrusion condition and extruder design, the objectives of this study are to investigate the effects of process conditions on textural properties and to optimize feed rate, screw speed and barrel temperature of the novelty developed puffed corn-fish puffed snack (Shahmohammadi *et al*., 2014a).

Materials and Methods

Materials

Freshly-harvested Silver Carp *(Hypophthalmichthys molitrix)* was obtained from Gilan province on the southern coast of the Caspian Sea. Yellow corn grits with 12% moisture content (wet basis) were purchased from Golfam Talaei Alborz (Iran). The particle size distribution of the corn grits was 2.1% for 0-300 microns, 10.6% for 300-500 microns, 11% for 500-700 microns, 11.1% for 700-800 microns, 54.2% for 800-1200 microns, 6% for 1200-1400 microns and 5% for up to 1400 microns as provided by the supplier. Metalized Biaxillary-Oriented Poly Propylene (BOPP) film was used to pack samples.

Sample preparation

The fresh fish was washed, gutted and filleted manually which was followed by deboning in a single drum meat separator machine (Baader-400, Germany). Mixing of all ingredients including 84.5% corn grits, 15% minced fish meat, and 0.5%magnesium silicate (Talc) was carried out in a 60-liter cutter-mixer (Iran steel Co, Iran) for 10 minutes (Shahmohammadi *et al*., 2014b). Each mixing batch was 10 kg. The mixture was held for 45 minutes at room temperature for moisture equilibration.

Extrusion

Ten kilograms of samples were used for each run. Fifteen runs were carried out as generated by the RSM (Box-Behnken). Extrusion was performed on a twin screw extruder (65-I SLG Jinan Saibainuo Technology Co., China 2009).Barrel length to diameter(L/D) had the ratio of 15.7. In each run, extrudates were collected in a steady state (five minutes after the run began). Collected samples were dried at 60°C in a convective air dryer for 30 minutes. Approximately 70 grams of extrudates from each run were packaged and sealed in 80 BOPP pouches of dimensions 170×290 mm(L×W).

Sensory analyses

The sensory analyses of extrudates were carried out in the individual booth at the sensory laboratory of the National Fish Processing Research Center (NFPRC- Iran), using a 7-point hedonic scoring scale (Bhattacharya and Prakash, 1994; Altan *et al.*, 2008) at room temperature (25ºC). A group of 16 experienced and competent panelists from among the researchers and staff of the NFPRC were selected for the test. Texture and overall acceptability were evaluated and the panelists rinsed their mouths with water in-between testing the samples.

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 ER (Dileep *et al*., 2010).

Bulk density

Bulk density (BD)was calculated according to $BD= 4m/\pi d^2L$where *m* (g) is the mass, *L* (cm) is the length and d (cm) is the diameter of cylindrical extrudate (Alvarez *et al*., 1988; Pansawat *et al*.,2008; Stojceska *et al.*,2009). The results were converted to kg/m^3 to follow SI units by multiplying by 1000. The average of 10 measurements was reported.

Texture analysis

The textural properties of extrudate were measured using a texture analyzer 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

Table 1. Experimental data for expansion ratio (ER), bulk density (BD), sensory texture (ST), overall acceptability (OA), linear distance (LD) and peaks count (PC) from the RSM experiments on extrusion of corn-fish blends

