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Effect of Extrusion Variables on the Physico-Chemical Properties of Soyabean-Fish Based Ready-to-Eat Snacks

[1]R.K. Majumdar, [2]G. Venkateshwarlu and [2]A.K. Roy
[1]College of Fisheries, Central Agricultural University, Lembucherra, Tripura-799210, India
[2]Central Institute of Fisheries Education, Mumbai-61, India

Abstract: A formulation containing fish, rice, corn and soyabean flour was extruded using a co-rotating twin-screw extruder. A (3×2×2) factorial design layout was used for this experiment to study the effects of extrusion conditions such as screw speed (350, 425, 500 rpm), barrel temperature (100, 120°C) and die diameter (3, 3.5 mm) as independent variables on the physical properties of extrudates, i.e., dependent variables expansion index and bulk density. Analysis of Variance (ANOVA) was carried to study the effects of main factors and interaction effects of various factors and multiple regression analysis was carried out to explain the variability. Neither main factors nor two factors interaction effect on expansion index were found to be statistically significant. Whereas in case of bulk density, all the main factors (temperature, screw speed and die diameter) and interaction effect (r x t) are found to be statistically significant. From the multiple regression analysis, R^2 value was found to be 0.872 and 0.996, respectively for expansion index and bulk density. It was revealed from this study that independent variables significantly affected the physical properties of extrudates. From the treatment means for different treatment conditions, it was found that at a temperature of 120°C with screw speed 350 rpm showed least bulk density of 0.29 g cm^{-3}.

Key words: Extrusion, expansion index, extrusion variables, fish snacks, ANOVA, multiple regression analysis

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. In the modern cereal based industry, extrusion technology plays a central role especially for the production of snack foods 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 product such as ready-to-eat snacks, breakfast cereal with low bulk density, high expansion and low shear stress.

Fish are not only excellent sources of high nutritional value protein but also excellent sources of lipid that contains Ω3 fatty acids, especially, Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA) (Kris-Etherton *et al.*, 2000; Kris-Etherton *et al.*, 2002). The Ω3 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).

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; Rolfe *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.

Corresponding Author: R. K. Majumdar, College of Fisheries, Central Agricultural University, Lembucherra, Tripura-799210, India

The objective of this research was to study effects of extrusion conditions like barrel temperature, screw speed and feed moisture content on the physical properties of extruded snacks from rice flour, corn flour, fish powder and soyabean flour.

MATERIALS AND METHODS

Preparation of fish flour: Silver carp (*Hypophthalmicthys molitrix*) 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 43-45°C. The dried fish muscle was powdered in a domestic mixer. The fish power was packed in polythene pack after sieving and stored in refrigerator till preparation of blend. Other ingredients such as rice, corn and soyabean flour were procured from the market.

Blend preparation and mixing: The ingredients used for ready-to-eat snack preparation were fish powder, rice flour, corn and soyabean flour. The formulation of blend was fish powder (18%), rice (45%), corn (30%) and soyabean flour (7%) with 20% water and 2% salt. The proximate composition of the ingredients are shown in Table 1.

The ingredients were equilibrated to room temperature and weighed according to the formulation before mixing. All the ingredients except fish powder were mixed in mixer with required quantity of water and salt (2%), packed in polythene bag and kept at room temperature for 3 h. The fish powder was mixed thoroughly and kept further for 1 h. The mixtures were sieved using 0.5 mm mesh screen before extrusion.

Experimental design: A 3×2×2 factorial design (Box and Behnken, 1960) was used to study the effects of screw speed (350, 425 and 500 rpm), barrel temperature (100 and 120°C) and die diameter (3 and 3.5 mm) on each of Expansion Ratio (ER) and Bulk Density (BD) of the extrudates.

Extrusion process: Extrusion trials were performed with a co-rotating twin-screw extruder (Model BTPL-1, Basic Technology Pvt. Ltd. Kolkata, India) with a length to diameter ratio of 10:3.

Determination of product responses

Expansion Index (EI): 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.

Table 1: Proximate composition (g/100 g) of the ingredients and blends

Ingredients	Moisture	Carbohydrate	Protein	Fat	Ash
Fish powder	8.60	-	78.54	6.40	5.80
Rice flour	8.30	79.50	8.70	1.20	2.30
Corn flour	8.45	77.39	8.95	2.59	2.62
Soyabean flour	8.76	33.26	36.21	17.91	3.86
Blend FRCS	20.00	61.32	23.26	3.72	3.13

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}) = $4/\pi d^{-2}$ l. About 5 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 (1990). Carbohydrates were calculated by difference. All the experiments were replicated so that the data in the study are expressed as the mean (±SD) of triplicate analysis.

