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Optimization of Rice Flour (*Oryza sativa*) and Chapra (*Fenneropenaeus indicus*) Extrusion by Response Surface Methodology

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Chapra (*Fenneropenaeus indicus)* powder and rice flour mixture was used as base material for extrusion process. The process was optimized using response surface methodology. Response (dependent) variables were: expansion ratio, density, shearing strength and sensory texture acceptability. Independent variables were processing temperature and feed moisture. All other process variables *viz*., screw speed, feed speed and dye diameter were kept constant at 475 rpm, 28 g min^{-1} and 3 mm respectively. The expanded products obtained at 150°C with feed material containing 15% moisture had the best properties. The study showed that expanded products produced using rice and chapra flour under conditions that induced the maximum expansion, had the best texture and the highest acceptable snack product.

Keywords : ***Fenneropenaeus indicus*, protein, extrusion, expansion ratio, response surface, glass transition**

Chapra (*Fenneropenaeus indicus*), forms an important food item in the coastal areas of West Bengal, India. Chapra contains 20% protein, 1% fat, 76% moisture, 1.5% ash and a good amount of minerals. (USDA, 2002). A large amount of chapra is wasted every year due to lack of proper preservation measures. Extrusion process has been proposed as an effective solution to improve digestibility and keeping quality by removing antinutrients. (Hady & Habiba, 2003). Extrudates exhibit better nutritional quality compared to other traditionally cooked products (Bressani *et al*., 1992, Singh *et al.,* 2007). Response Surface Methodology (RSM) has been successfully applied for optimizing the conditions in extrusion cooking process (Batistuti *et al.,* 1991; Vargas-Lopez *et al.,* 1990, Banerjee *et al*., 1997, Wang *et al*., 2008). Chapra and rice flour mixture were extruded to improve the nutritional quality of extruded product and to study the related functionality of complex carbohydrate and shrimp-protein mixture.

In the present study, the process condition to make extruded products out of chapra and rice flour was optimized using RSM. A high expansion index and firm texture are desirable qualities for ready to eat snacks. The objective of the present study is to find out the relationship between extrusion cooking parameter and product quality, and thereby to find out the optimum conditions for an extruder to produce rice and shrimp protein based products.

Materials and Methods

Rice (*Oryza sativa* L*)* and table salt were procured from local market. Chapra *(Fenneropenaeus indicus)* collected from coastal area was washed thoroughly in fresh water. The water was drained and dried in an oven

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(800 W grill oven Sanyo, JP) at 60°C for 2 h. Rice was also washed and dried under similar conditions. The dried shrimp and rice were finely ground separately, into powder form (40 mesh) with a blender (Mixer Grinder, Bajaj, GM-550). Rice and chapra powder was mixed in 5:1 ratio. The moisture was adjusted to 11, 13, 15 and 17% by adding the required amount of water to the flour mixture and conditioned at room temperature for 48 h.The flour was sealed in polyethylene bags and stored at 4°C. Moisture content of the control and extruded products were measured using air oven (Model No-06104, SC Dutta & Co, Kolkata) according to AOAC (2002). The proximate composition of extrudate and unextrudate were analysed using standard method (AOAC, 2002).

A co-rotating fully intermeshing twin screw extruder was used (screw profile 12:1, barrel length 350 mm, barrel bore diameter 38 mm, screw diameter 37.8 mm, conveying angle 30°, intermeshing screws 24 mm apart) for extrusion of the feed mixture using a 3 mm diameter dye. The screw speed of the extruder was set at 475 rpm while the feed rate was maintained constant at 28 g min^{-1}.

The extruder functioned properly with the feed mixture at 110°C and at 11% feed moisture but totally stopped after 170°C and at 19% feed moisture. The temperature of the extruder at the time of product discharge was noted at 110, 130, 150 and 170°C respectively. The product temperature was maintained at 50°C by circulating cooling water. The process was optimized using RSM for maximum values of expansion ratio, sensory texture acceptability, minimum value of shear strength and density for extrudates. Initial experiments at feed moisture of 10 to 20% and end zone temperature at the time of product discharge noted as 130-170°C, showed that a good expansion could be obtained at around 150°C and 15% moisture.