		Independent Variables			Dependent Variables (Responses)					
Run Ord.	Pt Type	T (°C)	FR (Hz)	SS. (Hz)	ER	BD (kg/m³)	ST	OA	LD (kg.s)	PC (No.)
1	2	105	16	34	4.3±0.3	37.1±3.1	4.5±0.8	4.6±0.7	245±48	260±51
2	2	115	24	40	5.3±0.0	35.5±2.3	4.7±0.7	4.6±0.3	96±18	354±70
3	2	105	24	34	4.3±0.3	41.0±3.5	4.1±0.8	4.2±0.4	145±19	363±55
4	2	115	24	28	5.4±0.3	45.8±6.0	4.3±1.0	4.1±0.7	166±31	301±59
5	0	115	20	34	5.1±0.2	38.5±2.9	4.5±0.8	4.3±0.7	82±9	389±77
6	0	115	20	34	5.0±0.0	39.2±1.4	4.7±0.8	4.6±0.3	157±21	307±60
7	2	125	20	28	5.4±0.2	36.1±3.2	4.0±0.5	4.3±0.9	252±18	278±35
8	2	115	16	28	5.1±0.2	36.7±2.6	4.6±0.7	4.6±0.5	146±20	405±80
9	2	125	16	34	4.7±0.5	38.1±2.8	4.8±1.0	4.0± 0.7	112±11	327±29
10	0	115	20	34	5.2±0.2	39.6±2.2	4.7±0.8	4.6±0.5	123±21	421±21
11	2	125	24	34	5.2±0.2	41.3±2.8	4.5±0.9	4.3±0.5	222±38	231±33
12	2	105	20	28	5.0±0.0	40.3±2.6	4.4±0.7	4.6±0.6	93±6	286±44
13	2	115	16	40	4.8±0.3	40.3±5.0	4.6±1.0	4.5±0.4	70±8	371±73
14	2	125	20	40	5.1±0.1	35.9±2.1	4.5±0.6	4.6±0.3	78±9	456±63
15	2	105	20	40	5.0±0.2	35.8±2.4	4.5±0.9	4.6±0.3	138±27	302±60

T: Temperature, FR: Feed Rate, SS: Screw speed

and peaks count (PC) (Meng *et al*., 2009). The results were analyzed by Texture Exponent 32 (Surrey, UK) software. 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 (Singh *et al*., 2009).

Experimental design

Expansion ratio (ER)and bulk density (BD) versus feed rate(FR) were studied by changing FR 10-30 Hz (0.5-1.5 kg/min) while screw speed (SS) was fixed at 34 Hz (180 rpm) and temperatures in three zones were 50, 105, and 125°C respectively (Table 1). ER and BD versus SS were also recorded by changing SS, 24-40 Hz (124-212 rpm) while FR was fixed at 20 Hz (1kg/min) and temperatures in three zones were maintained as before.

Response surface methodology (RSM) was used to investigate the effect of extrusion condition on textural properties of corn-fish snack. A Box-Behnken design with three factors (Pansawat *et al*., 2008), 1 replicate, 15 runs, and 1 block were selected to determine the extrusion condition in optimum point. The center point values and suitable extruder operating window of three independent variables were selected based on preliminary trials result and maximum capability of the extruder. FR (16-24 Hz or 810-1206 g/min), barrel temperature in second zone (105-125°C), SS (28-40 Hz or 146-208 rpm) were used as the independent variables.

ER, BD, crispness from sensory texture (ST) evaluation, overall acceptability (OA), peaks count (PC) and linear distance (LD) from texture analyzer were used as the dependent variables while RSM fixed parameters were temperature in: first zone = 50°C and temperature in: third zone = 125°C. Moreover extrusion conditions were optimized by using a conventional graphical method of RSM in order to obtain extrudates with favorable properties. The non-significant factors ($p>0.05$) were dropped from the initial model and only the reduced model was reported.

Statistical analysis

A second-order polynomial regression model $y= \beta^o+ \beta_1\ x_1+ \beta_2\ x_2+ \beta_3 x_3+ \beta_{11} x_1^{\ 2}+ \beta_{22}\ x_{22}+ \beta_{33}\ x_3^{\ 2}+\beta_{12} x_1 x_2 +\beta_{13} x_1 x_3 +\beta_{23} x_2 x_3$ was established to fit the experimental data for each response (y_i), where the x_1, x_2 and x_3 were barrel temperature in the 2nd zone (°C), FR (Hz) and SS (Hz) respectively. β_0, β_1, β_2, β_3, β_{11}, β_{22}, β_{33}, β_{12}, β_{13} and β_{23} 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 statistically 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 and RSM were evaluated using Minitab-14 (Minitab Inc. USA, 2003) software.