Statistical analysis: A (3×2×2) factorial design layout was used for this experiment to determine the effects of barrel temperature (100 and 120°C), screw speed (350, 425 and 500 rpm) and die diameter (3.0 and 3.5 mm) on expansion index and bulk density of the extrudates separately. Analysis of Variance (ANOVA) was carried to study the effects of main factors and interaction effects of various factors and multiple regression analysis was carried out using the statistical software SPSS (Version 12.00, SPSS Inc. Thailand).

RESULTS

Effects of barrel temperature, screw speed and die diameter on the expansion index of the extrudates: The effects of various extrusion variables on the expansion index of the extrudates with respect to mean values are shown in Table 2. The expansion index of the products ranged from 2.11-2.46 with the highest EI obtained with process conditions of barrel temperature, screw speed and die diameter of 120°C, 350 rpm and 3.0 mm, respectively. Whereas, the lowest EI was found with process conditions of barrel temperature, screw speed and die

Table 2: Means of extrusion variables affecting expansion index based on (3×2×2) factorial experiment

		Temperature (t)			
		100°C (t_1)		120°C (t_2)	
	Screw speed	3.0 (d_1)	3.5 (d_2)	3.0 (d_1)	3.5 (d_2)
Sample	(r)	Die diameter (d)			
FRCS	350 (r_1)	2.39	2.11	2.46	2.21
	425 (r_2)	2.24	2.32	2.37	2.14
	500 (r_3)	2.38	2.34	2.40	2.34

Table 3: Means of extrusion variables affecting bulk density based on (3×2×2) factorial experiment

		Temperature (t)			
		100°C (t_1)		120°C (t_2)	
	Screw speed	3.0 (d_1)	3.5 (d_2)	3.0 (d_1)	3.5 (d_2)
Sample	(r)	Die diameter (d)			
FRCS	350 (r_1)	0.28	0.44	0.21	0.38
	425 (r_2)	0.34	0.41	0.32	0.42
	500 (r_3)	0.27	0.33	0.26	0.31

Table 4: ANOVA of a (3×2×2) factorial experiment showing the mean and interaction effect of extrusion variables as screw speed (RPM), Temperature (TEMP) and Die Diameter (DD) on the expansion index

Source of variation	Sum of squares	Degree of freedom	Mean square	F-ratio	p-value
Expansion ratio					
RPM (r)	2.052e-02	2	1.026e-02	1.218	0.4509^{ns}
TEMP (t)	5.070e-02	1	5.070e-02	6.018	0.1337^{ns}
DD (d)	1.633e-03	1	1.633e-03	0.194	0.7027^{ns}
r x t	2.765e-02	2	1.383e-02	1.641	0.3786^{ns}
r x d	6.317e-03	2	3.158e-03	0.375	0.7273^{ns}
t x d	7.500e-03	1	7.500e-03	0.890	0.4450^{ns}

^{ns}: non-significant

diameter of 100°C, 350 rpm. and 3.5 mm, respectively. Analysis of Variance (ANOVA) of a (3×2×2) factorial experiment on the effect of screw speed (RPM), Temperature (TEMP) and Die Diameter (DD) on the expansion index of extrudates is shown in Table 3.

Effects of barrel temperature, screw speed and die diameter on the bulk density of the extrudates: The Table 4 shows the effects of various extrusion variables on the bulk density of the extrudates with respect to means. The bulk density of the product ranged from 0.21-0.44 g cm^{-3}.

The lowest BD obtained with process conditions of barrel temperature, screw speed and die diameter of 120°C, 350 rpm and 3.0 mm, respectively. Whereas, the highest BD was found with process conditions of barrel temperature, screw speed and die diameter of 100°C, 350 rpm and 3.5 mm, respectively.

ANOVA of a (3×2×2) factorial experiment on the main effect and interaction effect of screw speed (RPM), Temperature (TEMP) and Die Diameter (DD) on the bulk density of extrudates is shown in Table 5.