Preliminary experiment shows that minimum feed moisture and process temperature for proper operation was 11% and 110°C respectively. The experimental design adopted was Central Composite Design (-1, -.33, +.33, +1) (Cochran & Cox, 1957; Myers, 1971; Box *et al.*, 1978; Akhnazarova & Kafarov 1982). Table 2 shows the experimental matrix using 14 experimental runs.

A second order polynomial was fitted through ref. analysis. STATISTICA for Windows Release 9 Copyright, Stat Soft Inc. 2009 was used for statistical calculations and graphical analysis. The polynomial stated was:

$$Z=b_o+ b_1X_1+ b_2X_2+ b_{11}X_1^2+ b_{22}X_2^2+ b_{12}X_1 X_2+e$$

where Z=dependent variable (Expansion ratio, shear strength, ratio of shear strength to extrudate diameter, density, or sensory acceptance of the texture): X_1= Feed moisture; X_2 =Temperature of the central zone of the barrel; e= Experimental error with normal distribution.

Expansion ratio was determined as the ratio of extruded product diameter to the diameter of the dye. Values reported were averages of 30 measurements in each temperature and moisture combination. The density (ρ, $mg.mm^{-3}$) was calculated as $\rho=4M/\Pi d^2L$ where M= mass average of extrudate in mg (mean of 30 weighing in an analytical balance); D = diameter of the extrudate (mean of 30 measurements with vernier Caliper) in mm and L= average length of extrudate in mm (mean of 30 measurements with a vernier caliper). A universal Texture Analyzer (model-4301 Instron London, UK) was used to test in compression mode to record the required force to break the extruded products. The extruded samples (5 cm long) was placed on the platform transversally over a metal sheet support (1 cm thick) and operated in a compression mode with a sharp testing blade (3 mm thick, 6.93 mm wide). The texturometer head moved the probe down at a rate of 15 mm min^{-1} until it broke the extrudates. Values reported were averages of 30 measurements in each temperature and moisture combination as reported in optimization section using load of 50 N.

To evaluate the sensory acceptance of the extruded product, a 100 mm long sample was used (Land & shepherd 1988). The texture acceptability score was defined as the distance from origin of the mark assigned on the scale by panelists relative to the central point on the scale which was assigned as the acceptability score of reference product (a commercial brand of unflavoured extruded corn). The panelist was instructed to consider only the texture and ignore the colour and flavour. Every panelist assessed the texture with reference to relative texture acceptability of a standard sample coded with the letter p, and asked to indicate the score on the ballot.

The analysis of variance (ANOVA) was carried out for the experimental data using STATISTICA for Windows Release 4.5 Copyright, Stat Soft Inc. 1993. The statistical significance of process variables used in the regression equation was also examined.

Results and Discussion

The proximate composition of rice, chapra and extruded flour is depicted in Table 1. The result shows that chapra flour could be used for preparation of protein enriched, nutritionally superior extruded foods.

Table 1. Proximate composition of rice and chapra extrudate

Material	Moisture (%)	Protein (%)	Lipids (%)
Rice flour	13	6.9	0.4
Chapra flour	76	20.1	1
Extruded flour	6.87	23.06	0.9

The physical properties of the rice and chapra extrudate obtained from 16 measurements and the effect of independent and response variables of extrudates are presented in Table 2. The products with the highest expansion ratio obtained at 150°C and 15% moisture had the most appropriate texture for consumption. Thus, the greater the expansion, the lower the shearing force. At the same time, lesser the shear stress greater the textural sensory acceptability observed for the extrudate, obtained at 150°C and 15% moisture. ANOVA of expansion ratio in Table 3 shows significant effect of process temperature and moisture on response variables.

