# Textural and Microstructural Properties of Extruded Snack Prepared from Rice Flour, Corn Flour and Deoiled Rice Bran by Twin Screw Extrusion

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## ABSTRACT
Rice flour, corn flour and deoiled rice bran blends were used to prepare ready-to-eat extrudates at barrel temperature ($110^0$C, $120^0$C and $130^0$C) and moisture content (14%, 15% and 16%). A three-level, two-factor central composite rotatable design was employed to investigate the effect of temperature and feed moisture content and their interactions, on the mechanical hardness of extruded product. It was found that the increase in feed moisture content leads to increase in hardness of extrudates while increasing temperature leads to decrease in hardness of product. A numerical optimization technique was used to obtain compromised optimum processing conditions of barrel temperature ($120^0$C) and moisture content (15%). A good agreement between the predicted (14.91N) and actual value (15.105N) of the response confirms the validation of RSM model. The surface morphology of extrudates, examined through scanning electron microscopy (SEM) showed large number of sheared and flattened granules at varied temperature. The more damage of starch granules was observed at higher temperature i.e. at $130^0$C.

## Keywords
RSM, barrel temperature, hardness, SEM, extruded product.

## 1. INTRODUCTION
Cereals and starch-based products provide a large proportion of energy to all the humans. Besides, providing energy, starch also contributes to the texture as well as the structure of the food that we consume. The textural and the functional properties of the final product depends upon the gelatinization, molecular degradation and/or reassociation of the raw material [1]. The technology of extrusion cooking is no exception. The extrusion technology is growing day by day because of its versatility and economical production. It produces variety of food products with attractive texture, size and shape [2]. It can be considered as continuous cooking, mixing and forming process in which raw material undergo many chemical and structural transformations. In the food industry, the extrusion cooking plays a significant role and considered as efficient technology for the production of breakfast cereals, baby foods, flat breads, snacks, meat and cheese analogues and modified starches, etc. [3,4].

The process of food extrusion is very complicated process in which small variations in the processing conditions affect the quality of final product [5]. The use of extruders has widened the scope of extrusion technology. Due to several advantages, the twin screw extruders used to large extent for the production of starch based food products as compared to single screw extruders. Inspite of high cost and complexity, twin screw extruders, allows greater flexibility of operating conditions for the achievement of desired time, temperature and shear history for the processed material [6]. The product coming out of the extruder depends upon several factors like type of raw material, moisture content of raw feed, temperature of the barrel section, screw speed, type of extruder, screw configuration etc. [7]. A lot of work has been reported on extrusion cooking of rice flour. It remains an attractive ingredient in extrusion industry, due to its ease of digestion, attractive white colour and hypoallergenicity [8]. It is the most important cereal product used as staple food for many populations over the worldwide. The major product obtained during rice milling is 70% rice (endosperm) and remaining are by-products consisting of 20% rice husk, 8% rice bran and 2% rice germ [9-11].

During de-husking and milling of paddy, the brownish portion of rice taken out in form of fine grain, is the rice bran which is nearly 8% of milled rice [12, 13]. Rice bran is highly nutritious compound as it is rich source of micronutrients like oryzanols, tocopherols, tocotrienols, phytosterols which comprises of vitamin E and exhibit significant antioxidant activity. Rice bran also contains 20% oil, 15% protein, 50% carbohydrates (mainly starch), dietary fibers like pectin, beta-glucan and gum [14-17].

In the earlier times, rice bran was used as either fertilizer or animal feed. But in these days, it is used for extraction of oil namely rice bran oil (RBO) [9, 18, 19]. Rice bran is rich in proteins, dietary fiber and bioactive compounds [20] that help in reducing the risk of coronary heart disease. It helps in lowering blood cholesterol [21, 22], decrease of arthrosclerosis disease [23] and it posseses laxative effect [20]. The substitution of rice bran in food products will increase the nutritional value as well as provide health benefits to consumers. Deoiled cake, a residue of rice bran after extraction of oil, possesses high protein and vitamin contents. It can be utilized to prepare functional food which keeps humans healthy due to low fat content. So, value added, edible food products can be obtained by utilizing defatted rice bran through extrusion cooking.

