Optimum extrusion-cooking conditions for improving physical properties of fish-cereal based snacks by response surface methodology

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Abstract To establish the effect of barrel temperature, screw speed, total moisture and fish flour content on the expansion ratio and bulk density of the fish based extrudates, response surface methodology was adopted in this study. The experiments were optimized using five-levels, four factors central composite design. Analysis of Variance was carried to study the effects of main factors and interaction effects of various factors and regression analysis was carried out to explain the variability. The fitting was done to a second order model with the coded variables for each response. The response surface plots were developed as a function of two independent variables while keeping the other two independent variables at optimal values. Based on the ANOVA, the fitted model confirmed the model fitness for both the dependent variables. Organoleptically highest score was obtained with the combination of temperature—110⁰ C, screw speed—480 rpm, moisture—18 % and fish flour—20 %.

Keywords Twin-screw extrusion · Extrusion variables · Fish snacks · Response surface methodology · Central composite design · Quadratic polynomial model equation

Introduction

Extrusion cooking is a high temperature short residence time (HTST) process by which moistened starchy and proteinaceous

materials are plasticized and cooked in a tube by combination of high pressure, intense mechanical shear and heat to create fabricated, shaped products of varying texture. Extruded snack like products are mostly cereal based and developed mainly from corn, wheat and rice. However, rice has relatively low protein content (6–8 g/100 g db) and an amino acid profile that is high in glutamic and aspartic acid, while lysine is the limiting amino acid. Thus, proteinaceous additives are needed to ensure nutritional diets. Guha and Ali (2006) reported that the glutinous rice was suitable material to produce the expanded extrudate rice products such as ready-to-eat snacks, breakfast cereal with low bulk density, high expansion and low shear stress. Research on extrusion processing of fish muscle started in the 1980s (Choudhury and Gogoi 1995). Fish are not only excellent sources of high nutritional value protein but also excellent sources of lipid that contains *omega*-3 fatty acids, especially, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Kris-Etherton et al. 2000, 2002). The *omega*-3 fatty acids are essential for normal growth and development and may prevent or moderate coronary artery disease, hypertension, diabetes, arthritis, others inflammatory and autoimmune disorders, as well as cancer (Simopoulos 2000). A number of studies have reported successful incorporation of fish flesh or fish powder into starch-based materials by extrusion processes to produce nutritious extruded products that were acceptable by consumers (Gogoi et al. 1996; Suknark et al. 2001). Studies have been undertaken to develop dry expanded snack food products from fish mince and starchy ingredients using single- and twin-screw extruders (Choudhury et al. 1998). The incorporation of fish hydrolysates along with cereals has been attempted to improve the nutritional quality of extrudates (Choudhury et al. 1998). Rhee et al. (2004) successfully developed a snack food by extrusion of minced catfish with corn and defatted soya flour. The advantages of developing fish-based extruded products will help in supplying nutritious and balanced diets to

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undernourished people in developing countries (Venugopal and Shahidi 1995).

Product characteristics of extrudates made from rice and other starchy ingredients depend on physicochemical changes that occur during extrusion due to the effects of extrusion variables (Pansawat et al. 2008). Typically, the degree of expansion achieved during high temperature extrusion is proportional to starch concentration (Linko and Linko 1981). During the extrusion process, heat and shear facilitate hydration of starches and proteins, both classified as structure-forming materials (Guy 2001). Starch and protein are turned into a melt where droplets of water are entrapped. The physical quality of extrudate is strongly affected by ingredient selection (Banerjee and Chakraborty 1998; Rolf et al. 2000). The independent process variables such as screw speed, barrel temperature and feed moisture content are likely to have a direct bearing on the product quality.

