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EFFECTS OF TWIN SCREW PARAMETERS UPON THE MECHANICAL HARDNESS OF READY-TO-EAT EXTRUDATES ENRICHED WITH DE-OILED RICE BRAN

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Abstract: *Mechanical properties of ready-to-eat extrudates are perceived by the consumers as quality criteria. Texture quality of any product has a strong influence on the sensory evaluation as well as on the acceptability of the product. The main texture characteristics influencing the product acceptability are crispness, elasticity, hardness and softness. In the present work, we investigate one of the most important texture characteristics of extrudates i.e. hardness. A five-level, four-factor central composite rotatable design was employed to investigate the effect of temperature, screw speed, feed moisture content and feed composition mainly rice bran content and their interactions, on the mechanical hardness of extrudates. Among these, feed moisture was found to be a prominent factor affecting the product hardness. It was found that with the increase of feed moisture content, the rice bran proportion leads to increase in hardness of extrudates whereas the increase of temperature leads to decrease of hardness of product. A good agreement between the predicted (26.4899 N) and actual value (28.73N) of the response confirms the validation of response surface methodology (RSM)-model.*

Keywords: *Texture, crispness, barrel temperature, screw speed, feed moisture, response surface methodology*

1. Introduction

Deoiled rice bran, a co-product of rice milling and rice bran oil extraction, is rich source of proteins, carbohydrates, dietary fibers like beta-glucan, pectin and gum and micronutrients like oryzanols,tocopherols, tocotrienols, phytosterols [1-4]. After extraction of oil, the remained defatted rice bran possesses unique functional and nutritional properties and has great potential to add value to food products. It keeps humans healthy due to low fat content. Rice bran obtained from different coloured varieties of rice are rich in antioxidants compounds namely polyphenols, carotenoids, vit.E and tocotrienol help in preventing the body tissue damage and oxidative damage of DNA [5]. Due to presence of Proteins, dietary fibers and bioactive compounds [13], rice bran helps in reducing the risk of coronary heart disease, lowering blood cholesterol [7,8], decrease of artherosclerosis disease [9] and it posses laxative effect [6].

Although the nutritional profile and health benefits of deoiled rice bran have been recognized, but it is still used as animal food. Very few studies concerning the incorporation of rice bran into the food products have been available. Keeping in view, the nutritional composition of rice bran, it must be provided opportunity for incorporation into extruded products. The substitution of rice bran in food products will increase the nutritional value as well as provide health benefits to consumers. So, value added, edible food products can be obtained by utilizing defatted rice bran through extrusion cooking.

The technology of extrusion is a latest, continuous, high temp., short-time processing, used in various food industries due to several advantages like fast process, significant reduction in energy consumption, more production and final products at lower prices. This process involves the use of corn meal, rice, wheat or potato flour to produce variety of snack foods in many shapes and variety of textures. Published literature shows the use of extrusion process in cereals, vegetables, fruits and legumes to improve their nutritional profile. The extrusion processing of food is growing day by day due to its economical production with attractive texture, size and shape [10]. Twin Screw Extruder is the most commonly used for extrusion process.

The present work was designed to implement deoiled rice bran in the preparation of ready-to-eat extrudates. RSM was used to optimize the process conditions for the production of easily consumable, highly nutritive, physically attractive extrudates with good taste and flavor and also used to study the effect of operating conditions like moisture content, barrel temperature, screw speed etc. upon the mechanical properties of the product.

2. Material and methods

Experimental design

Response surface methodology (RSM) was adopted in the experimental design [11]. The main advantage of RSM is reduced number of experimental runs needed to provide sufficient information for statistically acceptable result. A five-level, four-factor central composite rotatable design was employed. Table 1 shows independent variables selected for the experiments. The variables and their levels were chosen by taking trials of samples. Hardness was considered as response variable. The five levels of the process variables were coded as -2, -1, 0, 1 and +2 [11]. And design in coded (x) form and at the actual levels (X) is given in Table 2 & Table 3.

Preparation of sample

Ingredients for the production of highly nutritious ready-to-eat snack food consisted of deoiled rice bran, corn flour, rice flour. Deoiled rice bran (DRB) used for present study was procured from M/s. AP Solvex Ltd., Dhuri. Corn flour (CF) and rice flour (RF) were purchased from local market Sangrur, Punjab, India. Ingredient formulations for extrusion products are given in Table 3. In the blend preparation Rice Bran (RB) at levels of 100, 200, 300, 400g were used while corn flour at level of 10% was kept constant in all samples. The moisture was adjusted by sprinkling the stilled water in all the dry ingredients. All the ingredients were weighed and then mixed in the Food Processor with mixer attachments for 20 min. This mixture was then passed through a 2 mm sieve to reduce the lumps formed due to addition of moisture. After mixing samples were stored in polyethylene bags at room temperature for 24h [12].