Optimization of the extrusion conditions

In order to optimize the extrusion conditions,

Table 2. The regression equations coefficients and significances probability (p) for the predicted reduced modelsa for response variables

	Expansion Ratio		Bulk Density		Linear Distance	
	Coefficients	p	Coefficients	p	Coefficients	p
Linear						
β_o	-27.4411	0.067	-58.7617	0.000	-304.611	0.870
β_1	0.5782	0.024	-	0.561*	5.262	0.746
β_2	0.6589	0.020	5.2792	0.028	-149.095	0.034
β_3	-0.5155	0.017	2.6583	0.028	99.037	0.035
Quadratic						
β_{11}	-0.0024	0.029	-	0.321*	-	0.228*
β_{22}	-0.0154	0.026	-	0.085*	-	0.550*
β_{33}	0.0074	0.019	-	0.095*	-	0.521*
Interaction						
β_{12}	-	0.201*	-	0.143*	1.312	0.032
β_{13}	-	0.377*	-	0.213*	-0.911	0.027
β_{23}	-	0.601*	-0.1448	0.006	-	0.631*
R^2 %	85.4		75.1		68	
p of Lack-of- fit	0.128		0.089		0.496	

a $y= \beta^o+ \beta_1 x_1+ \beta_2 x_2+ \beta_3 x_3+ \beta_{11} x_1^2+ \beta_{22} x_2^2+ \beta_{33} x_3^2+\beta_{12} x_1 x_2 +\beta_{13} x_1 x_3 +\beta_{23} x_2 x_3$ where x_1= Barrel temperature in 2nd zone (°C), x_2=Feed rate (Hz), x_3= Screw speed (Hz)

*Not significant at p>0.05

both graphical and numerical multiple optimization procedures were carried out using Minitab software-14 (Minitab Inc. USA, 2003). 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, two sample t-test and one 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 and Discussion

The effects of extrusion conditions on product responses are shown in Table 1. The table illustrated the independent variables including temperature (T), Feed rate (FR) and screw speed (SS), as well as dependent variables including expansion ratio (ER), bulk density (BD), sensory texture (ST), overall acceptability (OA), linear distance (LD) and peaks count (PC).The results of RSM regression analyses for significant responses (after dropping non-significant parameters) are shown in Table 2. The surfaces plots of ER and BD versus dependent variables are shown in Figures 1 and 2 respectively. Optimum combination of barrel temperature, feed rate and screw speed for the production of corn-fish snack with a twin-screw extruder are illustrated in Figure 3.

RSM regression analysis

The regression fitted line plot of ER and BD verses FR was drawn. ER has a good quadratic correlation versus FR (p= 0.000, R^2=95.9).The related regression equation is indicated by $ER = - 3.189 + 0.6564\ FR- 0.01261\ FR^2$. Regression analysis of density versus feed rate is illustrated by $BD= 628.6 - 91.86\ FR+ 4.410\ FR^2 - 0.06763\ FR^3$. This cubic model showed an acceptable correlation (p= 0.007, R^2= 80.1). On the contrary, no acceptable correlation was found for ER (p > 0.05, R^2=58.9) and BD (p > 0.05, R^2=51.2) versus SS. They are in agreement with Mezreb *et al*.,(2003) who reported no