Product density and expansion ratio are closely related. Bulk density has been reported to be linked with the expansion ratio in describing the degree of puffing in extrudates (Asare et al. 2004). Meng et al. (2010) used Response Surface Methodology to study the effects of feed moisture content (16–18 %), screw speed (250–320 rpm) and barrel temperature (150–170 °C) on extruder system parameters and physical properties (expansion, bulk density, hardness etc.) of a chickpea flour-based snack. They observed all three variables to affect product responses significantly. In their study, desirable products characteristics of high expansion ratio and low bulk density and hardness were obtained at low feed moisture, high screw speed and medium to high barrel temperature. Extrusion of corn grits with fish flesh/fish protein can be used to produce high-protein products that would be an option to provide nutrient snacks for consumers and to increase fish consumption (Shaviklo et al. 2011a). Shaviklo et al. (2011b) studied the acceptability of corn snack fortified with fish protein powder at different rates and reported that snacks fortified with 9 % fish protein powder showed significantly lower liking in respect of odour, texture, flavour and overall acceptability, whereas, snacks with 3 %, 5 % and 7 % fish powder showed similar sensory attributes with better acceptability.

Response surface methodology (RSM) is an important tool in process and product improvement. RSM is a collection of experimental design and optimization techniques that enables the experimenter to determine the relationship between the response and the independent variables. RSM is typically used for mapping a response surface over a particular region of interest, optimizing the response, or for selecting operating conditions to achieve target specifications or customer requirements (Myers and Montgomery 2002).

Extrusion processes can be optimized by the use of RSM (Milan-Carrillo et al. 2002).

The objective of this research was to investigate the effect of extrusion conditions like barrel temperature, screw speed, total moisture content and fish flour on the physical properties (expansion ratio and bulk density) and sensory characteristics of snack-like extruded products from fish-rice-corn blends when die diameter, preconditioning and feeding rate were kept constant.

Materials and methods

Extrusion

Extrusion trials were performed with a laboratory-scale co-rotating twin-screw extruder (Model BTPL-1, Basic Technology Pvt. Ltd. Kolkata, India). The screws of the extruder were 29.7 mm in diameter and 350 mm in length. The pitch of the screw was 75 mm with a flight depth of 3.5 mm. The die diameter and feeding rate were kept constant for all the experiment as 3.0 mm and 10 kg/h respectively. The extrudates were at $50 \pm 5^{\circ}\text{C}$ for three hours in a hot air drier before analysis.

Raw materials

Indian major carp (*Labeo rohita*) was brought under ice from the local market. The fish were de-scaled, beheaded, eviscerated and washed with potable water. The dressed fish was cooked by boiling in water for 10–12 min under normal atmospheric pressure. The cooked fish was cooled, de-skinned and de-boned manually. The separated cooked meat was dried in an electrically heated cabinet drier at $43\text{--}45^{\circ}\text{C}$. The dried fish muscle was powdered in a domestic mixer. The fish flour was packed in polythene pack after sieving and stored in refrigerator till preparation of blend. Other ingredients such as rice flour and corn flour were procured from the market. Different composition for extrusion was prepared with predetermined level of fish flour alongwith other ingredients such as rice and corn flour at 1:1 ratio. Total moisture content was calculated considering the moisture level of the ingredients. The ingredients were equilibrated to room temperature and weighed according to the formulation before mixing. All the ingredients except fish flour were mixed in mixer with required quantity of water (predetermined) and salt (2 %), packed in polythene bag and kept at room temperature ($27\text{--}31^{\circ}\text{C}$) for three hours. The fish flour was mixed thoroughly and kept further at room temperature for one hour. This preconditioning procedure

was employed to ensure uniform mixing and hydration and to minimize variability in the state of the feed material. The mixtures were sieved using 0.5 mm mesh screen before extrusion.

Determination of product responses

Expansion ratio (ER)

For determination of expansion ratio, the cross sectional diameter of the extrudates was measured with a Vernier caliper. The expansion ratio was calculated as the cross-sectional diameter of the extrudate divided by the diameter of the die opening (Ding et al. 2005). The ER values were obtained from 15 random samples with 3 locations in each for each extrusion condition.