The moisture content of all the samples was estimated before extrusion by using the Hot air oven method [13].

Preparation of extrudates

Extrusion trials were performed using a co-rotating twin-screw extruder (G.L. Extrusion Systems Pvt. Ltd., Delhi). The main drive is provided with 7.5 HP motor (400 V, 3ph, 50 cycles). The extruder is provided with standard design of screw configuration, automatic cutting knife fixed on rotating shaft and a temperature sensor. It was kept running for suitable period of time to stabilize the set temperatures and sample were then poured in to feed hopper and the feed rate was adjusted to 4kg/h for easy and non-choking operation. The die diameter of 4 mm was selected as recommended by the manufacturer for such product. The product was collected at the die end and packed in for proper storage.

Table 1
Values of independent variables at five levels of the CCRD design

Independent variables	Uncoded	Levels in coded form				
		-2	-1	0	+1	+2
Feed composition (%)	X_1	75:15:10	70:20:10	65:25:10	60:30:10	55:35:10
Feed moisture (%)	X_2	13	14	15	16	17
Screw speed (rpm)	X_3	275	300	325	350	375
Die temperature (°c)	X_4	100	110	120	130	140

Feed composition (RF:RB:CF)

Table 2
Experimental design in coded form for response surface analysis

Coded variables				Combinations	Replications	No. of Expt.
X_1	X_2	X_3	X_4			
±1	±1	±1	±1	16	1	8
±2	0	0	0	2	1	2
0	±2	0	0	2	1	2
0	0	±2	0	2	1	2
0	0	0	±2	2	1	2
0	0	0	0	1	6	6

Code '0' is for centre point of the parameter range investigated '±1' for factorial points, and '±2' for star points; X_1 - Feed composition (%), X_2 - Feed moisture(%), X_3 - Screw speed (rpm) and X_4 - Die temperature (°C)

Table 3

Experimental combination in Coded and Uncoded levels for extruded snacks

Sr. No.	Coded variables				Uncoded variables			
	X_1	X_2	X_3	X_4	X_1 Feed Proportion (RF:RB:CF)	X_2 Moisture content(%)	X_3 Screw speed (rpm)	X_4 Temperature (°c)
1	-1	-1	-1	-1	70:20:10	14	300	120
2	1	-1	-1	-1	60:30:10	14	300	120
3	-1	1	-1	-1	70:20:10	16	300	120
4	1	1	-1	-1	60:30:10	16	300	120
5	-1	-1	1	-1	70:20:10	14	350	120
6	1	-1	1	-1	60:30:10	14	350	120
7	-1	1	1	-1	70:20:10	16	350	120
8	1	1	1	-1	60:30:10	16	350	120
9	-1	-1	-1	1	70:20:10	14	300	130
10	1	-1	-1	1	60:30:10	14	300	130
11	-1	1	-1	1	70:20:10	16	300	130
12	1	1	-1	1	60:30:10	16	300	130
13	-1	-1	1	1	70:20:10	14	350	130
14	1	-1	1	1	60:30:10	14	350	130
15	-1	1	1	1	70:20:10	16	350	130
16	1	1	1	1	60:30:10	16	350	130
17	-2	0	0	0	75:15:10	15	325	125
18	2	0	0	0	55:35:10	15	325	125
19	0	-2	0	0	65:25:10	13	325	125
20	0	2	0	0	65:25:10	17	325	125
21	0	0	-2	0	65:25:10	15	325	125
22	0	0	2	0	65:25:10	15	325	125
23	0	0	0	-2	65:25:10	15	325	125
24	0	0	0	-2	65:25:10	15	325	125
25	0	0	0	0	65:25:10	15	325	125
26	0	0	0	0	65:25:10	15	325	125
27	0	0	0	0	65:25:10	15	325	125
28	0	0	0	0	65:25:10	15	325	125
29	0	0	0	0	65:25:10	15	325	125
30	0	0	0	0	65:25:10	15	325	125

Evaluation of textural property of extrudates

Mechanical properties of the extrudates were determined by a crushing method using a TA – XT2 texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 500 kg load cell. An extrudate 40 mm long was compressed with a probe SMS – P/75mm diameter at a crosshead speed 5 mm/sec to 3 mm of 90% of diameter of the extrudate. The compression generates a curve with the force over distance. The highest first peak value was recorded as this value indicated the first rapture of snack at one point and this value of force was taken as a measurement for hardness [12].