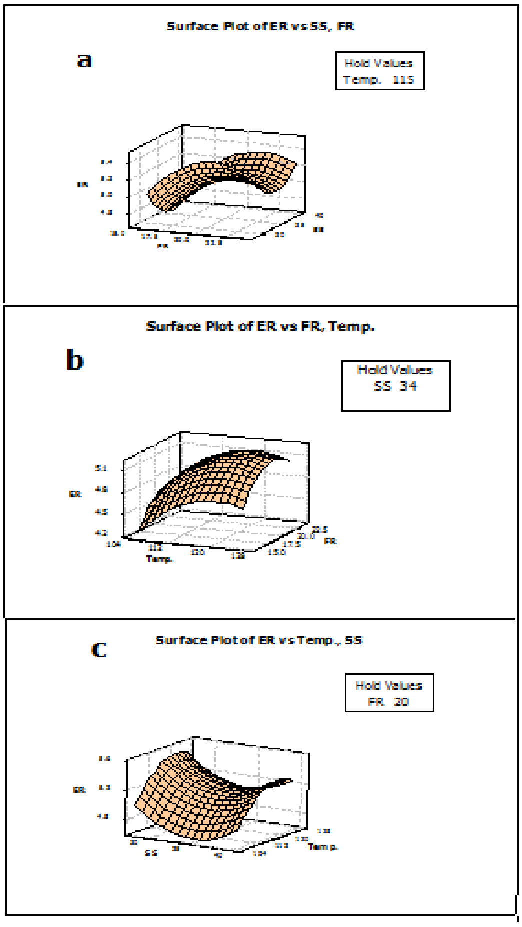

Figure 1. Effect of barrel temperature in the 2nd zone (°C , feed rate (Hz) and screw speed (Hz) on expansion ratio, where the hold value is feed rate at 20 Hz. a) ER vs FR and SS, b) ER vs T and FR, c) ER vs SS and T

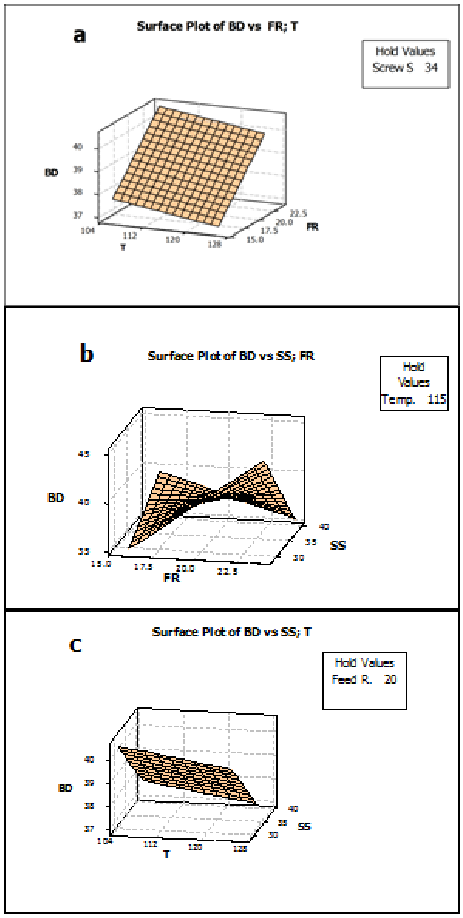

Figure 2. Effect of barrel temperature in the second zone (°C), feed rate (Hz) and screw speed (Hz) on bulk density of extrudates. a) BD vs T and FR, b) BD vs FR and SS, c) BD vs T and SS

significant evaluation occurred between 200 and 300 rpm for corn extrudates; however a significant drop was recorded for a speed of 500 rpm which is out of range of the present study (124-212 rpm).

As shown in Table 2, the regression models for ER, BD were significant ($p < 0.05$) with an acceptable coefficient of determination (R^2=85.4, 75.1). Furthermore, models showed no significant lack of fit ($p> 0.05$), indicating that the second order polynomial models were correlated with the measured data and were statistically significant ($P<0.05$). On the contrary, neither sensory attributes including texture (crispness) and overall acceptability nor instrumental textural characteristic (peaks count and linear distance) were significant ($P> 0.05$) i.e. they were low in the coefficient of determination ($R^2<70\%$). Thus, in RSM optimization procedure, ER and BD, as the most important physical properties (Tiwari *et al.*, 2009) were kept as dependent variables.

