# Process Optimization for Development of Extruded Product from Brown Rice-Amaranth-Moringa Seed Powder Blend


## ABSTRACT

The study was aimed at utilizing brown rice, germinated amaranth and moringa seed powder in the development of nutritious extruded product. The extruded product was optimized by employing Response Surface Methodology using Central Composite Rotatable Design (CCRD). The experiment consists of three independent variables each having five different levels. The process variables were selected as feed moisture content (8-16%), blend ratio of brown rice flour: germinated amaranth flour: defatted moringa seed powder (50:45:5, 50:40:10, 50:35:15, 50:30:20 and 50:25:25) and barrel temperature (100-140ºC). Optimization was done on the basis of product responses i.e. bulk density, expansion ratio and hardness. The values of bulk density, expansion ratio and hardness of extruded products ranged between 0.06 to 0.35 $g/cm^2$, 2.30 to 3.34 and 497.48 to 1425.17 g, respectively. The optimum values of extrusion conditions obtained through numerical optimization were blend ratio (50:30:20), feed moisture content (12%) and barrel temperature (130 $^0$C).The corresponding predicted values for bulk density, expansion ratio and hardness was 0.0964 $g/cm^3$, 3.33 and 617.16 g, respectively with desirability 0.912. Whereas the corresponding experimental values for bulk density, expansion ratio and hardness was 0.0939 $g/cm^3$, 3.35 and 635.56 g, respectively. Thus, it is concluded that the brown rice, germinated amaranth and defatted moringa seed has potential to be incorporated in the development of nutritious extruded snacks.



***Keywords**: Brown rice; amaranth; moringa seed; extruded snack; RSM*


## 1. INTRODUCTION

Extrusion cooking is a widely recognized industrial technology with a large number of food processing applications, since in addition to conventional benefits of heat processing, extrusion has the possibility of modification in the functional properties of food items. The advantages of this cooking process are mainly due to application of high temperature short time (HTST) method, which minimizes the chances of the degradation of food nutrients by heat while process bring improvement in digestibility through gelatinization of starch, denaturing protein and deactivating undesirable compounds, such as enzymes and anti-nutritional factors [1].

Extrusion cooking is described as a process that combines thermal and mechanical treatments to plasticize and cook protein and/or starch rich ingredients within a barrel, resulting in a desirable specific shape. The final product is formed by forcing the mixture through the narrow die opening at the extruder outlet [2].

In the present scenario of food processing sector, the application of extrusion technology is extended to a wide range of purposes such as shearing, separation, encapsulation, shaping, mixing, flavor generation, heating, sterilization, venting moisture & volatiles, conveying and co-extrusion [3].

The food extrusion process is extensively used in the development of a wide range of products, including pasta, breakfast cereals, snacks, meat and cheese analogs. Extrusion cooking utilizes diverse raw material combinations including, cereals, grains, starches, tubers, oilseeds, legumes, meat and proteins [4].
Brown rice (*Oryza sativa L.*) is a kind of rice in which only the husk has been removed. Recently, there has been a rise in the popularity of brown rice among consumers on account of its enhanced nutritional profile and health advantages in comparison with polished rice [5]. Brown rice, also known as unmilled rice consists of around 6-7 per cent bran layers, 2-3 per cent embryo and around 90 per cent endosperm. It is highly nutritious, containing abundant amounts of proteins, dietary fibre, vitamin B complex, vitamin E, calcium, as well as many beneficial polyphenols and gamma amino butyric acid (GABA) [6].
Amaranth seeds (13-21% protein) have been converted into value added protein concentrates (52.5% protein). The proteins are composed mainly of three major fraction albumins, globulins and glutelin with little or no storage prolamine [7]. Amaranth protein isolates have protein content ranging from 79.4–85.4 per cent [8]. The supplementation of food with amaranth protein has many advantages such as non-allergic, gluten-free and highly digestible.
Germination is a cost-effective and efficient method for processing amaranth, which has been shown to enhance the bioactivity and bioavailability of phytochemical composites. In addition to that, it has been used to develop bioactive peptides, resulting in the production of functional foods with improved health benefits [9].
Moringa has the potential to improve nutritional status and food security to the population. The moringa seeds can be eaten as green, roasted or in powdered form. The seed extract is consumed as a green tea and also used in the preparation of curries [10].
Defatted cake contains crude protein, crude fat, ash, crude fiber and carbohydrate 50.80, 3.06, 10.00, 12.96 and 18.15 per cent, respectively [11].
The *Moringa oleifera* seed flour is used for fortification of wheat flour-based bread, biscuits and cookies making to improve nutritional and rheological qualities [12]. The fresh pods, kernels and roots have been utilised in conventional healthcare as pickles, sauces, juices and vegetables for consumption [13].
The blend of flours made from brown rice, germinated amaranth and moringa seed is rich in nutrients and possesses therapeutic characteristics. Keeping in view all the above facts the present research was designed to exploit nutritional properties of brown rice, germinated amaranth and moringa seed into single extruded product. The study was conducted to standardize the process parameters for development of extruded product from brown rice-amaranth-moringa seed powder blend by using response surface methodology.