Statistical analysis of responses

The responses such as hardness for different experimental combinations were related to the coded variables (xi, i=1,2,3 and 4) by a second degree polynomial (Equation 1) as given below:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 + \beta_{12} x_1.x_2 + \beta_{13} x_1.x_3 + \beta_{14} x_1.x_4 + \beta_{23} x_2.x_3 + \beta_{24} x_2.x_4 + \beta_{34} x_3.x_4 + \varepsilon \quad \textbf{(1)}$$

Where x_1, x_2, x_3 and x_4 are the coded values of rice flour, corn flour and rice bran mixture, moisture content of feed (%), screw speed (rpm) and temperature of die (^{0}c). The Coefficients of the polynomial were represented by β_0 (constant), β_1, β_2 , β_3, β_4 (linear effects); β_{12} , β_{13} , β_{14} , β_{23} , β_{24} , β_{34} (interaction effects) ; β_{11} , β_{22}, β_{33}, β_{44} (quadratic effects) ; ε (random error). Multiple regression analysis was used for data modeling and statical significance of the terms was examined by analysis of variance. Design expert 6.0 (version 6.0, by STAT-EASE inc., USA) was used for statistical analysis of the data To check the adequacy of the regression model, R^2, Adjusted R^2, Adequate Precision and Ficher,s F-test were used [11]. Regression coefficients were used for statistical calculations and for the generation of three dimensional surface plots.

3. Results and discussion

Variation of responses such as hardness of extrudates with independent variables (corn flour, rice flour and rice bran proportion, moisture content, die temperature and screw speed) were analysed. A complete second order model (Equation 1) employed for its adequacy to decide the variation of response with independent variables. For visualization of variation in hardness with respect to processing variables, three dimensional response surfaces were drawn using design expert 6.0 (version 6.0, by STAT-EASE inc., USA) was used .

Diagnostic checking of the fitted models

Regression analyses indicated that the fitted quadratic model accounted for more than 85.7% of the variations in the experimental data, which was found to be highly significant. All main effects, linear, quadratic and interaction were calculated. The regression coefficients are shown in Table 4. The correlation coefficients for the response was 0.9353 was quite high for response surfaces.

Table 4

Estimated coefficients of the fitted quadratic equation for Hardness based on t-statistic

Coefficients	Hardness	Coefficients	Hardness
X_0	34.58***	X_4^2	0.062 NS
X_1	2.43***	$X_1 X_2$	-0.37 NS
X_2	1.99***	$X_1 X_3$	-0.59 NS
X_3	0.26 NS	$X_1 X_4$	-1.68**
X_4	-1.04**	$X_2 X_3$	0.92**
X_1^2	-0.68**	$X_2 X_4$	-0.27 NS
X_2^2	0.78**	$X_3 X_4$	-0.54 NS
X_3^2	-1.38**		
R^2 =	**0.9353**		

**P < 0.1 , **P < 0.05 , ***P<0.0001, NS : Non significant*

Analysis of variance

Analysis of Variance was calculated to evaluate the goodness of the model. The F-value for model was 15.47 (Table 5) and significant at 99% level. On the other hand, the lack of fit (2.0) was found to be non-significant. On this basis, it can be concluded that the selected models adequately represent the data for the response.

Table 5

Analysis of Variance for Hardness

Source	Df	F value Hardness
X_0	14	15.47***
X_1	1	71.66***
X_2	1	48.29***
X_3	1	0.83 NS
X_4	1	13.13**
X_1^2	1	6.41**
X_2^2	1	8.51**
X_3^2	1	26.62**
X_4^2	1	0.053 NS
$X_1 X_2$	1	1.12 NS
$X_1 X_3$	1	2.84 NS
$X_1 X_4$	1	22.81**
$X_2 X_3$	1	6.86**
$X_2 X_4$	1	0.58 NS
$X_3 X_4$	1	2.35 NS
Residual	15	2.0
Lack of Fit	10	
Pure error	5	
Total	29	

**P < 0.1 , **P < 0.05 , ***P<0.0001*
NS : Non significant

Effect of process variables on texture of extrudates (Hardness)