Although, deoiled rice bran is highly nutritious compound and possesses several health benefits, but it is still underutilized for the development of functional foods. The research work concerning the use of rice bran in the preparation of extruded product is very scanty. Jadhav et al.,(2012) used deoiled rice bran for the development of biodegradable and medium water resistant agriculture planting containers by the application of twin screw extruders [24]. Keeping in view, the nutritional value as well as health benefits of deoiled rice bran, an attempt has been made to prepare ready to eat extruded product. The functional properties of extruded product are highly dependent upon extrusion conditions and type of raw material. So, in the present research work, the effect of barrel temperature ($110^0$c-$130^0$c) and moisture content (14%-16%) on the textural properties (hardness) of the product during twin screw extrusion cooking of deoiled rice bran and the surface morphology of the extrudates through scanning electron microscopy have been studied.

# 2. MATERIALS AND METHODS

## 2.1 Materials

Ingredients for the production of highly nutritious ready-to-eat snack food consisted of deoiled rice bran, corn flour, rice flour. Deoiled rice bran used for present study was procured from M/s. AP Solvex Ltd., Dhuri. Corn flour and rice flour were purchased from local market Sangrur, Punjab, India.

## 2.2 Preparation of Sample

For the preparation of value added extruded product, the different powdered ingredients like rice flour, deoiled rice bran and corn flour were mixed in the 70:20:10 ratio. The feed composition and screw speed of 300 rpm was kept constant for all the experimental runs. The moisture content of all the flours was determined before extrusion by using the hot air oven method [26]. The required moisture was adjusted by sprinkling the stilled water to 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 [27].

## 2.3 Extruder and Extrusion cooking

A co-rotating twin-screw extruder (G.L. Extrusion Systems Pvt. Ltd., Delhi) having barrel with two electric band heaters and two water cooling jackets received the raw feed from a variable speed feeder was used. The main drive is provided with 7.5 HP motor (400 V, 3ph, 50 cycles) and a temperature sensor was fitted on the front die plate. The output shaft of worm reduction gear was provided with a torque limiter cooling. The standard screw configuration design for processing cereals and flour-based products was used. The die plate of the die fixed by a screw nut tightened by a special wrench provided. The automatic cutting knife is fixed on rotating shaft. The extruder barrel temperature was maintained at $110^0$c, $120^0$c and $130^0$c respectively and the moisture was adjusted to 14%, 15% and 16% by adding required amount of water to all the flours. The twin screw extruder 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 already numbered zipped lock packets for proper storage.

## 2.4 Experimental Design

Response surface methodology (RSM) was adopted in the experimental design. [25]. The main advantage of RSM is reduced number of experimental runs needed to provide sufficient information for statistically acceptable result. A three level, two factor central composite rotatable design was employed. Table 1 show independent variables and their levels which were chosen by taking trials of samples. The ranges having good expansion are taken. Experimental Design comprises of 13 experiments. The independent variables chosen for study were barrel temperature and moisture content of the raw material while the response variable was hardness. The three levels of the process variables were coded as -1, 0, 1 [25] and experimental design in terms of actual levels is given in Table 2.

**Table 1. Values of independent variables at three levels of the CCRD design**

| Independent variables | coded | Levels in uncoded form | | |
|---|---|---|---|---|
| Feed moisture (%) | $X_1$ | 14 | 15 | 16 |
| Barrel temperature (°c) | $X_2$ | 110 | 120 | 130 |

**Table 2. Central Composite Rotatable Experimental design in actual levels for extruded snacks**

| Independent Variables | | | Dependent Variables |
|---|---|---|---|
| **S. No.** | **Moisture Content (%)** | **Barrel Temperature ($^0$C)** | **Hardness (N)** |
| 1. | 15.00 | 134.14 | 14.76 |
| 2. | 14.00 | 130.00 | 11.57 |
| 3. | 15.00 | 120.00 | 14.91 |
| 4. | 16.41 | 120.00 | 18.71 |
| 5. | 15.00 | 105.86 | 16.02 |
| 6. | 15.00 | 120.00 | 14.91 |
| 7. | 14.00 | 110.00 | 12.78 |
| 8. | 16.00 | 110.00 | 17.56 |
| 9. | 15.00 | 120.00 | 14.91 |
| 10. | 15.00 | 120.00 | 14.91 |
| 11. | 16.00 | 130.00 | 19.27 |
| 12. | 15.00 | 120.00 | 14.91 |
| 13. | 13.59 | 120.00 | 11.89 |

## 2.5 Evaluation of textural characteristics of extrudates

### *2.5.1 Hardness*

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 [27].