## 2. MATERIAL AND METHODS

### 2.1 Procurement and Preparation of Raw Materials

#### 2.1.1 Preparation of Brown Rice Flour

The grains of brown rice (*Gujarat Anand Rice 14*) hand pounded unparboiled were procured from local market and milled in a laboratory pulveriser. Brown rice flour was packed in low density polyethylene bags (LDPE) and stored under ambient conditions for further use in extrusion process.

#### 2.1.2 Preparation of Germinated Amaranth Flour

Amaranth (*Gujarat Amaranth-6*) was procured from Centre for Crop Improvement, SDAU, Sardarkrushinagar.The germination was carried out according to the methodology [14] with necessary modification.

#### 2.1.3 Preparation of Defatted Moringa Seed Powder

The commercial *Moringa Oleifera* seed (*PKM-1*) were procured from local market and were pre-treated with boiling at 90 °C for 20 minutes to reduce bitterness. The seed were sorted, screened; oven dried (2.5 h, 40 °C), milled into powder and sieved. The moringa seed powder was defatted three times with hexane at a 1:3 (w/v) ratio for 6 h and air dried for 24 h. The moringa seed powder was packed in low density polyethylene (LDPE) bags and stored at room temperature.

### 2.2 Twin Screw Extruder

The laboratory model High Shear Twin-screw extruder (Make*: Basic Technology Private Ltd., Kolkata*) was employed for development of extruded product.

### 2.3 Experimental Design

The Central Composite Rotatable Design of Response Surface Methodology (RSM) was employed to minimize the number of experimental runs while maintaining result accuracy and assessing the interactive effects of variables on the response [15]. In this study Central Composite Rotatable Design (CCRD) with three independent variables (five levels of each variable) was selected and the design matrix is presented in Table 1. The three independent variables namely; blend ratio (brown rice flour: germinated amaranth flour: defatted moringa seed powder), feed moisture content and barrel temperature were selected for development of ready to eat extruded product. The experimental plan consisted of 20 treatments combinations of each independent variable selected. The data obtained from the experiment outlined were processed using the software Design Expert. The adequacy of model was tested using F ratio and coefficient of determination $R^2$. The model was considered when the calculated F ratio was more than that of table value [16].

Responses obtained as a result of the proposed experimental design were subjected to regression analysis in order to assess the effects of blend ratio, moisture content and barrel temperature on product characteristics. Second order polynomial regression models were established for the dependent variables to fit experimental data for each response using statistical software Design Expert. Data was analyzed by multiple regression analysis and statistical significance of the terms was examined by analysis of variance (ANOVA) to observe the effect of above given parameters on measured response. The adequacy of quadratic models for all responses was on the basis of $R^2$, F-value and *P*-value at 5 per cent level of significance.

**Table 1. Experimental design matrix for different levels of process parameter**

| Run | Coded values | | | Actual values | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| 1 | -1 | -1 | -1 | 50:40:10 | 10 | 110 |
| 2 | 1 | -1 | -1 | 50:30:20 | 10 | 110 |
| 3 | -1 | 1 | -1 | 50:40:10 | 14 | 110 |
| 4 | 1 | 1 | -1 | 50:30:20 | 14 | 110 |
| 5 | -1 | -1 | 1 | 50:40:10 | 10 | 130 |
| 6 | 1 | -1 | 1 | 50:30:20 | 10 | 130 |
| 7 | -1 | 1 | 1 | 50:40:10 | 14 | 130 |
| 8 | 1 | 1 | 1 | 50:30:20 | 14 | 130 |
| 9 | -2 | 0 | 0 | 50:45:05 | 12 | 120 |
| 10 | 2 | 0 | 0 | 50:25:25 | 12 | 120 |
| 11 | 0 | -2 | 0 | 50:35:15 | 08 | 120 |
| 12 | 0 | 2 | 0 | 50:35:15 | 16 | 120 |
| 13 | 0 | 0 | -2 | 50:35:15 | 12 | 100 |
| 14 | 0 | 0 | 2 | 50:35:15 | 12 | 140 |
| 15 | 0 | 0 | 0 | 50:35:15 | 12 | 120 |
| 16 | 0 | 0 | 0 | 50:35:15 | 12 | 120 |
| 17 | 0 | 0 | 0 | 50:35:15 | 12 | 120 |
| 18 | 0 | 0 | 0 | 50:35:15 | 12 | 120 |
| 19 | 0 | 0 | 0 | 50:35:15 | 12 | 120 |
| 20 | 0 | 0 | 0 | 50:35:15 | 12 | 120 |