Expansion Ratio

Expansion ratio "as an index of puffing level" which is one of the most important physical characteristics of the extrudates (Rehrah *et al.*, 2009), ranged from 4.3 to 5.4.The regression analyses results (Table 2) indicated that barrel temperature and feed rate, had a positive linear effect while the screw speed had negative linear effect followed by quadratic significant effects on expansion ratio. However, interaction effects were not significant for all three factors. Response surface plot (Figure 1.b) showed that at low feed rate and temperature, increasing FR leads to a significant increase in ER but less sensitivity was observed at high feed rates. The significant quadratic effect of barrel temperature was also illustrated on the curved surface of the plot (Figures 1.b and c).

Expansion ratio of experiments increased with barrel temperature to a maximum point at about 120ºC then declined. Similar findings have also been reported by Ilo *et al.* (1996) who found the same pattern for ER in extrusion cooking of maize grits at 150-160ºC product temperature and 47-60 kg/h FR. Dogan and Karwe (2003) reported similar results in the extrusion of quinoa at 130-170ºC, 250-500 rpm SS and 300 g/min FR. Meng *et al.* (2009) also reported a peak at about 168ºC in extrusion of chickpea flour where the SS varied between 250 and 320 rpm and barrel temperature was between 150 and 170ºC.

They stated that the existence of temperature plateau for expansion ratio between 150ºC and 170ºC depended on the type of food material. This could be due to excessive structure breakdown and starch degradation at high temperature, which weakened the extrudate structure and therefore caused its collapse. The expansion reduction at higher temperature may also be the result of increased axial or longitudinal expansion (Ali *et al.*, 1996; Valle *et al.*, 1997). Therefore, precise control of extrusion conditions is important to achieve desirable extrudate properties (Meng *et al.*, 2009).

The differences between peak temperatures of this study (which was about 120^{o}C) and the aforementioned peak at 150-170^{o}C (reported by other researches) is due to the different recorded temperature zones in addition to different types of food material; i.e. this study has considered the temperature in the second zone, which is normally 15-30^{o}C lower than in the third zone and product temperature (reported by others). It is expected because the product temperature is increased due to high friction and changing mechanical energy to heat, besides the higher set temperature in the third zone. The ER of the extrudate was in the range of 4.3-5.4 (Table 1) which is higher than ER of similar cereal-based extrudates at 3.06- 4.99 that was reported by Meng *et al.* (2009) and 2.5-4.7 by Patil *et al.* (2007).

Bulk density

The sectional expansion ratio is considered only in the direction perpendicular to extrudate flow in the barrel, while bulk density as an indicator of volumetric expansion, would have less variability than the other types of expansion (Patil *et al*., 2007). BD was measured as an important physical property, which plays a vital role in appearance and overall acceptability (Tiwari *et al*., 2009).

The BD of the extrudates varied between 35.5 and 45.8 kg/m3, which was close to 50 kg/m^3 of commercial corn snack but much lower and better than some similar studies such as 90-320 kg/m^3 for maize grits extrudates (Ilo *et al.*, 1996), 130-275 kg/m^3 for chickpea flour-based snack (Meng *et al.*, 2009) and 160-238 for seasoned corn snack (Suknark *et al*., 1997). Besides, it was significantly affected by the linear influences of feed rate and screw speed as shown in Table 2.

The response surface plots (Figure 2.a) illustrated that the BD of extrudates decreased linearly with increasing temperature and increased linearly with increasing feed rate when the screw speed was fixed at 34 Hz (177 rpm). It is also apparent in Figure 2c that BD linearly decreases with increased temperature and SS when the FR is fixed on 20 Hz (1008 g/min). The interaction effect of SS and FR when the temperature is fixed at 115 can be observed in Figure 2b. The result was in agreement with the investigation on extrusion cooking of corn meal performed by Curic *et al*. (2009).

