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Effect of Extrusion Process Variables on In-vitro Protein Digestibility of Fish–Wheat Flour Blends

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ABSTRACT

The effects of extrusion process variables (feed ratio, length to diameter ratio of the extruder, temperature of extrusion and screw speed) on in-vitro protein digestibility (PD) of extrudates, comprising minced fish and wheat flour, were studied. Extrusion was carried out with a developed variable length single screw cooking extruder and moisture content of the extruder feed was 35%. The extrudates showed slight increases in PD values due to extrusion. Statistical analysis using analysis of variance (ANOVA) technique showed that, among the process variables, only the effect of feed ratio and temperature of extrusion were significant ($P \leq 0{\cdot}05$). A first order regression equation relating PD and the process variables was also developed.

INTRODUCTION

Extrusion alters the nature of many food constituents, such as starches and proteins, by changing their physical, chemical and nutritional properties. Extrusion processing normally affects the nutritional character of the extruded product by changing the bio-availability of protein, carbohydrate, lipids, and vitamins. Denaturation of protein, alteration of carbohydrate structure, oxidation of fat, and reactions between the different food components (such as the Maillard reaction) alter the nutritional quality of the extrudate. Since extrusion cooking is a typical High-Temperature,

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Short-Time (HTST) process, it favours nutrient retention, as well as inactivation of both the growth inhibitors and contaminating micro-organisms (Harper, 1981).

Several reviews (Jansen *et al.*, 1978; Harper, 1981; Linko *et al.*, 1982; Bjorck & Asp, 1983) have been published on the nutritional status of extruded products. Bjorck & Asp (1983) and Pham *et al.* (1984) measured available lysine of the extrudate as an index for protein quality. Besides this method, estimation of in-vitro protein digestibility (*PD*) using enzymes is another acceptable and simple method for evaluating protein quality and availability (Hsu *et al.*, 1977) of many foods, including products of extrusion cooking. Peri *et al.* (1983), Bhattacharya & Hanna (1985) and Fapojuwo *et al.* (1987) measured *PD* of extrudates and found an increase in the *PD* values of extrudates over the non-extruded samples. But all of these researches were conducted on feeds derived from plant sources only. No literature is available about the *PD* values of extruded products of animal origin, such as fabricated seafood products (Babbit, 1986). Moreover, the details of the effect of the extrusion process variables on *PD* are not well documented.

The present study was undertaken to evaluate the effect of the extrusion process variables (feed composition, length to diameter (*L*/*D*) ratio of the extruder, temperature of extrusion, and screw speed) on the in-vitro protein digestibility of an extruder feed composed of minced fish and wheat flour.

MATERIALS AND METHODS

Extruder feed

The extruder feed was composed of partially dried fish (after dressing) and wheat flour such that the ratio of the solids of fish to wheat flour was either 1:1 or 3:1, while the moisture content of the feed was kept constant at 35%. The fish used for this purpose was the low-cost 'by-catch' lean fish, Bombay Duck (*Harpodon nehereus*). The proximate composition of fish muscle (prior to drying) and wheat flour as obtained by AOAC (1980) are shown in Table 1. The reported values are the mean ± standard deviation of five observations.

Extruder

A variable length, single-screw, cooker–extruder having a barrel bore of 25 mm was developed (Bhattacharya, 1987) for the present investigation. This stainless steel extruder could be adjusted at three different lengths (8, 12 and 16 times the internal diameter of the barrel) by use of different screws and interchangeable barrel sections. The extruder was provided with electrical heaters fitted externally to the barrel, and was equipped with

TABLE 1
Proximate Composition of Fish Muscle and Wheat Flour. The Values are Expressed as Per Cent Basis

	Fish muscle	*Wheat flour*
Moisture	89·72 ± 1·96	14·04 ± 0·72
Protein[a]	6·78 ± 0·58	10·27 ± 0·87
Fat	0·86 ± 0·11	0·84 ± 0·20
Ash	2·07 ± 0·33	0·72 ± 0·09
Carbohydrate (by difference)	0·57	74·13