Where; A= Blend Ratio, B= Feed Moisture Content (% wb), C = Barrel Temperature ($^oC$)

## 2.4 Physical and Textural Properties of Developed Extruded Product

### 2.4.1 Expansion Ratio

The ratio of diameter of the extrudates (mm) to that of the die nozzle diameter (mm) was utilized to express the expansion ratio [17].

### 2.4.2 Bulk Density:

Bulk density is quantified as the mass of solid particles of the material divided by the total volume they occupy, encompassing particle volume, inter-particle void volume, and internal pore volume. It is important to note that bulk density is not an intrinsic property of a material. The calculation of bulk density (BD, g/cm$^3$) follows the method [18].

### 2.4.3 Textural Properties of Extruded Products

The hardness of the extruded products was assessed using the 3-Point Bending Rig (HDP/3PB) with a 5 kg load cell on the TA.HdPlusC texture analyzer (Make:*Stable Micro Systems, UK*).

## 2.5 Optimization of Extruded Products

Several responses obtained for the process were analyzed using Design Expert and the results were fitted to a second order polynomial equation. Mathematical models obtained were accepted only at higher $R^2$ (coefficient of determination) values. Optimization was done for expansion ratio, bulk density and hardness. The software was used to generate optimum processing conditions and to predict the corresponding responses as well.

## 3. RESULTS AND DISCUSSION

### 3.1 Development of Extruded Product

The blend of flours of brown rice, germinated amaranth and defatted moringa seed were utilized for the development of nutritious extruded product. The effect of process variables such as blend ratio, feed moisture content and barrel temperature on the product responses (bulk density, expansion ratio and hardness) are presented in Table 2. A complete second order model was tested for its adequacy to evaluate the effect of process variable on product responses.

**Table 2. Effect of process variables on various product responses**

| Run | Blend Ratio (BRF:GAF:DMSP) | Feed Moisture Content (% wb) | Barrel Temperature (°C) | Bulk Density (g/cm$^3$) | Expansion Ratio | Hardness (g) |
|---|---|---|---|---|---|---|
| 1 | 50:40:10 | 10 | 110 | 0.12 | 3.17 | 1010.42 |
| 2 | 50:30:20 | 10 | 110 | 0.18 | 2.86 | 1033.78 |
| 3 | 50:40:10 | 14 | 110 | 0.22 | 2.84 | 1221.32 |
| 4 | 50:30:20 | 14 | 110 | 0.31 | 2.51 | 1280.15 |
| 5 | 50:40:10 | 10 | 130 | 0.13 | 3.26 | 502.75 |
| 6 | 50:30:20 | 10 | 130 | 0.11 | 3.28 | 602.37 |
| 7 | 50:40:10 | 14 | 130 | 0.10 | 3.29 | 712.98 |
| 8 | 50:30:20 | 14 | 130 | 0.12 | 3.34 | 688.56 |
| 9 | 50:45:05 | 12 | 120 | 0.14 | 3.24 | 1175.81 |
| 10 | 50:25:25 | 12 | 120 | 0.17 | 3.12 | 834.33 |
| 11 | 50:35:15 | 08 | 120 | 0.15 | 3.19 | 800.95 |
| 12 | 50:35:15 | 16 | 120 | 0.35 | 3.14 | 768.68 |
| 13 | 50:35:15 | 12 | 100 | 0.12 | 2.30 | 1425.17 |
| 14 | 50:35:15 | 12 | 140 | 0.06 | 3.34 | 497.48 |
| 15 | 50:35:15 | 12 | 120 | 0.17 | 3.25 | 700.86 |
| 16 | 50:35:15 | 12 | 120 | 0.14 | 3.24 | 818.56 |
| 17 | 50:35:15 | 12 | 120 | 0.15 | 3.20 | 757.25 |
| 18 | 50:35:15 | 12 | 120 | 0.16 | 2.92 | 920.77 |
| 19 | 50:35:15 | 12 | 120 | 0.12 | 3.15 | 888.31 |
| 20 | 50:35:15 | 12 | 120 | 0.13 | 3.05 | 857.27 |

