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Development of Nutritious Snack from rice industry waste using twin screw extrusion.

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Abstract. Deoiled rice bran, a byproduct of rice milling industry was transformed into highly nutritious snack by the application of twin screw extrusion process. Response Surface Methodology (RSM) with four- factor- five level central composite rotatable design (CCRD) was employed to investigate the effects of extrusion conditions including moisture content of different raw flours, feed composition, barrel temperature and screw speed of extruder on properties of extrudates was studied. Second order quadratic regression model fitted adequately in the variation. The significance was established at $P \le 0.05$. The regression models can be used to interpret the effect of feed composition, moisture content, screw speed and barrel temperature on the properties of the final product. It was shown that higher rice bran in feed composition showed in minimum water absorption index and maximum water solubility index. Numerical optimization technique resulted in 123.83°C of barrel temperature, 294.68 rpm of screw speed, 13.94 % of feed moisture and 17.73 % of deoiled rice bran. The responses predicted for these optimum process conditions resulted water absorption index, 5.91468 g/g and water solubility index of 18.5553 % for the development of value added product with health benefits.

1 Introduction

The nutrient security is an important issue in developing countries. Utilization of edible discards to increase the nutritional value of food products proved to be successful. The food processing industry generates large quantities of waste co-products. Much of the waste produced is disposed of, or used on a low technological and economical level. The cost of various foods and other products is highly dependent upon the ability of manufacturer to get value from unexplored low market value products like wastes of food industry. The commercial processing of these industrial wastes in the form of highly nutritious food items will not only keep the prices of food products low, but also ease pressure on scare land resources. With this in mind, the by-product which is targeted in this study is rice bran originate from the rice milling industry. In the past years, rice bran was used as either fertilizer or animal feed. Presently, it is used for extraction rice bran oil (RBO) [1-3]. However deoiled rice bran, after extraction of oil known to contain high levels of beneficial compounds such as dietary fibre, antioxidants, micronutrients like oryzanols, tocopherols, tocotrienols, phytosterols. All these micronutrients are rich source of vitamin E and have antioxidant activity [4-7]. But they are still underutilized. Rice bran being rich source of proteins, dietary fiber and bioactive compounds [8], helps in prevention of coronary heart disease, blood cholesterol [9,10] and artherosclerosis disease [11].

Snack foods have always been a significant part of modern life and with the continuing growth of the processed food industry, the demand for specialty-type snacks is expected to increase. However, it is the aim of this study to utilize the highly nutritious and under-used by-product of cereals for application in novel, high quality and healthy snack-type products by using twin screw extruder. Unlike other fried snacks, which are rich in fat content, the present product is free of fat and not fried because of extrusion cooking.

Extrusion cooking is a latest, continuous, high temp., short-time processing technology, gaining increasing popularity in the global agro-food processing industry, particularly in the food and feed sectors due to fast nature, significant reduction in energy consumption, more production and final products at lower prices [12]. Extrusion cooking technology is used for cereal and protein processing in food. This process involves high temperatures, high pressures and several shear forces inside the extruder barrel, chemical reactions and molecular modifications like starch gelatinization, denaturation of proteins, inactivation of several food enzymes and reduction of microbes [12]. Twin Screw Extruder is the most commonly used for extrusion process.

Response surface methodology (RSM) is an effective tool to optimize the process variables with minimum number of experimental runs. An experimental design such as the

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central composite rotatable design (CCRD) to fit a model by least square technique has been selected during the study. The basic principle of RSM is to relate product properties of regression equations that describe interrelations between input parameters and product properties [13].

The objectives of present study are (a) To utilize the highly nutritious and under-used by-product of rice industrial waste for application in novel, high quality and healthy snack-type products by using twin screw extruder. (b) To study the effects of different parameters on the properties of the extruded product using RSM and (c) To optimize the different process conditions for the production of easily consumable, highly nutritive snack with good taste and flavor.

2 Material and Methods

2.1 Experimental Design

A four-factor five-level, central composite rotatable design of Response surface methodology (RSM) was adopted in the experimental design [14]. The main advantage of RSM lies in reduction of experimental runs needed to provide sufficient information for statistically acceptable result. Table 1 shows independent variables selected for the experiments. The variables and their levels were chosen by taking trials of samples. The five levels of the process variables were coded as -2, -1, 0, 1 and +2 [14]. Design in coded (x) form and at the actual levels (X) is given in Table 2.