[a] N × 6·25 for fish muscle and N × 5·7 for wheat flour.

automatic temperature control devices. The extruder screw had a channel depth ratio (ratio of the depths of screw channel at feed and metering section) or compression ratio of 3 and a helix angle of 22°. The extruder was run by a 3 hp variable speed DC motor; a thyristor type speed controller was attached to obtain the desired speed at the motor shaft. The extruder die was 21·5 mm long, and had an internal diameter of 8 mm.

Protein digestibility

The in-vitro protein digestibility (*PD*) was measured for extruded and non-extruded samples comprising partially dried minced fish and wheat flour, according to the method suggested by Hsu *et al.* (1977). The *PD* values reported here are the mean ± standard deviation of three replicates.

Experimental design

The orthogonal factorial 2^n (n = number of independent variables) experimental design (Myers, 1971) was used to judge the effect of the extrusion process variables (x_1, x_2, x_3 and x_4) in coded levels (x) of -1 and $+1$ over the response function, *PD*. The feed ratio (x_1), i.e. ratio of the solids of fish and wheat flour, the length to diameter ratio (L/D ratio) of the extruded screw (x_2), temperature of extrusion (x_3) and screw speed (x_4) were designated as independent variables of the process, which satisfactorily fit a polynomial of low order of the type:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \quad (1)$$

where b_0, b_1, b_2, b_3 and b_4 are constants.

The actual levels of the corresponding process variables were feed ratio $(X_1) = 1$ and 3, L/D ratio $(X_2) = 8$ and 16, temperature of extrusion $(X_3) = 100$ and 140°C, screw speed $(X_4) = 30$ and 90 rev/min. Table 2 shows the 2^n factorial experimental design of the independent extrusion process variables.

TABLE 2
2^n Factorial Experimental. Design of Variables (in coded levels)

Experiment no.	*Extrusion process variables*			
	x_1	x_2	x_3	x_4
1	−1	−1	−1	−1
2	1	−1	−1	−1
3	−1	1	−1	−1
4	−1	−1	1	−1
5	−1	−1	−1	1
6	1	1	−1	−1
7	1	−1	1	−1
8	1	−1	−1	1
9	−1	1	1	−1
10	−1	1	−1	1
11	−1	−1	1	1
12	1	1	1	−1
13	1	1	−1	1
14	1	−1	1	1
15	−1	1	1	1
16	1	1	1	1

Statistical analysis

The data were statistically analyzed to estimate the significance of individual process variables over the response function, using the Analysis of Variance (ANOVA) technique (Myers, 1971). The significance of the process variables was judged by the *F*-test, at probability levels of 0·01 and 0·05. All terms not significant at the 0·05 probability level were combined with the residual. Lack-of-fit was calculated as the difference between the residual sum of squares and the pure sum of squares. The correlation coefficient (r) was between experimental and predicted (by regression equation) values of the response function.

RESULTS AND DISCUSSION

Table 3 shows the in-vitro protein digestibility (*PD*) value of the extrudates. The *PD* values are between 80·1 and 86·2, and there is an increase of up to 5·84% in *PD* values over the non-extruded samples. The possible explanation may be due to the inactivation of proteolytic inhibitors present in wheat flour (Wogan, 1976) due to extrusion cooking. Extrusion of corn

TABLE 3
Effect of Process Variables (feed ratio, *L/D* ratio, extrusion temperature and screw speed) on in-vitro Protein Digestibility (PD)