## 2.6 Statistical Analysis of Response

The response (hardness) for different experimental combinations was related to the coded variables (xi, i=1 and 2) by a second degree polynomial equation.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{12} x_1 . x_2 + \varepsilon$$

Where $x_1$ and $x_2$ are the coded values of moisture content of feed (%) and temperature of barrel ($^0$c). The coefficients of the polynomial were represented by $\beta_0$ (constant), $\beta_1$, $\beta_2$ (linear effects); $\beta_{12}$ (interaction effects) ; $\beta_{11}$ , $\beta_{22}$, (quadratic effects) ; ε (random error). Multiple regression analysis was used for data modeling and for response, the statical significance of the terms were examined by analysis of variance. Design expert 9.0 (version 9.0, 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 [25]. In order to generate three dimensional plots for the regression model, statistical calculations were made by using regression coefficients.

## 2.7 Microstructural Analysis

### *2.7.1 Scanning Electron Microscope (SEM)*

Scanning electron microscope (Jeol JSM-7500, Jeol Ltd, Tokyo, JAPAN)) was used to view extrudate in three dimensions and to determine the shape and surface of extrudate. The sample was mounted on SEM stub using double sided adhesive tape and was coated with platinum. An accelerating potential of 5KV was used during micrography.

## 3. RESULT AND DISCUSSION

Variation of response (hardness) of extrudates with independent variables (moisture content and barrel temperature) was analyzed. A complete second order quadratic model employed to fit the data and adequacy of the model was tested to decide the variation of responses with independent variables. The analysis of variance tables were generated and the effect and regression coefficients of individual linear, quadratic and interaction terms were determined. The significances of all terms in the polynomial were jugged statistically by computing the F-value at probability (p) of 0.01 or 0.05. The regression coefficients were then used to make statistical calculation to generate contour maps from the regression model. Optimization of parameters was done by partially differentiating the model with respect to each parameter, equating zero and simultaneously solving the resulting functions. Design expert 9.0 (version 9.0, by STAT-EASE inc., USA) was used for optimization of selected parameters.

## 3.1 Effect of Process Variables on Mechanical Hardness of extrudates

The textural properties of extrudates are very important properties and are closely related to the acceptance of the product. Hardness and crispness of the ready-to-eat extrudates are found to be associated with expansion and cell structure. The instrumental method for the determination of hardness is by measuring the force (Newton) required to break the extrudates. In our study, hardness of the extrudates varied between 11.57 and 19.27 shown in Table 2. Table 3 shows the coefficients of the model and other statistical attributes of hardness. Regression model fitted to experimental results of hardness (Table 3) shows that model F-value of 54.78N was significant, whereas lack-of-fit value of 0.55 was not significant. The chance of large model F-value due to noise was only 0.01%. The fit of model was also expressed by the coefficient of determination $R^2$, which was found to be 0.9751, indicating that 97.51 % of the variability of the response could be explained by the model, whereas Adjusted $R^2$ was 0.9573. Adequate Precision was 23.774 which are greater than 4 suggesting 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:

$$H = 14.91 + 2.77\ X_1 – 0.16\ X_2 + 0.18\ X_1^2 - 0.23\ X_2^2 + 0.73\ X_1X_2 \quad \text{Eq. (1)}$$