Where; **BRF**-Brown rice flour, **GAF**- Germinated amaranth flour, **DMSP**- Defatted moringa seed powder



### 3.2 Effect of Process Variables on Characteristics of Extruded Product

#### 3.2.1 Effect of Extrusion Parameters on Bulk Density

The bulk density of extruded products is a crucial factor for storage considerations. It reflects changes in cell structure and the formation of pores and voids within the product. Generally, lower bulk density often indicates greater acceptability among consumers.

The bulk density value of extruded products was found to be in the range of 0.06 g/cm$^2$ to 0.35 g/cm$^2$ with variation of process parameters during extrusion cooking (Table 2). The average value of bulk density was found 0.15 g/cm$^2$.

The blend composition (50% brown rice: 35% germinated amaranth: 15 per cent defatted moringa seed powder), feed moisture content 12 per cent and barrel temperature 140 $^0$C had minimum bulk density, whereas highest bulk density was observed for blend composition (50% brown rice: 35% germinated amaranth: 15% defatted moringa seed powder), feed moisture content 16 per cent and barrel temperature 120 $^0$C (Table 2).

The significance of coefficient of fitted quadratic model was evaluated by using F value and *P*-value. The analysis of variance (ANOVA) for bulk density of quadratic model is given in Table 3. Regression model fitted to experimental result of bulk density showed the model F-value was 10.47 and *P*-value was 0.0005 implies the model was significant and *P*-value for lack of fit as 0.0837 which implies the lack of fit was not significant.

The high value of coefficient of determination ($R^2$= 0.90) suggests that the model could be used adequately for prediction within the range of experiments(Table 4).The regression coefficient indicated that bulk density was linear significantly affected by feed moisture content (B) and (C) barrel temperature (Table 3). Further quadratic effect of feed moisture content (B) and barrel temperature (C) had significant effect on bulk density. Regression analyses (Table 4) indicated that bulk density increased with increase in feed moisture content (Fig.1) and decreased with the increase in barrel temperature (Fig. 2). The barrel temperature (C) had negative significant effect while feed moisture content (B) had positive significant effect on bulk density of extruded product.

**Table 3. Analysis of variance (ANOVA) showing the coefficient quadratic model for bulk density**

| Source | Sum of Squares | df | Mean Square | F value | *P*-value | |
|---|---|---|---|---|---|---|
| Model | 0.079537 | 9 | 0.008837 | 10.47329 | 0.0005 | **S** |
| A-Blend Ratio | 0.002756 | 1 | 0.002756 | 3.266447 | 0.1008 | |
| B-Feed Moisture Content | 0.023256 | 1 | 0.023256 | 27.56111 | 0.0004 | |
| C-Barrel Temperature | 0.015006 | 1 | 0.015006 | 17.78399 | 0.0018 | |
| AB | 0.000613 | 1 | 0.000613 | 0.725877 | 0.4142 | |
| AC | 0.002813 | 1 | 0.002813 | 3.333109 | 0.0979 | |
| BC | 0.007813 | 1 | 0.007813 | 9.258636 | 0.0124 | |
| $A^2$ | 0.000172 | 1 | 0.000172 | 0.203546 | 0.6615 | |
| $B^2$ | 0.017475 | 1 | 0.017475 | 20.7101 | 0.0011 | |
| $C^2$ | 0.004675 | 1 | 0.004675 | 5.540752 | 0.0404 | |
| Residual | 0.008438 | 10 | 0.000844 | | | |
| Lack of Fit | 0.006688 | 5 | 0.001338 | 3.821753 | 0.0837 | **NS** |
| Pure Error | 0.00175 | 5 | 0.00035 | | | |
| Cor Total | 0.087975 | 19 | | | | |
| S= Significant, NS= Non- significant | | | | | | |