Table 1. Values of independent variables at five levels of the Central Composite rotatable design.

Independent variables	coded	Levels in actual 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:DRB:CF)**

2.2 Preparation of Sample

The different ingredients for the production of highly nutritious extruded 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 process are given in Table 2. In the blend preparation the composition of deoiled rice bran (DRB) and rice flour (RF) was varied while corn flour (CF) at level of 10% was kept constant in all samples. The moisture was adjusted by adding more distilled water in all the dry flours. The weighed ingredients were mixed in the food processor for 20 min. This mixture was then passed through a 2 mm sieve for the removal of lumps which were formed due to addition of water. The samples were stored in polyethylene bags at room temperature for 24h [15]. The moisture content of all the samples was estimated before extrusion by using the Hot air oven method [16].

2.3 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. The raw flours poured into feed hopper and the feed rate (was adjusted to 4kg/h for easy and non-choking working of twin screw extruder. The recommended die diameter of 4 mm was selected. The collected product was packed for further analysis.

Table 2. 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 Composition	X_2 Moisture content	X_3 Screw speed	X_4 Temp.
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

2.4 Evaluation of Properties of Extrudates

2.4.1 Water Absorption Index (WAI) and Water Solubility Index (WSI)

WAI and WSI were determined according to the standard method developed for cereals [15, 17& 18]. The fine ground extrudate was suspended in water at room temperature for 30 min with simultaneous stirring and then centrifuged at 3000g for a time period of 15 min. The supernatant liquid was decanted into an evaporating dish of known weight. The WAI was the weight of gel obtained after removal of the supernatent liquid per unit weight of original dry solids. The WSI was measured as the ratio of the weight of dry solids in the supernatent to the original weight of sample.

$$\text{WAI (g/g)} = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}}$$

$$\text{WSI (\%)} = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}} \text{ X 100}$$

2.5 Statistical Analysis of Responses

The responses such as water absorption index (WAI) and water solubility index (WSI) 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:

$$Y = \beta 0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 + \beta_{12} x_1.x_2 + \beta_{13} x_1.x_3 + \beta_{14} x_1.x_4 + \beta_{23} x_2.x_3 + \beta_{24} x_2.x_4 + \beta_{34} x_3.x_4 + \varepsilon \quad (1)$$

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 β0 (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 statistical 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 F-test were used [14]. 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 water absorption index (WAI) and water solubility index (WSI) of extrudates with independent variables (corn flour, rice flour and rice bran proportion, moisture content, die temperature and screw speed) were analyzed. A complete second order model (Equation 1) employed for its adequacy to decide the variation of response with independent variables. For visualization of variation 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 .

3.1 Effect of process variables on product water absorption index (WAI)

WAI measures the amount of water absorbed by starch that can be used as an index of gelatinization and it is generally agreed that barrel temperature and feed moisture content exerts greatest effect on the extrudate by promoting gelatinization [19]. The WAI ranged from 4.54 to 6.3 g/g for rice bran, rice flour and corn flour extrudates. Table 3 and 4 shows the coefficients of the model and other statistical attributes of WAI. Regression model fitted to experimental results of WAI (Table 3) showed that Model F-value of 10.68 was highly significant ($P<0.0001$) whereas lack-of-fit F-value of 0.3 was not significant ($P>0.05$). The coefficient of determination, R^2 which was 0.9088, indicating that 90.88 % of the variability of the response could be explained by the model. The Adjusted R^2 was 0.8238 and Adequate Precision was 13.035 which is greater than 4 indicating that the model can be used to navigate the design space. Considering all the above criteria, the model (Eq. 2) was selected for representing the variation of WAI and for further analysis. Multiple regression equation between water absorption index (g/g) of extrudates and coded levels of independent variables was as follows:

$$WAI = 5.39 - 0.22X_1 + 0.19X_2 - 0.27X_3 - 0.11\ X_4 + 0.12X_1^2 + 0.015X_2^2 + 0.021X_3^2 - 0.11X_4^2 - 0.054X_1X_2 - 0.11X_1X_3 - 0.052X_1X_4 + 0.042X_2X_3 - 0.091X_2X_4 - 0.026X_3X_4 \quad (2)$$

The analysis of variance of Eq. (2) shows that WAI of extrudates had highly significant ($P < 0.0001$) negative linear effect of feed composition (X_1) and screw speed (X_3). Other linear terms, feed moisture (X_2) had positive significant ($P<0.001$) while barrel temperature (X_4) had negative significant ($P<0.05$) linear effect on WAI.