The most expanded extrudates were obtained at 150°C and 15% moisture. The data for significant linear, quadratic and interaction terms for multiple regression analysis of variance for the full regression is represented in Table 2. The variance analysis for these data obtained a determination coefficient (r^2) greater than 0.91 (Table 3). An agreement of 90% is expected for second order polynomial model for food extrusion. (Aguilera & Kosikowsiki, 1976). The result obtained for expansion ratio indicated that the experimental error was kept to a minimum.

The results showed that linear and second order effects of temperature and moisture were significant ($p<0.05$) (Table 3). The resultant polynomial for this variable was:

$$Y_1 = 0.159X_1+0.066\ X_2+0.004\ X_1\ X_2 -0.065X_2^2 - 0.031X_1^2 -2.636$$

The response surface for this variable is presented in Fig. 1. Result shows expansion ratio of final product increasing with increasing moisture and temperature up to a limiting value and then decreasing. The predictive equation obtained for these analyses, allowed a range of products with variable characteristics attending the various consumption standard to be obtained. Fig. 1 shows the extrudate for all temperature and moisture condition assayed. More uniform texture and the most expanded products were obtained at 150°C and 15% moisture.

Table 2. Specification matrix of the second order design and result of the effect of independent and response variables of rice and chapra extrusion

Assay	Independent Variable				Response Variable				
n[a]	X_1* $(x_1$-M)/S	X_2* $(x_2$-M)/S	x_1 (T°C)	x_2 (% moisture db)	Expansion Ratio Y_1^b	Shear force (N) Y_2^c	Shear Stress (N/m^2) Y_3^d	Density (mg.mm^{-3}) Y_4^e	Acceptance of Texture (mm in a 100 mm scale) Y_5^f
1	-0.33	-1	130	11	2.17 ± 0.87	24.43 ±0.168	3.67´10^5 ±0.68´10^5	0.57 ±0.007	46.74±2.536
2	0.33	-0.33	150	13	2.50 ± 0.7	15.76 ±0.144	3.19´10^5 ±0.48´10^5	0.39 ±0.017	56.78±8.670
3	0.33	-1	150	11	2.18 ± 0.11	19.12 ±0.240	3.26´10^5 ±0.27´10^5	0.44 ±0.003	45.87±1.230
4	0.33	1	150	17	2.60 ± 0.71	14.54 ±0.489	3.25´10^5 ±0.37´10^5	0.32 ±0.010	80.9±5.037
5	-0.33	0.33	130	15	2.30 ± 1.06	19.76 ±0.72	3.45´10^5 ±0.57´10^5	0.38 ±0.027	71.87±3.031
6	-0.33	1	130	17	2.45 ± 0.28	18.23 ±0.221	3.60´10^5 ±0.42´10^5	0.33 ±0.012	70.8±3.507
7	1	0.33	170	15	2.78 ± 0.23	14.54 ±0.168	3.26´10^5 ±0.46´10^5	0.28 ±0.008	65.8±2.149
8	0.33	0.33	150	15	2.86 ± 0.35	14.18 ±0.44	3.15´10^5 ±0.32´10^5	0.23 ±0.006	80.9±7.768
9	1	1	170	17	2.70 ± 0.57	16.12 ±0.115	3.30´10^5 ±0.30´10^5	0.32 ±0.004	75.9±1.179
10	-0.33	-0.33	130	13	2.30 ± 0.45	22.56 ±0.104	3.57´10^5 ±0.30´10^5	0.52 ±0.004	70.21±1.117
11	-1	0.33	110	15	2.2 ± 0.28	20.13 ±0.165	3.70´10^5 ±0.30´10^5	0.45 ±0.006	52.23±3.234
12	1	-1	170	11	2.34 ± 0.71	18.89 ±0.76	3.17´10^5 ±0.30´10^5	0.36 ±0.006	75.67±2.154
13	-1	1	110	17	2.28 ± 0.35	18.56 ±0.45	3.90´10^5 ±0.30´10^5	0.43 ±0.006	57.34±6.101
14	1	-0.33	170	13	2.67 ± 0.17	15.56 ±0.67	3.23´10^5 ±0.30´10^5	0.37 ±0.006	79.45±5.254

*Specification of the matrix X_1=(x_1-M)/S, X_2=(x_2-M)/S,
where M=average of minimum and maximum of the variable
S = Half of the difference between minimum and maximum
[a] does not correspond in order of processing [b-f] Average of 30 measurement

The present work showed that chapra presented a typical response surface behaviour of proteinaceous material with a region of maximum expansion ratio for feed moisture content and temperature noted at the time of product discharge.