**Table 4. Regression analysis of bulk density**

| | |
|---|---|
| **S.D.** | 0.029048 |
| **Mean** | 0.1575 |
| **C.V.%** | 18.4434 |
| **PRESS** | 0.058559 |
| **R-Squared** | 0.904086 |
| **Adjusted R-Squared** | 0.817763 |
| **Predicted R-Squared** | 0.33437 |
| **Adequate Precision** | 14.48373 |

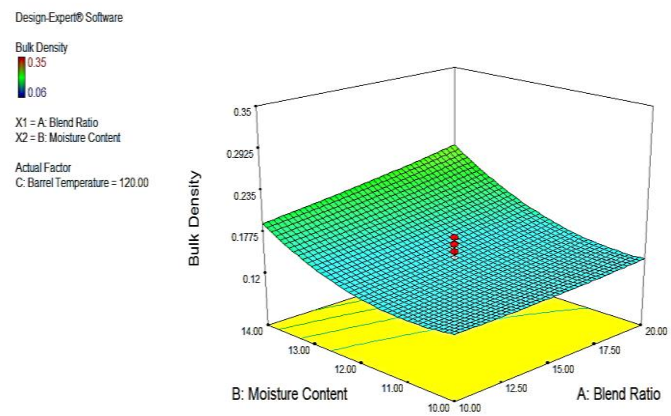


**Fig. 1. Effect of blend ratio and moisture content on bulk density of extruded product**

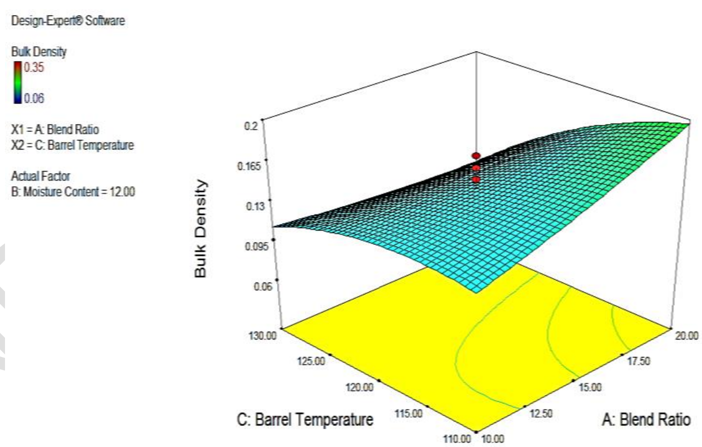


**Fig. 2. Effect of blend ratio and barrel temperature on bulk density of extruded product**

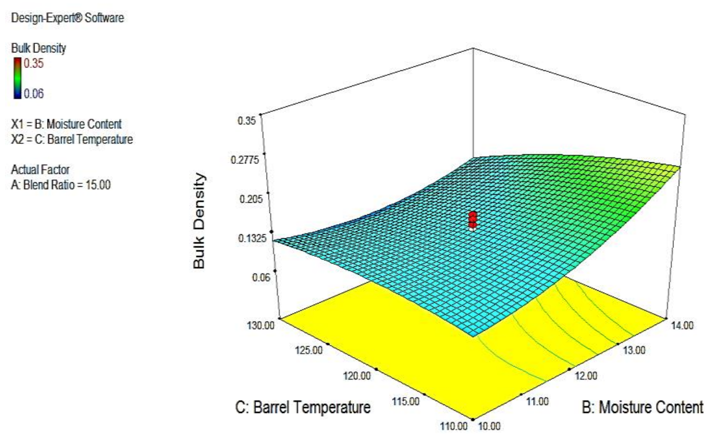


**Fig. 3. Effect of moisture content and barrel temperature on bulk density of extruded product**

The quadratic model derived from regression analysis for bulk density (BD) based on the coded levels of the variables was formulated as follows:

$$\text{Bulk Density} = 0.145227 + 0.013125A + 0.038125B^{*} - 0.03063C^{*} + 0.00875AB - 0.01875AC - 0.03125BC^{*} + 0.002614A^2 + 0.026364B^{2*} - 0.01364C^{2*} \quad (1)$$

(* Significant at 5% level of significance)

Where,

A-Blend Ratio (%)

B-Feed Moisture Content (%)

C-Barrel Temperature ($^0$C)

The high dependence of bulk density on the feed moisture would reflect its influence on elastic characteristics of starch based materials. The dominating effect of moisture on bulk density can be justified by the reason that high moisture content reduces the elasticity of the dough through plasticization of the melt, which reduces the gelatinization and decreases the expansion and therefore increases the bulk density of extrudates.