Bulk density (BD)

Bulk density (g/cm^3) of extrudates was calculated by measuring the actual dimensions of the extrudates (Thymi et al. 2005). The diameter and length of the extrudates were measured using Vernier caliper. The weight per unit length of extrudate was determined by weighing measured lengths. The bulk density was then calculated using the following formula, assuming a cylindrical shape of extrudate.

Bulk density (g/cm^3) = M/V , where M is mass (g) and V is the volume $1/4 \times \pi \times (\text{diameter})^2 \times \text{length}$ in cm^3 . Five pieces of extrudate were randomly selected and average taken.

Compositional analysis

Moisture, ash, protein and fat analysis of raw materials and extrudates was carried out using standard procedures of AOAC (2000). Carbohydrates were calculated by difference. All the experiments were replicated, so that the data in the paper are expressed as the mean ($\pm$ SD) of triplicate analysis.

Optimization of experimental design

The optimum conditions for extrusion of fish based snack products were determined by response surface methodology (RSM). Based on the results of preliminary studies, the experiments were optimized using five-levels, four factors central composite design (CCD). The range and center point values of the four independent variables are shown in Table 1. The CCD in the experimental design consisted of 29 treatments with five replicates of the central point. The physical quality of

extrudate is strongly affected by several process variables besides ingredient selection. Out of many processing factors, barrel temperature, screw speed, total moisture content and fish flour content were chosen as the independent variables. Quality extruded snacks have two important attributes, expansion and density. Extrudates' expansion ratio and bulk density were selected as dependent variables.

Statistical analysis

The experimental data for expansion ratio and bulk density from different treatments was analyzed using multiple regression analysis using statistical software (The Unscrambler, Version 9.5, CAMO Process AS, Oslo, Norway). The fitting was done to a second order model for each response. This model can be expressed with the coded variables (A, B, C, D) with the following equation.

$$Y = \beta_0 + \beta_1A + \beta_2B + \beta_3C + \beta_4D + \beta_{11}A^2 + \beta_{22}B^2 + \beta_{33}C^2 + \beta_{44}D^2 + \beta_{12}AB + \beta_{13}AC + \beta_{14}AD + \beta_{23}BC + \beta_{24}BD + \beta_{34}CD + \varepsilon$$

where Y represented the estimated response, β_0 represented the equation parameters for the constant term, β_i represented the linear terms, β_{ii} represented the quadratic terms for a single variable, β_{ij} represented the interaction terms ($i=1-4$; and $j=1-4$), and ε represented the random error. The response surface plots were developed as a function of two independent variables while keeping the other two independent variables at optimal values.

Sensory analysis of extruded snacks

Sensory evaluations were conducted using a ten-member trained panel. Panelists were trained to evaluate the extrudates for general appearance, surface texture, flavour, crispiness and overall acceptability on 0–5 scale (Larmond 1977) and the results were averaged. The data obtained from biochemical and sensory analysis was further analyzed and interpreted by using suitable statistical method with SPSS windows 16.0 software and ANOVA.

Results and discussions

Experimental results

The composition of ingredients used in the experiments is presented in Table 2. Table 3 shows the central composite design and responses of dependent variables (expansion

Table 1 Composition of ingredients used in the experiments

Independent variables	Symbol	Levels				
		Code values				
		–2	–1	0	+1	+2
		Real values				
Barrel temperature (°C)	A	90	100	110	120	130
Screw speed (rpm)	B	320	360	400	440	480
Total moisture (%)	C	14	16	18	20	22
Fish flour (%)	D	10	15	20	25	30

ratio and bulk density of the extrudates) together with the predicted value according to the second order response surface models. Regression analysis was employed to fit a full response surface model for every response investigated including all linear (A, B, C, D), interaction (AB, AC, AD, BC, BD, CD), and quadratic terms (A^2 , B^2 , C^2 , D^2). The regression coefficients for the response surface model in terms of coded units are shown in Table 4.