Fig. 2 explains response surface for the effect of feed moisture and process temperature on force to completely shear rice and shrimp (chapra) protein mixture extrudate. The shear strength of the extruded samples was also determined and the minimum force to shear the sample completely was obtained at the central point (15% moisture and 150°C). The r^2 for this variable from the regression was 0.84. The quadratic effect of moisture and temperature in the model was significant ($p<0.05$).

Table 3. ANOVA for the effect of feed moisture and process temperature on expansion ratio of rice and shrimp

ANOVA (r^2=0.92)	df	SS	MS	F
Regression	2	1.17413	0.587065	38.77083
Residual	13	0.196845	0.015142	
Total	15	1.370975		
	Coefficients	Standard Error	t Stat	P-value
Intercept	2.54225	0.036399	69.84313	3.95E-18
X Variable 1	0.1995	0.027515	7.25049	6.45E-06
X Variable 2	0.1375	0.027515	4.997205	0.000244

Y_2= 0.584 X_1^2 +0.883X_1 X_2+0.672 $X_2^{\ 2}$ –1.615X_1-0.932 X_2+15.83

The greater the expansion volume the lower the shear strength. (Chinnaswamy & Hanna, 1988). In the present study, the maximum expansion, greatest volume and lowest stress were obtained at 150°C barrel temperature and 15% moisture.

When the shear force was divided by the extrudate area to obtain shear stress (N m^{-2}) a minimum value was obtained at the central point (15% moisture and 150°C barrel temperature). The r^2 from the multiple regression analysis was 0.90. The multiple regression showed significant quadratic effect of moisture and temperature ($p<0.05$). The resultant polynomial for this variable was:

Y_3 =11460X_1 X_2-6620X_2-4095X_1+ 1875$X_1^{\ 2}$ +6500 X_2^2 +3.442´10^5

Fig. 3. explains the response surface for the effect of feed moisture and process temperature to completely shear the extrudate.

Fig. 4. represents response surface for the effect of feed moisture and process

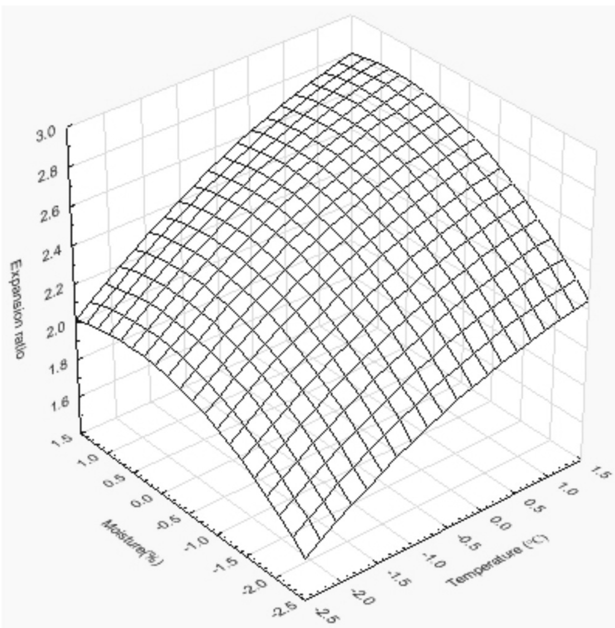

Fig. 1. Response surface for the effect of feed moisture and process temperature on expansion ratio of rice-shrimp (chapra) protein extrudate.