The textural property of extrudates was determined by measuring the force (Newton) required to break the extrudates. Hardness of the extrudates varied between 26.49 and 41.53 N. Table 6 and 7 shows the coefficients of the model and other statistical attributes of hardness. Regression model fitted to experimental results of hardness (Table 7) shows that model F-value of 15.47 was significant (P<0,0001) whereas lack-of-fit F-value of 2.0 was not significant (P > 0.2314). The fit of model expressed by the coefficient of determination, R^2 (0.9352), indicating that 93.52 % of the variability of the response could be explained by the model, whereas Adjusted R^2 (0.8748) and Adequate Precision (14.786) suggests that model may be used to navigate the design space. The quadratic model for hardness (H) in terms of coded levels of variables was developed as follows:

$$H = 34.58 + 2.43X_1 + 1.99X_2 + 0.26X_3 - 1.04X_4 - 0.68X_1^2 + 0.78X_2^2 - 1.38X_3^2 + 0.062X_4^2 - 0.37X_1X_2 - 0.59X_1X_3 - 1.68X_1X_4 + 0.92X_2X_3 - 0.27X_2X_4 - 0.54X_3X_4 \quad (2)$$

The analysis of variance of above equation predicting that hardness of the extrudates had highly significant (P < 0.0001) positive linear affect of feed composition (X_1) and feed moisture (X_2) whereas, barrel temperature (X_4) had significant (P<0.005) negative linear effect on hardness of product. With the increase in deoiled rice bran and moisture content, hardness of product also increases. This happens due to rupture of gas cells by dietary fiber content of rice bran [14]. While increase of temperature leads to decrease of hardness. The results are similar to findings of [15]. The quadratic terms of feed composition (x_1^2) and screw speed (x_3^2) had significant (P<0.05) negative quadratic effect indicating convex shaped variation on product hardness.

Table 6

Analysis of variance for Hardness (H).

Source	Coefficient of Model terms	Sum of squares	Mean square	DF	F Value	Prob>F
Model	34.58	427.89	30.56	14	15.47	<0.0001***
X_1	2.43	141.57	141.57	1	71.66	<0.0001***
X_2	1.99	95.40	95.40	1	48.29	<0.0001***
X_3	0.26	1.65	1.65	1	0.83	0.3754
X_4	-1.04	25.94	25.94	1	13.13	0.0025**
X_1^2	-0.68	12.67	12.67	1	6.41	0.0230**
X_2^2	0.78	16.81	16.81	1	8.51	0.0106**
X_3^2	-1.38	52.59	52.59	1	26.62	<0.0001***
X_4^2	0.062	0.10	0.10	1	0.053	0.8217
$X_1 X_2$	-0.37	2.21	2.21	1	1.12	0.3067
$X_1 X_3$	-0.59	5.61	5.61	1	2.84	0.1128
$X_1 X_4$	-1.68	45.06	45.06	1	22.81	<0.0002***
$X_2 X_3$	0.92	13.56	13.56	1	6.86	0.0193**
$X_2 X_4$	-0.27	1.15	1.15	1	0.58	0.4573
$X_3 X_4$	-0.54	4.63	4.63	1	2.35	0.1465

Significant at P<0.1, ** Significant at P<0.05,* Significant at P<0.001, df: degrees of freedom*

Table 7

Analysis of variance results of equation 2

Response	Source	Sum of squares	df	Mean squares	F-value	P-value
Hardness	**Regression**	427.89	14	30.56	15.47	<0.0001*
	Lack of Fit	23.70	10	2.37	2.0	0.2306
	Pure error	5.93	5	1.19		
	Residual	29.63	15	1.98		
	Total	457.52	29			
	R^2-value	0.9352				
	Adjusted R^2	0.8748				
	Adeq. Precision	14.786				

**Significant at P<0.05, df: degrees of freedom*

F-value for interaction term of feed composition and barrel temperature (X_1X_4) was 22.81 and p value 0.0002 predicting the term is significant. Since coefficient of term is negative, it will show convex shaped variation with the change in value of variables. Response surface plot (Fig.1), showing that hardness increased with increasing feed composition (X_1) and decreased with increasing barrel temperature (X_4). Therefore, a crispy texture was obtained with increasing temperature due to decrease in hardness. This result is in agreement with [16, 17].