**Table 3. Analysis of variance for Hardness**

| Source | Coeff. of Model terms | Sum of squares | Mean square | DF | F Value | Prob > F |
|---|---|---|---|---|---|---|
| Model | 14.91 | 64.07 | 12.81 | 5 | 54.78 | <0.0001*** |
| $X_1$ | 2.77 | 61.21 | 61.21 | 1 | 261.65 | <0.0001*** |
| $X_2$ | -0.16 | 0.21 | 0.21 | 1 | 0.88 | 0.3800 |
| $X_1^2$ | 0.18 | 0.23 | 0.23 | 1 | 0.99 | 0.3531 |
| $X_2^2$ | 0.23 | 0.36 | 0.36 | 1 | 1.54 | 0.2552 |
| $X_1\ X_2$ | 0.73 | 2.13 | 2.13 | 1 | 9.11 | 0.0194** |
| Lack of Fit | 0.55 | | | | | |
| $R^2$-value | 0.9751 | | | | | |
| Adj. $R^2$ | 0.9573 | | | | | |
| Adequate Precision | 23.774 | | | | | |
| F value | 54.78 | | | | | |

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

From the analysis of Equation (1), it was found that the linear term feed moisture content ($X_1$) has significant positive effect while barrel temperature ($X_2$) has significant negative hardness of rice flour, corn flour and rice bran extrud means hardness of extruded product increases with incr moisture content of raw material while it decrease increase in barrel temperature. In this case, for the line moisture content ($X_1$), the F value is 261.65 and P value than 0.0001(P<0.01), indicating term is significan negative significant effect of barrel temperature on h may be due to reduced expansion. F-value for interactio of feed misture and barrel temperature ($X_1X_2$) was 9.11 value 0.0194 (P<0.1) predicting the terms are sign Response surface plot (Fig.1) showing that hardness in with increasing feed moisture ($X_1$) and decrease increasing barrel temperature ($X_2$). As temperatu significant negative effect on hardness of extrudates, a texture was obtained with increasing temperature. This r in agreement with [28-31]. The results are also similar earlier findings of Tanuja et al., (2014) [32]. The incr decrease of hardness with moisture content and temperature is shown in Fig.2 and Fig.3.

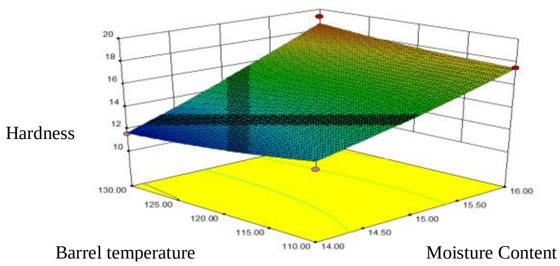


**Fig. 1: Response surface plot of hardness as a function of moisture content and Barrel Temperature**

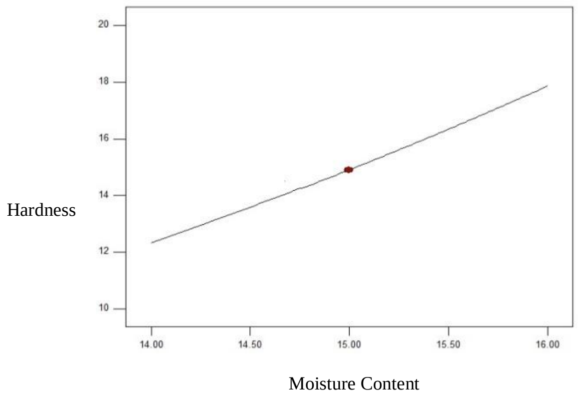


**Fig. 2: Effect of Moisture content upon hardness of extrudates**

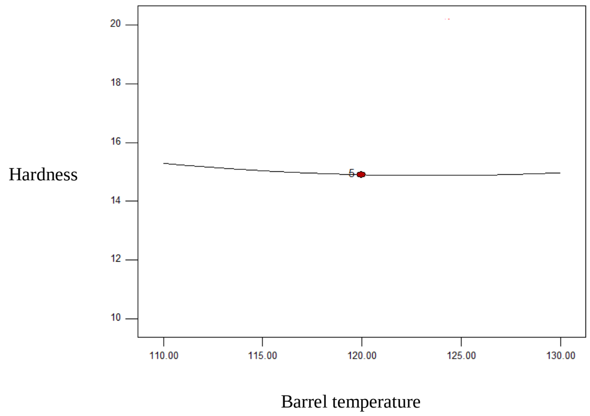


**Fig. 3: Effect of Barrel temperature upon hardness of extrudates**

## 3.2 Optimization

A numerical multi-response optimization technique was applied to determine the optimum combination of feed moisture content, and barrel temperature for the production of extrudates containing rice bran, rice flour and corn flour. The assumptions were to develop a product which would have maximum score in sensory acceptability so as to get market acceptability and minimum hardness. Under these criteria, the uncoded optimum operating conditions for development of rice bran, rice flour, corn flour extrudates were 120°C of barrel temperature and 15% of feed moisture as shown in Table 4. The response predicted for these optimum process conditions resulted in hardness value of 14.91N.