Table 3: Analysis of variance for water absorption index (WAI).

Source	Coeff. of Model terms	Sum of squares	Mean square	DF	F Value	Prob>F
Model	5.39	5.31	0.38	14	10.68	<0.0001***
X_1	-0.22	1.17	1.17	1	33.09	<0.0001***
X_2	0.19	0.86	0.86	1	24.08	0.0002***

X_3	-0.27	1.69	1.69	1	47.62	<0.0001***
X_4	-0.11	0.28	0.28	1	8.00	0.0127**
X_1^2	0.12	0.37	0.37	1	10.38	0.0057**
X_2^2	0.015	5.917E-003	5.917E-003	1	0.17	0.6889
X_3^2	0.021	0.012	0.012	1	0.34	0.5692
X_4^2	-0.11	0.34	0.34	1	9.62	0.0073**
$X_1 X_2$	-0.054	0.047	0.047	1	1.33	0.2664
$X_1 X_3$	-0.11	0.20	0.20	1	5.64	0.0313**
$X_1 X_4$	-0.052	0.043	0.043	1	1.21	0.2881
$X_2 X_3$	0.042	0.028	0.028	1	0.79	0.3880
$X_2 X_4$	-0.091	0.13	0.13	1	3.70	0.736*
$X_3 X_4$	-0.026	0.011	0.011	1	0.30	0.5944

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

Table 4 : Analysis of variance results of equation 2

Response	**Source**	**Sum of squares**	**df**	**Mean squares**	**F-value**	**P-value**
	Regression	5.31	14	0.38	10.68	<0.0001*
	Lack of Fit	0.20	10	0.020	0.30	0.9502
	Pure error	0.33	5	0.067		
WAI	**Residual**	0.53	15	0.036		
	Total	5.84	29			
	R^2-value	0.9088				
	Adjusted R^2	0.8238				
	Adeq. Precision	13.035				

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

In this case X_1, X_2, X_3, X_4, X_1^2, X_4^2 and X_1X_3 were significant model terms. F-value of the interaction term X_2X_4 was 3.70 with P-value 0.0736. It means it is significant (P<0.1). Since coefficient of' X_2X_4, was negative, it showed convex shaped variation with the change in value of variables. **Fig.1** shows that WAI increased with increasing feed moisture content(X_2) while decreased with increasing barrel temperature (X_4).

F-value of the linear term feed composition (X_1) was 33.09 indicates that term if highly significant (P<0.0001). Since coefficient of (X_1) was negative, the WAI of extrudates decreased with increasing level of the feed composition i.e. with rice bran proportion **(Fig.2)**. The results indicated that the presence of more bran in the mixture reduced the availability for gelatinization of the starch granules, thus reduced viscosity and WAI because of the replacement of the starch by fiber component. In contrast, reducing of bran content in the mixture caused more open structure of starch granules for allowing water penetration and retention to get more gelatinization and higher WAI. The similar effect of bran content on structural of starch component has been observed [20-22]. The negative coefficients of temperature indicated that the WAI value of the product decreased with increase in temperature. Similar findings were reported by Pelembe, Erasmus and Taylor (2002); Ding et al. (2006) and Aylin Altan (2008) [23-25]. A decrease in WAI with increasing temperature was probably due to decomposition or degradation of starch [23]. Ding et al. (2006) also stated that the WAI decreases with increasing temperature if dextrinization or starch melting prevails over the gelatinization phenomenon [24].

The WAI measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion [26]. Gelatinization, the conversion of raw starch to a cooked and digestible material by the application of water and heat, is one of the important effects that extrusion has on the starch component of foods. Water is absorbed and bound to the starch molecule with a resulting change in the starch granule structure. Barrel temperature and feed moisture are found to exert the greatest effect on gelatinization. The maximum gelatinization occurs at high moisture and low temperature or vice versa reported by Lawton and Henderson (1972) [27].