The examination of the fitted model was always necessary to ensure that it provided an adequate approximation to the true system (Zhou and Regenstein 2004). To develop the fitted response surface model equations, all insignificant terms ($P>0.05$) were eliminated and the fitted models are shown in Table 5. Coefficient of determination (R^2) is defined to be the ratio of the explained variation to the total variation and is a measurement of the degree of fitness (Nath and Chattopadhyay 2007). A small value of R^2 indicates a poor relevance of the dependent variables in the model. The model fit well with the actual data when R^2 approaches unity (Sin et al. 2006).

The analysis of variance (ANOVA) was used to evaluate the significance of the quadratic polynomial model equation. Any terms in the models with a large F-value and a small P -value would indicate a more significant effect on the respective response variables (Yuan et al. 2008). Table 6 shows the ANOVA for the models that explains the response of the dependent variables. Both the models were highly significant ($P\leq 0.01$) at the 99 % probability level.

In the present work, the optimum extrusion conditions for maximum expansion and minimum bulk density

were established by fixing two variables at coded zero level (Table 1) while varying the other two variables. The estimated response function and the effects of the independent variables (A, B, C and D) on the dependent variables (expansion ratio and bulk density) are shown in Figs. 1 and 2.

Results from sensory evaluations are presented in Table 6. Since expansion and bulk density are considered as two important physical qualities of the extruded snacks, extrudates only from 14 out of 29 treatments were subjected to sensory evaluation. The overall acceptability varied between 3.3 to 4.4. General appearance, surface texture, flavour and crispness scored 3.3–4.0, 3.2–3.9, 3.1–4.0 and 3.2–4.0 respectively.

Product's expansion ratio

The amount of expansion in food depends on the difference between the vapor pressure of water and the atmospheric pressure, as well as the ability of the exiting product to sustain expansion. The expansion ratio (ER) of the products ranged from 1.97 to 3.48. From the regression analysis, it was revealed that the A and B coefficients were not significant ($P>0.05$) whereas the C and D were highly significant ($P\leq 0.01$). Further, the interaction effect of temperature x fish flour ($P\leq 0.05$), screw speed x fish flour ($P\leq 0.05$), total moisture x fish flour ($P\leq 0.01$) and square of temperature ($P\leq 0.05$) and screw speed ($P\leq 0.01$) were found significant.

A high co-efficient of determination (R^2) for expansion in this experiment was 0.885 which indicates that the model (Table 5) was suitable to represent the real relationships

Table 2 Experimental design range and values of the independent variables in the central composite design for production of fish based extruded snack

Ingredients	Composition of ingredients (g/100 g)				
	Moisture	Protein	Fat	Carbohydrate	Ash
Rice flour	8.7±0.58	6.8±0.72	0.33±0.11	83.1±1.37	0.71±0.18
Corn flour	8.2±0.46	5.9±0.57	0.56±0.09	84.7±2.76	0.37±0.08
Fish flour	7.1±0.28	82.5±0.39	5.5±0.28	0.4±0.07	3.2±0.43

Table 3 Central composite design for optimizing the extrusion condition for expansion ratio and bulk density of the extrudates in coded units together with experimental data and their predicted value according to the 2nd order response surface models