Optimization

There is not a standard or unique definition for optimum physical properties including ER and BD of extrudates. In fact, it depends on different factors such as: kind of product, the working range of specifications and the consumers eating habits. Several researchers have considered high ER and low density as the desirable criteria (Shankar and Bandyopadhyay, 2004; Ganjyal and Hanna, 2006; Altan *et al*., 2008, Meng *et al.*, 2009). However, a research conducted by Pushpadass *et al.*, (2008) has considered low ER and medium BD, while Curic *et al*. (2009) performed optimization considering both ER and BD as high as possible.

Yu *et al*. (2013) concluded that “this type of study will be useful in identifying desirable operating conditions for targeted extruded products”. Since high moisture content of the feed (resulting from higher fish content), has the tendency to cause poor puffing and high porosity (low BD), in the present study, ER and BD were targeted to be as high as possible as the main criteria for the constraints of the optimization. The proposed limits for BD were at least 38 kg/m^3 and target value was identified as 42 kg/m^3. These limits were identified as 5 and 5.5 for ER respectively, which resulted from overlaid contour plots.

The optimum ranges are illustrated in the overlaid counter plot showing the range of variables which could be considered as the optimum for the best product texture. Furthermore, Figure 3 shows the optimum point of extrusion condition to achieve a desirable extrudates texture. The optimum combination of operating conditions was derived from: temperature in the second zone =116ºC, feed rate= 22 Hz (1107 g/min) and screw speed = 28 Hz (148 rpm). Under optimal conditions, the properties of extrudates were ER= 5.5 and BD = 41.2 kg/m^3.

Validation

In order to validate the optimum point, which was obtained by the reduced models, theoretical validation of the models was tested by two sample t-test. No significant difference was found between those values for BD ($p = 0.995$) and ER ($p = 0.057$)

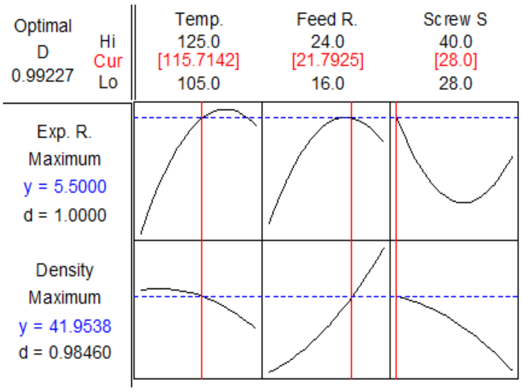

Figure 3. Response optimizer of expansion ratio and density versus barrel temperature, feed rate and screw speed.

as the responses. 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.

For practical validation of the reduced models, extrusion was carried out under optimal process condition resulting from RSM response optimizer (T =116ºC, FR= 22 Hz and SS= 28 Hz). Then the ER and BD as the dependent variables were measured and the adequacy of the response surface equation was checked by comparison of experimental and predicted values by one sample t-test. Results indicated that with 95% confident interval there was no significant difference ($p \geq 0.05$) between the predicted and experimental data for both responses at optimum point. Therefore, it can be concluded that the models theoretically and practically are valid in the working interval of independent variables.

Conclusion

Extrusion blends of 15% silver carp minced meat, 84.5% corn grit and 0.5% talc with desirable textural properties with high expansion ratio and bulk density can be obtained in a twin screw extruder. The optimum combination of process variables was: Temperature = 116ºC, FR =1107 g/min and SS= 148 rpm which resulted expansion ratio at 5.5 and bulk density at 42 kg/m^3.

Despite the argument that the peaks count is an indicator of crispiness, the results showed that peaks count versus treatments is not significant ($p>0.05$) and is insufficient as a texture indicator parameter. Since the extrusion process is very sensitive to any changes of feed composition, extrusion condition and extruder design, it should be noted that the results could be applied to the range of the experiments.

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