Experiment no.	*Protein digestibility (PD)*	*Increase in PD due to extrusion (%)*
1	80·24 ± 0·21	3·50
2	85·61 ± 0·73	3·27
3	81·33 ± 0·69	4·90
4	82·05 ± 0·68	5·84
5	80·12 ± 0·54	3·35
6	84·47 ± 0·48	0·72
7	85·13 ± 1·03	2·29
8	85·49 ± 0·28	3·13
9	82·36 ± 0·28	3·50
10	80·91 ± 0·45	4·36
11	80·97 ± 0·46	4·44
12	86·16 ± 0·28	3·93
13	84·35 ± 0·52	1·75
14	85·25 ± 0·28	2·84
15	81·93 ± 0·96	5·68
16	85·73 ± 0·65	3·42

gluten meal (Bhattacharya & Hanna, 1985) and sorghum powder (Fapojuwo *et al.*, 1987) also resulted in an increase in their *PD* values.

Table 4 is the Analysis of Variance (ANOVA) Table for the extrusion process variables at the coded (x_1, x_2, x_3 and x_4) levels of -1 and $+1$. The non-significant lack-of-fit, and high value of correlation coefficient (r) prove the adequacy of the regression model to predict the *PD* of the extrudate. On comparing the coefficients of the regression equation, as shown in Table 4, it may be observed that all the process variables, except the screw speed, have positive relationships with PD values. Among the process variables, the feed ratio (x_1) has the maximum effect on *PD*, followed by temperature of extrusion (x_3). The effect of other process variables such as *L/D* ratio (x_2) and screw speed (x_4) on *PD* values appears to be insignificant ($P = 0{\cdot}05$).

The first order regression equation between *PD* and process variables in coded level is:

$$PD = 83{\cdot}256 + 2{\cdot}017\ x_1 + 0{\cdot}443\ x_3 \qquad (2)$$

and in the actual level of variables:

$$PD = 76{\cdot}576 + 2{\cdot}017\ X_1 + 0{\cdot}0221\ X_3 \qquad (3)$$

Increase in feed ratio from 1 to 3 increases the *PD* of the non-extruded

TABLE 4
Analysis of Variance (in coded level of variables) for the Effect of Extrusion Process Variables (feed ratio, L/D ratio, temperature of extrusion, and screw speed) on Protein Digestibility (PD) of Extruded Product

Source of variation	*Coefficient of regression Eqn (1)*	*Sum of squares*	*Degrees of freedom*	*Mean sum of squares*	*F-value*
Regression		110 974·67	5	22 194·93	
Constant, x_0	83·256	110 905·65	1	110 905·65	336 539·31**
Feed ratio, x_1	2·017	65·13	1	65·13	197·65**
L/D ratio, x_2	0·147	0·13	1	0·35	1·05^{NS}
Temperature, x_3	0·443	3·12	1	3·12	9·46*
Screw speed, x_4	−0·162	0·42	1	0·42	1·28^{NS}
Lack-of-fit		0·77	2	0·38	1·17^{NS}
Residual		4·39	13	0·34	1·03^{NS}
Error		3·63	11	0·33	
$r = 0·97$					

* Significant at $P \leq 0·05$.
** Significant at $P \leq 0·01$.
NS Non-significant at $P = 0·05$.

samples from 77·5 to 82·9 due to the presence of a higher amount of better quality protein from fish. Increase in temperature of extrusion enhances the degree of inactivation of protease inhibitors in wheat flour, and consequently, *PD* values are increased. Extrusion, even at 140°C, does not have any adverse effect on *PD*, which may be attributed to the lesser residence time of food dough within the extruder, and a weaker non-enzymatic browning (Maillard) reaction due to extrusion with feeds of higher moisture (35%) content. On the other hand, L/D ratio and screw speed, although they are related to the residence time of food inside the extruder, do not significantly ($P = 0·05$) alter the *PD* values. The effect of screw speed on nutritional status of extrudate is difficult to predict as two opposing effects occur simultaneously. Increase in screw speed reduces the residence time of food inside the extruder and thus the heat injury caused to the food constituents is less. On the other hand, shear damage is enhanced with increase in the rotational speed of the screw.

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