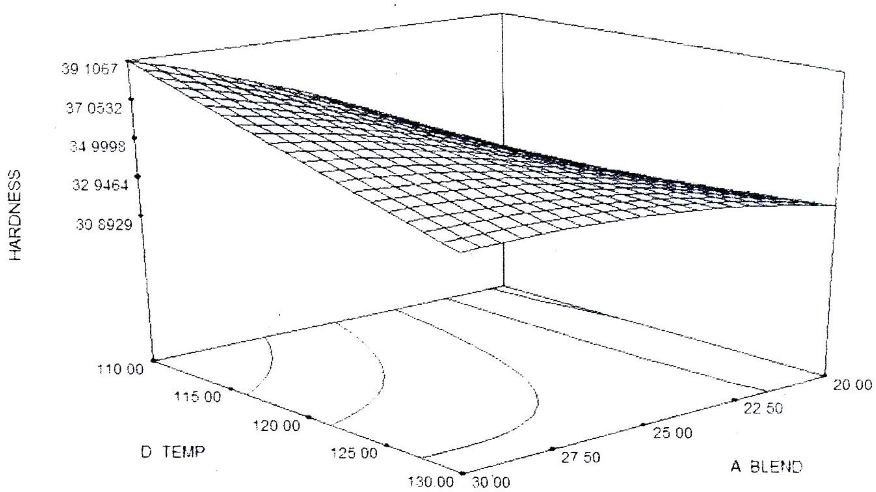

Fig. 1. Response suface plot for the Hardness value of extrudates as function of feed composition (X_1) and barrel temperature (X_4)

The interaction term of feed moisture and screw speed (X_2X_3) was significant at 95% confidence level (F-value 6.88 and P-value 0.0192). Coefficient of X_2X_3 was positive so causes concave shaped variation in product hardness. Response surface plot (Fig.2) showing variation in hardness with increase in feed moisture and screw speed. With increasing feed moisture content (X_2), the hardness of the extrudates increased. The results are same as observed by [18].

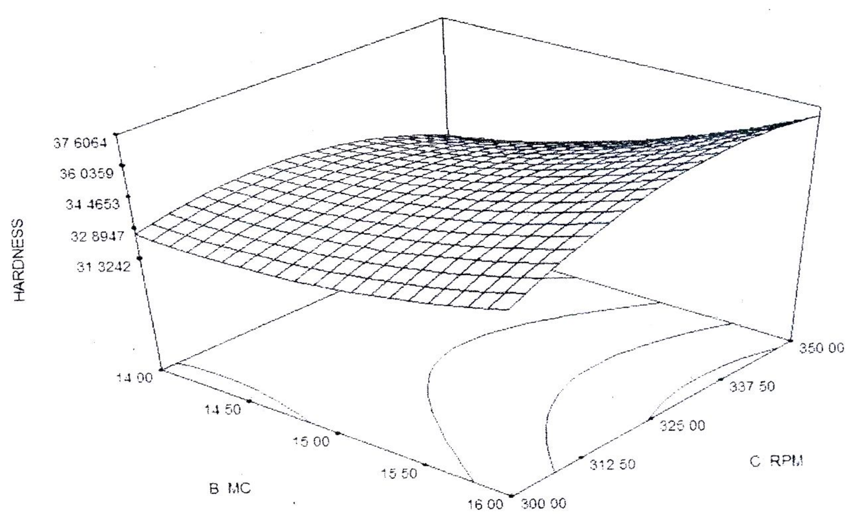

Fig.2. Response surface plot for the Hardness value of extrudates as a function of feed moisture content (X_2) nad screw speed (X_1)

The purpose of verification was done to test the adequacy of the response surface model for predicting response values. The predicted value of hardness obtained is 26.4899 N while actual value is 28.73N. A good agreement between the predicted and actual value of the response confirms the validation of RSM model in the preparation of ready-to-eat extrudates enriched with de-oiled rice bran.

4. Conclusion.

The use of extrusion process for the production of extrudates not only utilize rice milling by-product but also add value to commercialized product with health benefits. The application of response surface methodology serves as the useful tool in the present research. Analysis of regression model equations helps to interpret the relationship between the effects of extrusion operating variables on the mechanical properties of the product. Temperature of the barrel section, screw speed, moisture content of raw feed and feed composition i.e. rice bran proportion were found to have significant effect on the hardness of extrudates. Among these factors, feed moisture content is found to have prominent effect upon the product hardness. Increasing feed moisture content and rice bran proportion leads to increase in hardness of extrudates while increasing temperature leads to decrease of hardness of product.

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