**3.2.2 Effect of Extrusion Parameters on Expansion Ratio**

Expansion ratio is important characteristics of extruded product and governs the consumer acceptability of puffed snacks. Expansion ratio indicated the degree of puffing undergone by melt as it exits from the extruder [19].

The observed value for expansion ratio of extruded products varied between 2.3 to 3.34 with an average value of 3.08 (Table 2). The blend composition (50% brown rice: 35% germinated amaranth: 15% defatted moringa seed powder), feed moisture content 12 per cent and barrel temperature 100$^0$C had minimum expansion ratio, whereas highest expansion ratio was observed for blend composition (50% brown rice: 30% germinated amaranth: 20% defatted moringa seed powder), feed moisture content 14 per cent and barrel temperature130 $^0$C (Table 2).

The significance of coefficient of fitted quadratic model was evaluated by using F value and *P*-value. The analysis of variance (ANOVA) for expansion ratio of quadratic model is given in Table 5. Regression model fitted to experimental result of expansion ratio showed the model F-value was 13.49 and *P*-value was 0.0002 implies the model was significant and *P*-value for lack of fit as 0.872 which implies the lack of fit was not significant. The coefficient of determination ($R^2$) for the fitted quadratic model was 0.9239 (Table 6). ANOVA showed that expansion ratio was linear significantly affected by barrel temperature (Table 5). Further quadratic effect of barrel temperature (C) had significant effect on expansion ratio. Regression analyses indicated that expansion ratio increased with increase in barrel temperature (Fig. 5).The barrel temperature (C) had positive significant effect on expansion ratio of extruded product. The results of multiple regression analysis revealed that at linear and quadratic level of barrel temperature had significant effect on expansion ratio (Table 5).

**Table 5. Analysis of variance (ANOVA) showing the coefficient quadratic model for expansion ratio**

| Source | Sum of Squares | df | Mean Square | F value | p-value | |
|---|---|---|---|---|---|---|
| Model | 1.332193 | 9 | 0.148021 | 13.49309 | 0.0002 | **S** |
| A-Blend Ratio | 0.041006 | 1 | 0.041006 | 3.737977 | 0.0820 | |
| B-Feed Moisture Content | 0.029756 | 1 | 0.029756 | 2.712469 | 0.1306 | |
| C-Barrel Temperature | 0.936056 | 1 | 0.936056 | 85.32741 | < 0.0001 | |
| AB | 1.25×10-05 | 1 | 1.25×10-05 | 0.001139 | 0.9737 | |
| AC | 0.063013 | 1 | 0.063013 | 5.743985 | 0.0375 | |
| BC | 0.074113 | 1 | 0.074113 | 6.75582 | 0.0265 | |
| $A^2$ | 0.002869 | 1 | 0.002869 | 0.261512 | 0.6202 | |
| $B^2$ | 0.001208 | 1 | 0.001208 | 0.110127 | 0.7468 | |
| $C^2$ | 0.158183 | 1 | 0.158183 | 14.41939 | 0.0035 | |
| Residual | 0.109702 | 10 | 0.01097 | | | |
| Lack of Fit | 0.027552 | 5 | 0.00551 | 0.335383 | 0.8721 | **NS** |
| Pure Error | 0.08215 | 5 | 0.01643 | | | |
| Cor Total | 1.441895 | 19 | | | | |
| S= Significant, NS= Non- significant | | | | | | |

**Table 6. Regression analysis of expansion ratio**

| | |
|---|---|
| **S. D.** | 0.104739 |
| **Mean** | 3.0845 |
| **C.V.%** | 3.395642 |
| **PRESS** | 0.346751 |
| **R-Squared** | 0.923918 |
| **Adjusted R-Squared** | 0.855445 |
| **Predicted R-Squared** | 0.759517 |
| **Adequate Precision** | 14.49735 |

The response surface equation for predicting expansion ratio for any given combination of independent variable may be determined using following formula:

$$\text{Expansion Ratio} = 3.133864 - 0.05063A - 0.04313B + 0.241875C^{*} + 0.00125AB + 0.08875AC^{*} + 0.09625BC^{*} + 0.010682A^2 + 0.006932B^2 - 0.07932C^{2*} \quad (2)$$

(* Significant at 5% level of significance)

Where,

A-Blend Ratio (%)
B-Feed Moisture Content (%)
C-Barrel Temperature ($^0$C)

Increase in the proportion of germinated amaranth and defatted moringa seed powder reduced the expansion ratio (Fig. 5). The steady decrease in expansion ratio with increased level of germinated amaranth or defatted moringa seed powder could be the result of increased amount of fiber and protein to the blend.