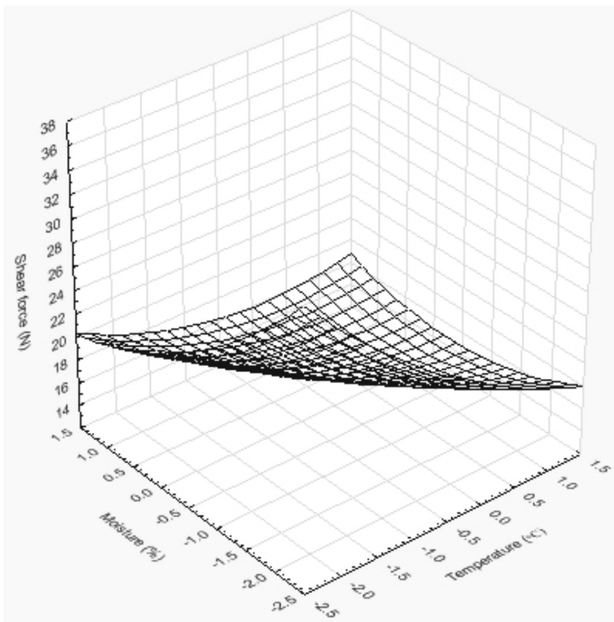

Fig. 2. Response surface for the effect of feed moisture and process temperature on force to completely shear rice-chapra extrudate

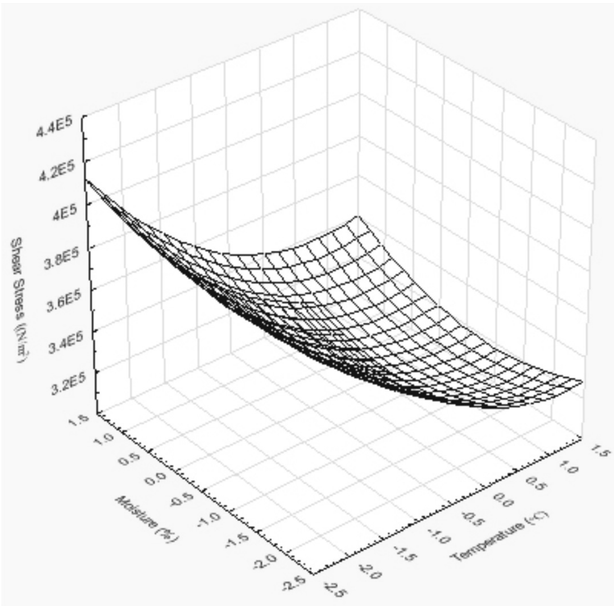

Fig. 3. Response surface for the effect of feed moisture and process temperature on ratio force to completely shear the sample of rice-chapra extrudate.

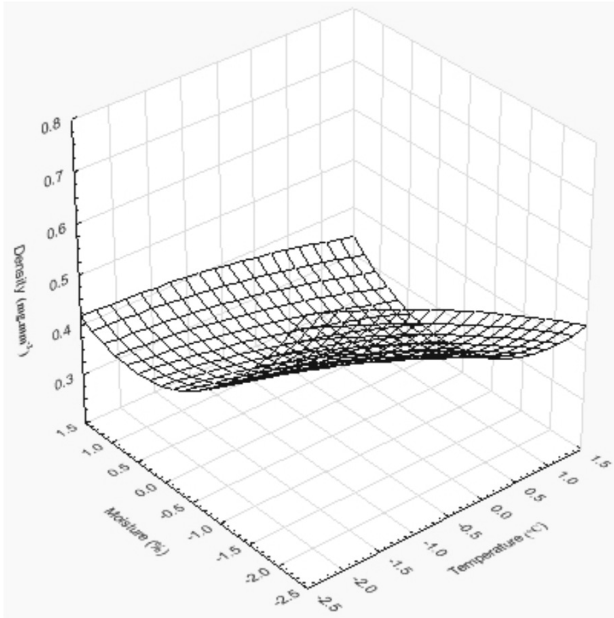

Fig. 4. Response surface for the effect of feed moisture and process temperature on density of rice-chapra extrudate