Treatment	Coded level of variables				Responses			
					Expansion Ratio (Y_1)		Bulk Density (Y_2)	
	A	B	C	D	Experimental	Predicted	Experimental	Predicted
1	−2	0	0	0	3.18	2.81	0.15	0.19
2	+2	0	0	0	2.86	2.81	0.19	0.19
3	0	−2	0	0	3.35	3.14	0.16	0.19
4	0	+2	0	0	3.46	3.14	0.10	0.19
5	0	0	−2	0	3.42	2.65	0.10	0.15
6	0	0	+2	0	2.05	2.17	0.30	0.23
7	0	0	0	−2	2.50	2.48	0.13	0.19
8	0	0	0	+2	1.97	2.34	0.18	0.19
9	−1	−1	−1	−1	3.48	3.20	0.08	0.19
10	+1	−1	−1	−1	2.93	3.00	0.08	0.14
11	−1	+1	−1	−1	3.45	2.99	0.09	0.14
12	+1	+1	−1	−1	2.97	2.79	0.16	0.19
13	−1	−1	+1	−1	2.72	2.96	0.24	0.23
14	+1	−1	+1	−1	2.81	2.69	0.09	0.18
15	−1	+1	+1	−1	2.25	2.46	0.28	0.18
16	+1	+1	+1	−1	2.18	2.26	0.28	0.23
17	−1	−1	−1	+1	2.42	2.43	0.24	0.19
18	+1	−1	−1	+1	2.43	2.63	0.07	0.14
19	0	+1	−1	+1	2.42	2.64	0.25	0.17
20	+1	+1	−1	+1	2.56	2.84	0.21	0.19
21	−1	−2	+1	+1	2.07	2.91	0.30	0.26
22	+1	−2	+1	+1	2.36	3.12	0.10	0.16
23	−1	+1	+1	+1	2.38	2.68	0.27	0.18
24	+1	+1	+1	+1	2.81	2.46	0.20	0.23
25	0	0	0	0	2.39	2.41	0.13	0.19
26	0	0	0	0	2.48	2.41	0.13	0.19
27	0	0	0	0	2.46	2.41	0.24	0.19
28	0	0	0	0	2.27	2.41	0.26	0.19
29	0	0	0	0	2.46	2.41	0.19	0.19

among the selected process parameters. The experimental values agreed well with the predicted ones that are obtained from the model (Table 3). Any terms in the models with a large F-value and a small P -value would indicate a more significant effect on the respective response variables (Yuan et al. 2008). ANOVA for the model as fitted shows significance ($P < 0.01$) with a moderate lack of fit which indicated the optimum models for this experiment.

Figure 1a shows the effect of temperature and screw speed on expansion ratio and the maximum predicted expansion ratio can be found with the screw speed of 480 rpm and the temperature of 110° C. Regression analysis showed that ER was significantly ($P \leq 0.01$) affected by the quadratic effect of both temperature (A^2) and screw speed (B^2). Launay and

Lisch (1983) proposed that the longitudinal and sectional expansions are dependent on the melt viscosity and elasticity. The increased temperature would yield a lower melt viscosity and increased longitudinal expansion, while the melt viscosity would be lowered and cause a decrease in sectional expansion. Similar observations of the effect of temperature on product expansion were reported for corn starch, corn grits and rice flour (Chinnaswamy and Hanna 1988; Ali et al. 1996; Hagenimana et al. 2006). The expansion ratio decreases with the decrease of screw speed. This behaviour could be explained by the development of less shear force and less pressure within the barrel.

The maximum predicted expansion can be found with the total moisture of 14 % and fish flour of 20 % when the barrel

Table 4 Regression coefficients for the 2nd order response surface models in terms of expansion ratio and bulk density of the extrudates

Parameter	Term	Responses			
		Expansion Ratio (Y ₁)		Bulk Density (Y ₂)	
		Coefficient	P-value	Coefficient	P-value
β_0	Intercept	2.412	0.0000	0.188	0.0000
β_1	Barrel temp. (A)	−0.003250	0.4778	−0.002	0.0829
β_2	Screw speed (B)	.000002083	0.9853	0.0004375	0.1253
β_3	Total moisture (C)	−0.121	0.0001	0.02042	0.0016
β_4	Fish flour (D)	−0.03667	0.0011	0.003667	0.1095
β_{12}	Barrel temp. × screw speed (AB)	0.009643	0.8397	0.02571	0.0375
β_{13}	Barrel temp. × Total moisture (AC)	0.8679	0.0848	−0.015	0.2055
β_{14}	Barrel temp. × fish flour (AD)	0.101	0.0493	−0.02143	0.0773
β_{23}	Screw speed × Total moisture (BC)	−0.02571	0.5912	0.000	—
β_{24}	Screw speed × fish flour (BD)	0.106	0.0397	0.000	—
β_{34}	Total moisture × fish flour (CD)	0.142	0.0087	−0.02036	0.0919
β_{11}	Barrel temp. × barrel temp. (A ²)	0.100	0.0161	0.000	—
β_{22}	Screw speed × screw speed (B ²)	0.183	0.0002	−0.00937	0.2836
β_{33}	Total moisture × total moisture (C ²)	0.03939	0.3017	0.00527	0.5566
β_{44}	Fish flour × fish flour (D ²)	0.06775	0.0864	−0.004370	0.6251