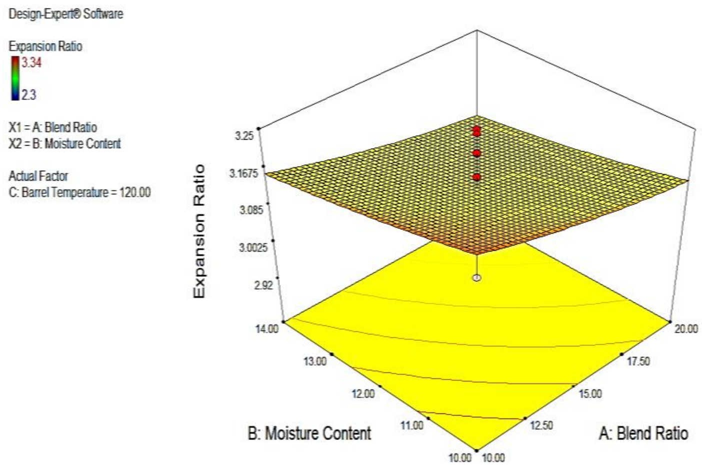


**Fig. 4. Effect of blend ratio and moisture content on expansion ratio of extruded product**

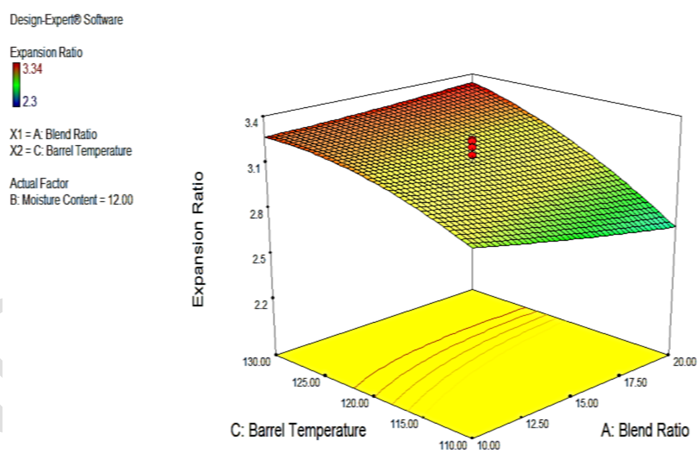


**Fig. 5. Effect of blend ratio and barrel temperature on expansion ratio of extruded product**

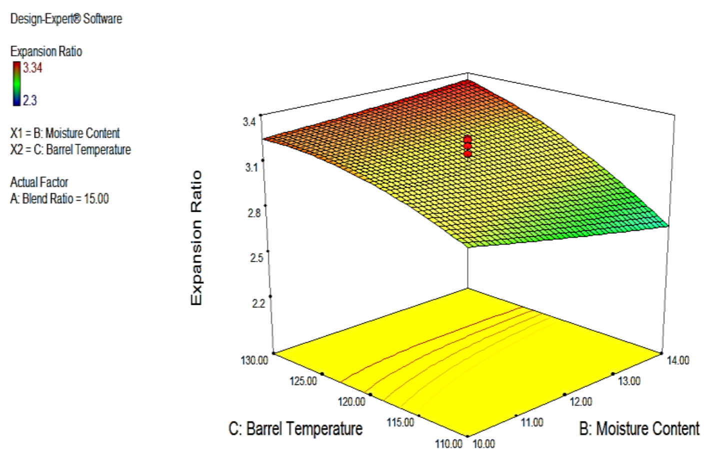


**Fig. 6. Effect of moisture content and barrel temperature on expansion ratio of extruded product**

### 3.2.3 Effect of Extrusion Parameters on Hardness

The maximum peak force value is regarded as an indicator of product hardness. The hardness of the expanded extruded products is related to human perception and is linked to the products expansion and cellular structure [20].

The hardness value of extruded products was found to be in the range of 497.48 g to 1425.17 g with variation of process parameters (Table 2). The blend composition (50% brown rice: 35% germinated amaranth: 15% defatted moringa seed powder), feed moisture content 12 per cent and barrel temperature 140 $^0$C had minimum hardness, whereas highest hardness was observed at blend composition (50% brown rice: 35% germinated amaranth: 15% defatted moringa seed powder), feed moisture content 12 per cent and barrel temperature100 $^0$C (Table 2). The average value of hardness was found to be 874.89 g.