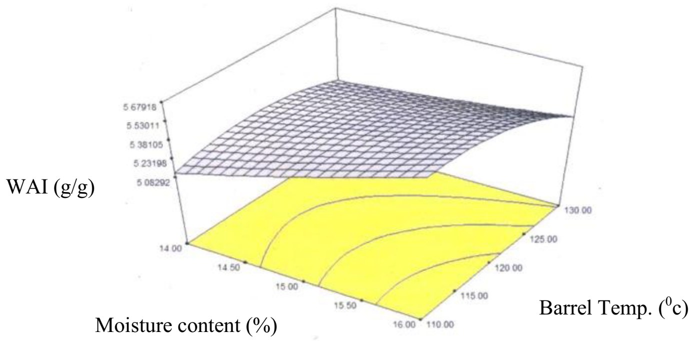

Fig.1. Response Surface Plot for variation of WAI as a function of moisture content (%) and Barrel Temperature (^{0}c).

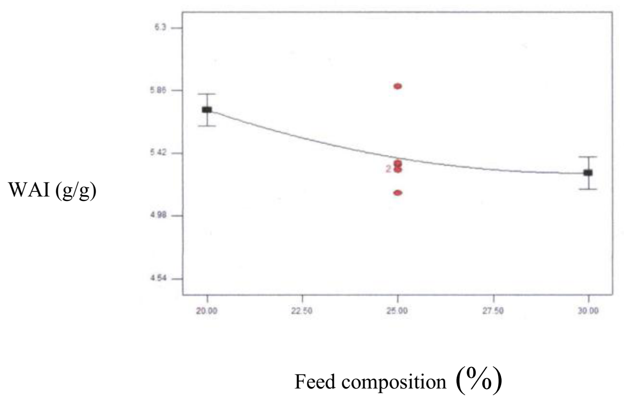

Fig.2. One Factor plot for the variation of WAI of extrudates as a function of feed composition.

3.2 Effect of process variables on product water solubility index (WSI)

WSI used as an indicator of degradation of molecular components. The WSI measures the amount of soluble polysaccharide released from the starch component after extrusion [19]. The WSI values ranged from 13.21% to 30.36%. The coefficients of the model and other statistical attributes of WSI are shown in Table 5 and 6. Regression model fitted to experimental results of WSI (Table 5) showed that Model F-value of 17.68 was highly significant ($P < 0.0001$) whereas lack of fit F-value of 1.92 was not significant ($P>0.05$). The coefficient of determination, R^2 was 0.9429 indicating that 94.29% of the variability of the response could be explained by the model. The Adjusted R^2 was 0.8895 and Adequate Precision was 19.632 which is greater than 4, justifying that this model can be used for prediction purpose. Considering all the above criteria, the model (Eq. 3) was selected for representing the variation of WSI and for further analysis.

$$WSI = 21.78 + 0.53X_1 - 0.97X_2 + 1.08X_3 - 1.54X_4 - 0.1X_1^2 + 0.84X_2^2 + 0.15X_3^2 - 0.92X_4^2 - 2.33X_1X_2 + 0.32X_1X_3 - 2.05X_1X_4 - 0.86X_2X_3 - 1.1X_2X_4 - 0.29X_3X_4 \quad (3)$$

In this case terms, X_1, X_2, X_3, X_4, X_2^2, X_4^2, X_1X_2, X_1X_4, X_2X_3 and X_2X_4 were significant. The analysis of variance of Eq. (3) showed that WSI of extrudates had highly significant ($P<0.0001$) negative linear effect of barrel temperature (X_4) followed by significant ($P<0.001$) positive linear effect of screw speed (X_3). Other linear terms, feed composition (X_1) has significant ($P<0.05$) positive linear effect while feed moisture (X_2) has significant ($p<0.05$) negative linear effect on WSI. The variation of water solubility index with moisture content of raw material and barrel temperature is shown in **Fig. 3A and Fig.3B.**

Table 5: Analysis of variance for water solubility index (WSI).