temperature and screw speed are at zero level (Fig. 1b). An inverse relationship was found between the expansion ratio with both the total moisture content and fish flour. According to the regression analysis, both total moisture and fish flour had a significant negative linear effect ($P \leq 0.001$) on the ER whereas the interaction effect of total moisture x fish flour (CD) showed significant positive linear effect ($P < 0.01$). Since the expansion ratio and bulk density are inversely related, this is similar to the observation of Pansawat et al. (2008) who reported that the extrusion conditions that produced the lowest and the highest product density were very similar to those producing the lowest and highest product moisture since they are closely related.

Figure 1c and d shows the effect of temperature along with fish flour and total moisture on expansion ratio. All the three independent variables showed inverse relationship with the expansion ratio when two out of the three variables along with the screw speed are kept constant at zero level. The interaction effect of temperature x fish flour (AD) showed a significant positive linear effect ($P < 0.05$) on the expansion whereas the interaction effect of temperature x total moisture (AC) was not significant ($P > 0.05$). The maximum ER can be found with the combination of temperature

and fish flour as 90⁰ C and 20 % and temperature and total moisture as 110⁰ C and 14 %. Shannon and Robert (2010) studied the effect of protein and moisture content on the physico-chemical characteristics of pea flour extrudates. They reported that EI decreased and bulk density, particle density and hardness increased with increase in protein or moisture content. The protein decreases shear force within the barrel, thereby lowering the die pressure and create a lower pressure differential between the die and the atmosphere resulting reduced amount of superheated water flashed off, thus expansion is decreased (Shannon and Robert 2010).

The effect of screw speed alongwith fish flour and total moisture on expansion ratio is shown in Fig. 1e and f. Regression analysis showed that the interaction effect of screw speed x fish flour (BD) had a significant positive linear effect ($P < 0.05$) on the extrudates' expansion.

Product's bulk density

The bulk density, which considers expansion in all directions, is an index of the extent of puffing. Bulk density, expressed as g cm^{−3}, measures expansion too. The bulk

Table 5 Response surface model for expansion ratio and bulk density of fish based extrudates

Response	Quadratic polynomial model*	R ²	P-value
Expansion ratio	$Y_1 = 2.412 - 0.121 C - 0.03667 D + 0.101 AD + 0.106 BD + 0.142 CD + 0.1 A^2 + 0.183 B^2$	0.885	0.0002
Bulk density	$Y_2 = 0.188 + 0.02042 C + 0.02571 AB$	0.694	0.01

*Y₁ (expansion ratio), Y₂ (bulk density, g/cm³), A (barrel temperature, °C), B (screw speed, rpm), C (total moisture, %), D (fish flour, %)

Table 6 Sensory scores of selected extrudates produced at different process conditions