**Table 4. Optimum Processing Conditions for extrusion**

| **Optimum Processing Conditions** | | | |
|---|---|---|---|
| **Moisture Content (%)** | | **Barrel Temperature ($^0$C)** | |
| **Coded** | **Actual** | **Coded** | **Actual** |
| 0 | 15 | 0 | 120 |

## 3.3 Verification of results

The suitability of the model developed for predicting the optimum response values was tested using the recommended optimum conditions of the variables and was also used to validate experimental and predicted value of the responses. The results of predicted and actual values of hardness of extrudates are shown in Table 5. The predicted value of hardness (14.91N) was found to be close to actual value i.e. 15.105N. The closeness of both values confirms the suitability as well as validation of RSM model.

**Table 5 Predicted and Actual values of Hardness**

| **Values of Response (Hardness)** | |
|---|---|
| **Predicted Value** | **Actual Value** |
| 14.91 | 15.105 |

## 3.4 Microstructural Analysis

Microstructure analysis performed by SEM revealed that extruded samples had porous, open-celled structures at three different process temperatures. At the highest temperature, SEM picture of extrudates shows maximum damage and breaking in continuous symmetrical structure. Fig.4 shows the damage of starch molecules which takes place during extrusion process. The extruded product had large no. of flattened and sheared granules. Damage of granules was started at 110$^0$C and it was highest in case of extrusion at 130$^0$C followed by 120$^0$C. The results are in agreement with the results of Bhattacharya et al. (2005) [33]. The damage of starch molecules increases with increase in temperature. The absence of symmetrical structure of starch granules in all figures indicates the complete gelatinization of starch during extrusion process.

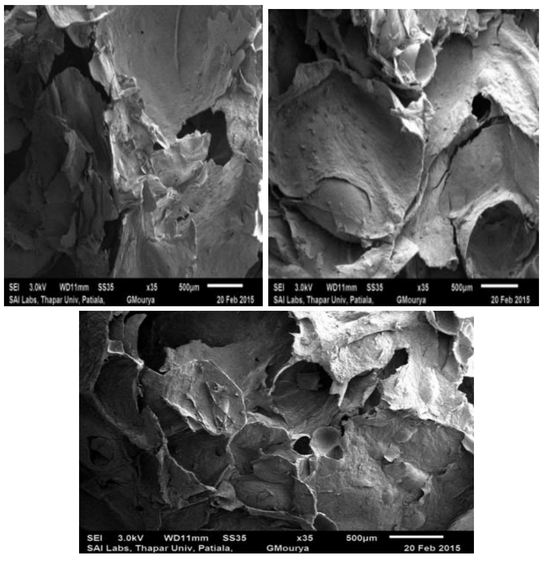

**Fig. 4. SEM picture of extruded product of rice, corn and deoiled rice bran at 110$^0$C, 120$^0$C and 130$^0$C**

## 4. CONCLUSION

The process of extrusion cooking not only utilize rice milling by-product but also add value to commercialized product with health benefits. The application of response surface methodology helps to interpret the relationship between the effects of barrel temperature and moisture content of raw material on the mechanical properties of the product. Increasing feed moisture content leads to increase in hardness of extrudates while increasing temperature leads to decrease of hardness of product. Microstructural studies reveals that the surface morphology of extrudates was also affected and the organized structure of starch molecules modified to flattened and sheared granules during extrusion process. The present invention describes a highly nutritious low-cost snack which can easily form part of a nutrition program for children and used in community kitchens or even for supply to defence and para-military force that require food in adverse conditions. Further the process of value addition using deoiled rice bran needs more study to improve its product quality along with nutritional quality as well as to improve market acceptability.

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