Source	Coeff. of Model terms	Sum of squares	Mean square	DF	F Value	Prob>F
Model	21.78	353.36	25.24	14	17.68	<0.0001***
X_1	0.53	6.86	6.86	1	4.80	0.0446**
X_2	-0.97	22.68	22.68	1	15.89	0.0012**
X_3	1.08	28.10	28.10	1	19.69	0.0005***
X_4	-1.54	56.89	56.89	1	39.85	<0.0001***
X_1^2	-0.10	0.28	0.28	1	0.19	0.6664
X_2^2	0.84	19.51	19.51	1	13.67	0.0022**
X_3^2	0.15	0.66	0.66	1	0.46	0.5081
X_4^2	-0.92	23.04	23.04	1	16.14	0.0011**
$X_1 X_2$	-2.33	86.72	86.72	1	60.75	<0.0001***
$X_1 X_3$	0.32	1.66	1.66	1	1.16	0.2982
$X_1 X_4$	-2.05	67.20	67.20	1	47.07	<0.0001***
$X_2 X_3$	-0.86	11.75	11.75	1	8.23	0.0117**
$X_2 X_4$	-1.10	19.47	19.47	1	13.64	0.0022**
$X_3 X_4$	-0.29	1.31	1.31	1	0.91	0.3541

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

Table 6 : Analysis of variance results of equation 3

Response	Source	Sum of squares	df	Mean squares	F-value	P-value
WSI	Regression	353.36	14	25.24	17.68	<0.0001*
	Lack of Fit	16.99	10	1.70	1.92	0.2442
	Pure error	4.42	5	0.88		
	Residual	21.41	15	1.43		
	Total	374.78	29			
	R^2-value	0.9429				
	Adjusted R^2	0.8895				
	Adeq. Precision	19.632				

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

The quadratic term of feed moisture content (X_2^2) had significant ($P<0.05$) positive effect, while quadratic term, barrel temperature (X_4^2), had negative significant ($P<0.05$) effect on product WSI.

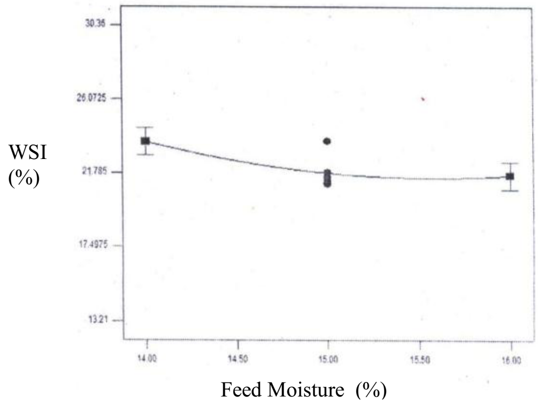

Fig.3 (A) One Factor plot for the variation of WSI of extrudates as a function of feed moisture content.

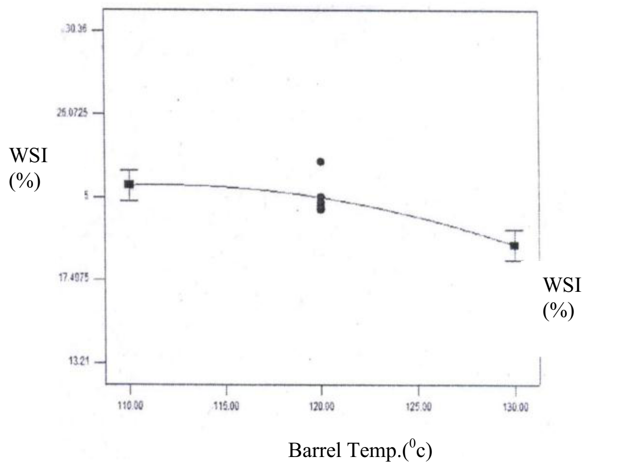

Fig.3 (b) One Factor plot for the variation of WSI of extrudates as a function of Barrel Temperature.

The F-value of the interaction term X_1X_4 was 47.07 with P-value of 0.0001 which indicates that the term is significant (P<0.001). Since coefficient of X_1X_4 was negative, it showed convex shaped variation with the change in the values of the variables. **Fig.4A** shows that the WSI increased with increasing feed composition X_1 (rice bran proportion) while decreased with increasing barrel temperature X_4. The F-value of the interaction term X_2X_4 was 13.64 with P-value of 0.0022 which indicates that the term is significant (P<0.001). Since coefficient of X_2X_4 was negative, it showed convex shaped variation with the change in the values of the variables. **Fig.4B** shows that the WSI increased with decreasing feed moisture (X_2) and barrel temperature (X_4). Similar results were found for rice based extrudates by Ding et al. 2005 [19].