Treatment	General Appearance	Surface Texture	Flavour	Crispness	Overall Acceptability
1	3.8±0.63 ^{ab}	3.7±0.67 ^{ab}	3.7±0.67 ^{abcd}	3.5±0.53 ^{abc}	3.7±0.82 ^{abc}
2	3.8±0.63 ^{ab}	3.8±0.63 ^{ab}	3.4±0.52 ^{abcd}	3.8±0.63 ^{abc}	3.7±0.48 ^{abc}
3	4.0±0.47 ^b	3.7±0.48 ^{ab}	3.5±0.53 ^{abcd}	3.8±0.92 ^{abc}	3.9±0.74 ^{abcd}
4	3.9±0.74 ^{ab}	3.8±0.79 ^{ab}	3.8±0.42 ^{bcd}	4.0±0.67 ^c	4.4±0.70 ^d
5	3.7±0.67 ^{ab}	3.8±0.63 ^{ab}	3.5±0.71 ^{abcd}	3.6±0.52 ^{abc}	3.7±0.48 ^{abc}
7	3.8±0.92 ^{ab}	3.6±0.52 ^{ab}	4.0±0.82 ^d	3.5±0.85 ^{abc}	3.8±0.79 ^{abcd}
9	3.9±0.57 ^{ab}	3.8±0.42 ^{ab}	3.9±0.74 ^{cd}	3.9±0.74 ^{bc}	4.2±0.63 ^{bcd}
10	3.8±0.63 ^{ab}	3.9±0.57 ^b	3.6±0.70 ^{abcd}	3.9±0.74 ^{bc}	3.8±0.92 ^{abcd}
11	3.8±0.63 ^{ab}	3.9±0.57 ^b	3.9±0.74 ^{cd}	3.7±0.67 ^{abc}	4.3±0.48 ^{cd}
12	3.8±0.63 ^{ab}	3.6±0.52 ^{ab}	3.8±0.63 ^{bcd}	3.9±0.57 ^{bc}	3.6±0.52 ^{abc}
13	3.5±0.53 ^{ab}	3.5±0.53 ^{ab}	3.1±0.32 ^a	3.4±0.52 ^{abc}	3.4±0.52 ^a
14	3.7±0.67 ^{ab}	3.8±0.79 ^{ab}	3.3±0.48 ^{abc}	3.5±0.71 ^{abc}	3.6±0.84 ^{abc}
20	3.4±0.52 ^{ab}	3.8±0.63 ^{ab}	3.2±0.42 ^{ab}	3.3±0.48 ^{ab}	3.3±0.48 ^a
24	3.3±0.48 ^a	3.2±0.42 ^a	3.3±0.48 ^{abc}	3.2±0.42 ^a	3.5±0.71 ^{ab}

Mean values in the column for all the samples with different superscripts are significantly different ($P<0.05$). Values are mean $\pm$ S.D. ($n=10$)

density (BD) of the products ranged from 0.07 to 0.3. From the regression analysis, it was revealed that only coefficient C was found highly significant ($P\leq 0.01$). Further, the interaction effect of only temperature $\times$ screw speed (AB) was found significant ($P\leq 0.05$).

A reasonably good co-efficient of determination (R^2) for bulk density in this experiment was 0.694 which indicates that 69.4 % of the variability in bulk density could be explained by this model (Table 4) and suitable to represent the real relationships among the selected process parameters. The predicted values agreed well with the experimental ones that are obtained from the model (Table 3). Based on the ANOVA, the P -value of the model showed significance ($P=0.01$). Meanwhile the lack of fit value was 0.72 which was not significant. These two values confirmed that the model fitness was good.

The response surface plot for the effect of temperature and moisture on the bulk density is presented in Fig. 2a. Both temperature and moisture showed positive relationship with the bulk density and minimum bulk density can be found with the temperature of 110⁰ C and moisture of 14 %. Further, fish flour too showed positive relationship with the bulk density when three other independent variables were kept constant and the minimum BD can be found with the combination of temperature of 110⁰ C and fish flour of 10 % (Fig. 2b). Similar effect of total moisture and fish flour on the bulk density was found (Fig. 2c). Only screw speed showed inverse relationship with the bulk density when three other independent variables were kept constant (Fig. 2d).