temperature on density of rice and chapra (shrimp) protein mixture extrudate. The determined density of the extrudates varied between 0.23-0.67 mg mm^{-3}. The result indicated that linear quadratic effects of both moisture and temperature were significant ($p<0.05$) and obtained $r^2 = 0.845$. The resultant polynomial for this variable was

$$Y_4 = 0.325- 0.036\ X_1 + 0.044\ X_2 + 0.024\ X_1\ X_2 + 0.014X_1^2 + 0.018\ X_2^2$$

The surface presented in Fig. 4. also shows decrease in density with an increase in process temperature and moisture. Lowest density was observed at 150°C and 15% process moisture condition. For starchy system, Gomez & Aguilera (1984) found that puffing was directly related to temperature and inversely related to moisture. Thus, here also, typical response surface behaviour of proteinaceous material was observed for the density analysis of the extrudates.

The response surface for the effect of feed moisture and process temperature on acceptance of texture of the extrudate is represented in Fig. 5. The multiple regression analysis for texture acceptance showed significant second order effect of moisture, temperature and the interaction term ($p<0.05$). The coefficient of determination (r^2) was 0.88 and the resultant polynomial for this variable was:

$$Y_4 = 4.691X_1 + 1.519X_2 + 2.108\ X_1\ X_2 - 2.003X_2^{\ 2} - 5.146\ X_1^2 - 80.677$$

The maximum sensory acceptance of the texture of the snack product was obtained in the samples processed at 15% moisture and 150°C process temperature, where, maximum scores were assigned by panelist, indicating higher acceptance of the texture when compared to standard. (a commercial brand of unflavored extruded corn).

The greater the expansion, the lower the shearing force, and the shear stress, and the greater the textural sensory acceptability.

The optimization of carbohydrate-protein extrudate shows a typical response

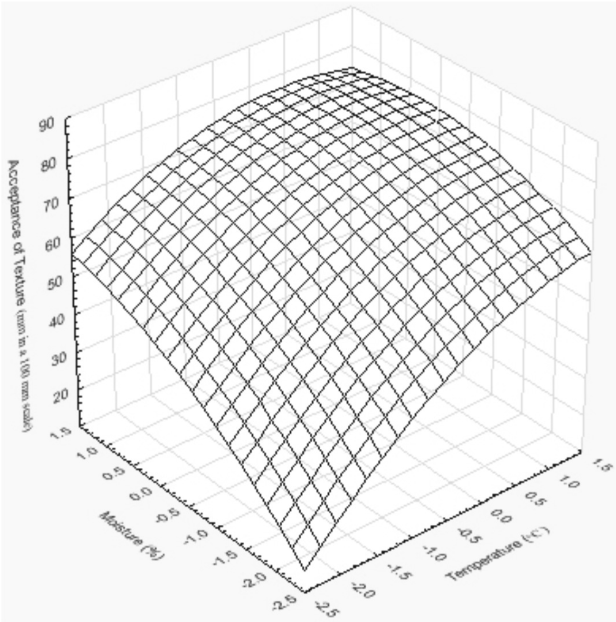

Fig. 5. Response surface for the effect of feed moisture and process temperature on acceptance of texture of rice-chapra extrudate.

surface behaviour where the expansion ratio shows a characteristics linear as well as quadratic pattern with the change of process moisture and process temperature. The optimization process also presents a characteristic surface behaviour of complex food system for expansion ratio, density, shear force, shear stress and texture acceptance of extrudate. This study thus demonstrates that chapra (shrimp) variety can be extruded and used as a high quality protein snack food. In the optimal process, the maximum expansion ratio obtained at 15% moisture and 150°C process temperature coincided with the minimum shear force of the product, and maximum sensory texture acceptance indicating a correlation between extrusion response variables. Response surface study indicated that the desired texture and sensory property could be obtained by controlling cooking temperature and moisture condition.

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