WSI determines the amount of free polysaccharide or polysaccharides released from the granule after addition of excess water [25&28]. Increase in feed moisture content significantly P<0.05) decreases WSI. Increase in feed moisture increases the plasticity of feed thus minimizes the chance of formation of small fraction polymer. WSI increased significantly (P<0.05) with increase in screw speed (X_3). Similar findings are reported for com meal and com and rice extrudates [25, 29&30].

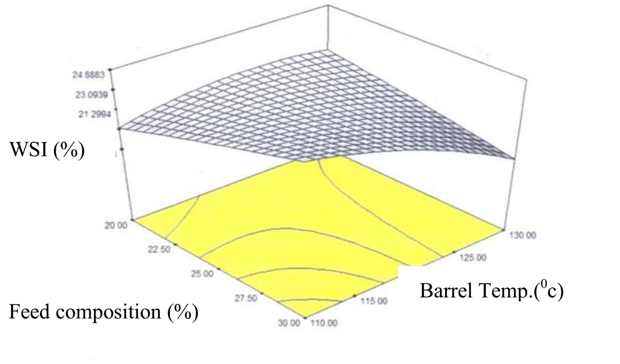

Fig.4A. Response Surface Plot for variation of WSI as a function of Barrel Temperature (^{0}c) and Feed Composition(%).

Mezreb et. al. (2003) reported that the increase of screw speed induced a sharp increase of specific mechanical energy, the high mechanical shear degraded macromolecules, and so the molecular weight of starch granules decreased and hence increase WSI [30].

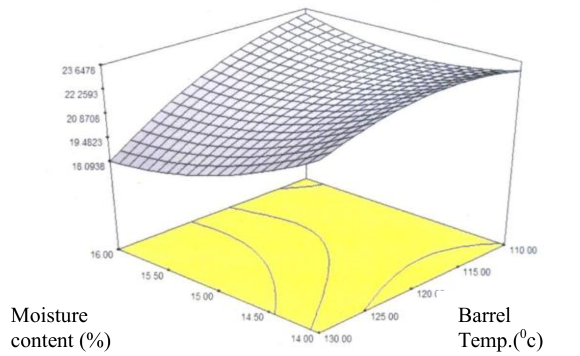

Fig.4B. Response Surface Plot for variation of WSI as a function of moisture content (%) and Barrel Temperature (^{0}c).

4 Optimization

A numerical multi-response optimization technique was applied to determine the optimum combination of rice bran and rice flour in feed composition, feed moisture content, screw speed and barrel temperature for the production of extrudates containing rice bran, rice flour, corn flour.

The assumptions were to develop a product which would have maximum score in sensory acceptability so as to get market acceptability, maximum expansion, minimum bulk density, and minimum hardness. Therefore, among responses, these parameters were attempted to be maintained whereas other parameters were kept within range. Under these criteria, the uncoded optimum operating conditions for development of rice bran, rice flour, corn flour extrudates were 123.83°C of barrel temperature, 294.68 rpm of screw speed, 13.94 % of feed moisture and 17.73 % of deoiled rice bran. The responses predicted by the Software for these optimum process conditions resulted water absorption index, 5.91468 g/g and water solubility index of 18.5553 %.

5 Conclusion

The finding of this study demonstrates the feasibility of developing value added extruded product form rice industrial waste by extrusion processing. The application of quadratic response surface methodology serves as useful tool for optimization of operating conditions for the production of extruded product enriched in deoiled rice bran. The regression models can be used to interpret the effect of feed composition, moisture content, screw speeed and barrel temperature on the properties of the final product. It was shown that increase in barrel temperature leads to minimum water absorption index whereas increased moisture content of the raw material resulted in product with maximum water absorption index and lower water solubility index. Higher rice bran in feed composition showed in minimum water absotption index and maximum water solubility index. In this experiment, numerical optimization technique resulted in 123.83°C of barrel temperature, 294.68 rpm of screw speed, 13.94 % of feed moisture and 17.73 % of deoiled rice bran for the development of value added product with health benefits.

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