Altan et al. (2008) investigated the physical characteristics of barley flour extrudates and reported that temperature had a dominant effect on the bulk density and in respect of screw speed they found a minor effect. The positive relationship between temperature and bulk density could

be explained by the decrease of expansion with increase of temperature. The reduction of expansion caused an increase in bulk density. A high barrel temperature reduce the melt viscosity to a larger extent and this could facilitate bubble growth; however, the bubble walls become too thin to contain the vapor pressure, resulting in more bubble fracture, thus increasing the rate of collapse and resulting in an overall reduction in expansion (Yuliani et al. 2006). According to Meng et al. (2010) product temperature or melt temperature plays an important role in changing the rheological properties of the extruded melts, which in turn affect the degree of expansion. Bulk density also describes the degree of expansion undergone by the melt as it exits the extruder (Meng et al. 2010).

Product's acceptability

The minimum and maximum overall acceptability corresponded to the treatment no. 20 and 4 respectively (Table 6). The general appearance of the extrudates evaluated were found satisfactory and scored between moderate to good. Surface texture scored lowest when fish flour and moisture content was 25 % and 20 % respectively. The flavour scored highest when fish flour content was low. The crispness, a perception of the human being and is associated with the expansion of the product and also one of the most important quality attribute to the consumer, varied between 3.2–4.0. Higher crispness was found for the extrudates produced with moderate level of fish flour and feed moisture content. Probably, in case of higher fish flour, the cross linkage of protein and development of a protein network as a result of starch protein interaction have increased the maximum force of hardness with reduced crispness (Jeyakumari and Rathnakumar 2006). Decrease of hardness with decreasing

Fig. 1 Response surface plots showing the effects of (a) temperature and screw speed, (b) moisture and fish flour, (c) temperature and fish flour, (d) temperature and moisture, (e) screw speed and moisture and (f) screw speed and fish flour on expansion ratio

feed moisture content was reported by Meng et al. (2010) while studying the effects of extrusion conditions on the physical

properties of chickpea flour based snack. Generally, incorporation of fish proteins reduced extrudate expansion and increased

Fig. 2 Response surface plot showing the effects of (a) temperature and moisture, (b) temperature and fish flour, (c) moisture and fish flour and (d) screw speed and moisture on bulk density

hardness resulting reduced crispness (Choudhury and Gautam 2003).

The overall acceptability of the extruded snacks was concerned; highest (4.4) was scored by the snacks from the treatment 4, where the process variables were barrel temperature 110°C , screw speed 480 rpm , moisture 18% and fish flour 20% . Extrudates from two other treatments, namely, treatment-9 and treatment-11 scored 4.2 and 4.3 respectively. The overall acceptability of the extrudates from these three treatments were not significantly different ($P < 0.05$). The process variables for treatment-9 and treatment-11 were similar in respect of barrel temperature (100°C), moisture (16%) and fish flour (15%) except screw speed which were 360 and 440 rpm respectively. Sharma and Basu (2003) observed that product prepared using fish flour beyond 30% became hard and the expansion ratio decreased. Dileep et al. (2010), based on the sensory scores for rice flour-fish mince-based extruded products, reported optimum process conditions as barrel temperature of 90°C and fish mince concentration of

10% , when extruded at a constant screw speed of 350 rpm using a 4 mm die diameter.

Conclusion

Change of extrusion conditions especially, barrel temperature, screw speed, moisture and fish flour are observed to have significant effect on the physical properties of extruded fish based ready-to-eat snacks in the present experiment. The products with high expansion ratio and low bulk density are generally considered as good characteristics of extruded snacks. An inverse relationship was found between the expansion ratio with both the total moisture content and fish flour. A desirable expansion ratio and bulk density were obtained with fish flour $15\text{--}20\%$, total moisture content $14\text{--}18\%$, barrel temperature $100\text{--}110^{\circ}\text{C}$ and screw speed $360\text{--}480\text{ rpm}$. The model developed could be used for designing of extrusion conditions for getting extrudates with desirable physical characteristics.

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