Table 5: ANOVA of a (3×2×2) factorial experiment showing the mean and interaction effect of screw speed (RPM), Temperature (TEMP) and Die Diameter (DD) on the bulk density

Source of variation	Sum of squares	Degree of freedom	Mean square	F-ratio	p-value
Bulk density					
RPM (r)	1.287e-02	2	6.433e-03	64.332	0.0153^{*}
TEMP (t)	3.101e-02	1	3.101e-02	310.078	0.0032^{**}
DD (d)	2.408e-03	1	2.408e-03	24.083	0.0391^{*}
r x t	6.467e-03	2	3.233e-03	32.333	0.0300^{*}
r x d	2.067e-03	2	1.033e-03	10.333	0.0882^{ns}
t x d	7.500e-05	1	7.500e-05	0.750	0.4778^{n}

^{s}**Significant at p<0.01; *Significant at p<0.05

DISCUSSION

From the Table 4, it is evident that in case of expansion index, neither main factors nor 2 factors interaction effect (r x t, r x d and t x d) on expansion index are found to be statistically significant. 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 (RSM) 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. It was found that in case of bulk density, all the main factors (temperature, screw speed and die diameter) and interaction effect (r x t) are found to be statistically significant. This is indicative of the fact that all the independent factors are having effect on extrudates.

Again interaction effect of screw speed and temperature was found to be significant at p<0.05 justifying the effect of these variables on bulk density. Since in case of bulk density, the interaction effect of temperature and screw speed is found significant, treatment means for different treatment combinations of temperature (100 and 120°C) and screw speed (350, 425 and 500 rpm) is shown in Table 6.

From Table 6, it is clear that screw speed of 350 rpm at a temperature of 120°C showed least bulk density of 0.29 g cm^{-3} followed by 0.31, 0.32 and 0.34, 0.35 and 0.36 g cm^{-3}. Both the screw speed and temperature has got much effect on the puffing of the expansion ratio of the product. At similar condition of screw speed and

Table 6: Treatment means for different treatment conditions for bulk density

Treatment conditions (Screw speed (rpm) x Temperature (°C))	Treatment means
350 rpm x 100°C	0.34
350 rpm x 120°C	0.29
425 rpm x 100°C	0.36
425 rpm x 120°C	0.35
500 rpm x 100°C	0.31
500 rpm x 120°C	0.32

temperature, less expansion and corresponding more bulk density has been observed with higher die diameter. The reason may be attributed to the fact that higher die diameter reduces die pressure and residence time resulting reduced shear stress and less expansion. It is reported that the lower pressure differential between the die and the atmosphere leads to lower expansion (Goga *et al*., 1997). In this experimental study, the highest expansion index and lowest bulk density was obtained at temperature of 120°C and screw speed of 350 rpm. Guha *et al*. (1997) reported that the combination of high temperature and high screw speed yielded a product with low density. Generally, high temperature provides more thermal input, leading to complete gelatinization even at high screw speeds that decrease residence time. In high shear environment, the structural breakdown of protein and starch also leads to low density of products. 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 (Meng *et al*., 2010). Bulk density also describes the degree of expansion undergone by the melt as it exits the extruder (Meng *et al*., 2010). To explore the possibility of functional relationship among variables, a multiple regression analysis for product expansion was carried out with EI as dependent variable and barrel temperature, screw speed and die diameter as independent variables.

From the analysis, R^2 (Coefficient of Determination) value was found to be 0.872. This is indicative of the fact that the 3 independent variables (temperature, screw speed and die diameter) together could explain 87.2% of total variability on the expansion index (dependent variable). The multiple regression analysis for product bulk density showed high R^2 of 0.996, respectively which indicates the fact that the fitted equations are capable of explaining 99.6% of the variability of bulk density with barrel temperature, screw speed and die diameter. Pansawat *et al*. (2008) studied the effects of extrusion conditions on the physical properties of fish and rice based snacks where in the regression models for product density and expansion ratio showed R^2 of 0.94 and 0.76, respectively. An inverse relationship between expansion ratio and density of extrudates has been observed in this study which has been reported earlier (Singh *et al*., 1996). Meng *et al*. (2010) used Response Surface Methodology (RSM) 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 this 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.

CONCLUSION

Change of extrusion conditions especially, screw speed, barrel temperature and die diameter are observed to have significantly affected the physical properties of extruded fish based ready-to-eat snacks in the present experiment. The products with highest expansion index and low product density which generally are good characteristics of extruded snacks were produced at highest temperature and moderate to high screw speed with lowest die diameter. From this study, one can safely conclude that die diameter at 3.0 mm at 120°C with screw speed 350 rpm is the best combination compared to other experimental conditions. Further studies in this area with different combinations of barrel temperature, screw speed and die diameter may be conducted to pinpoint best combination.

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