The significance of coefficient of fitted quadratic model was evaluated by using F value and p-value. The analysis of variance (ANOVA) for hardness of quadratic model is presented in Table 7. Regression model fitted to experimental result of hardness showed the model F-value was 9.50 and *P*-value was 0.0008 implies the model was significant and *P*-value for lack of fit as 0.1513 which implies the lack of fit was not significant. The coefficient of determination ($R^2$) for the fitted quadratic model was 0.8953 (Table 8).

Regression analysis (Table 7) showed that hardness was significantly affected by linear effect of barrel temperature, whereas, linear effect of blend ratio and feed moisture content was not significant. Further, interactive effect of blend ratio and feed moisture content (AB), blend ratio and barrel temperature (AC), feed moisture content and barrel temperature (BC) was not significant (Table 7). The quadratic effect of blend ratio, feed moisture content and barrel temperature on hardness was found not significant. Regression analysis (Table 7) indicated that hardness was decreased with increase in barrel temperature (Fig. 8). The hardness was increased with increase in feed moisture content (Fig. 9).

**Table 7. Analysis of variance (ANOVA) showing the coefficient quadratic model for hardness**

| Source | Sum of Squares | df | Mean Square | F value | p-value | |
|---|---|---|---|---|---|---|
| Model | 1079463 | 9 | 119940.4 | 9.505825 | 0.0008 | S |
| A-Blend Ratio | 17263.99 | 1 | 17263.99 | 1.36825 | 0.2692 | |
| B-Feed Moisture Content | 29682.98 | 1 | 29682.98 | 2.352512 | 0.1561 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| C-Barrel Temperature | 947892.1 | 1 | 947892.1 | 75.12479 | < 0.0001 | |
| AB | 980.5806 | 1 | 980.5806 | 0.077716 | 0.7861 | |
| AC | 6.107512 | 1 | 6.107512 | 0.000484 | 0.9829 | |
| BC | 3234.09 | 1 | 3234.09 | 0.256316 | 0.6236 | |
| $A^2$ | 49114.28 | 1 | 49114.28 | 3.892532 | 0.0768 | |
| $B^2$ | 2968.815 | 1 | 2968.815 | 0.235292 | 0.6381 | |
| $C^2$ | 27815.62 | 1 | 27815.62 | 2.204516 | 0.1684 | |
| Residual | 126175.7 | 10 | 12617.57 | | | |
| Lack of Fit | 91920.12 | 5 | 18384.02 | 2.683364 | 0.1513 | **NS** |
| Pure Error | 34255.56 | 5 | 6851.112 | | | |
| Cor Total | 1205639 | 19 | | | | |
| S= Significant, NS= Non- significant | | | | | | |

**Table 8. Regression analysis of hardness**

| | |
|---|---|
| **Std. Dev.** | 112.3279 |
| **Mean** | 874.8885 |
| **C.V.%** | 12.83912 |
| **PRESS** | 814486.7 |
| **R-Squared** | 0.895345 |
| **Adj R-Squared** | 0.801156 |
| **Pred R-Squared** | 0.324436 |
| **Adeq Precision** | 12.25763 |

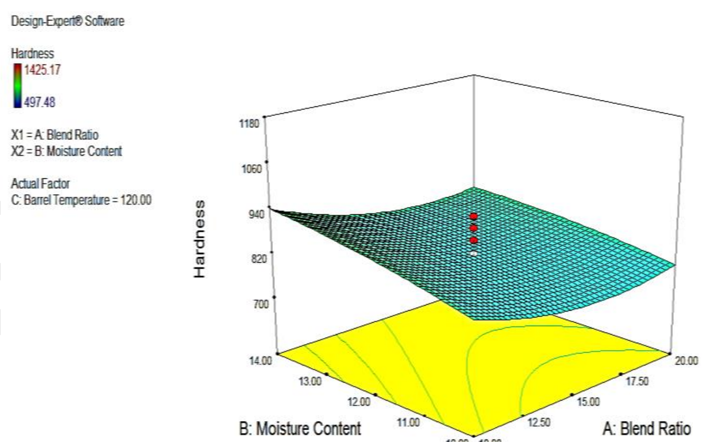


**Fig. 7. Effect of blend ratio and moisture content on hardness of extruded product**

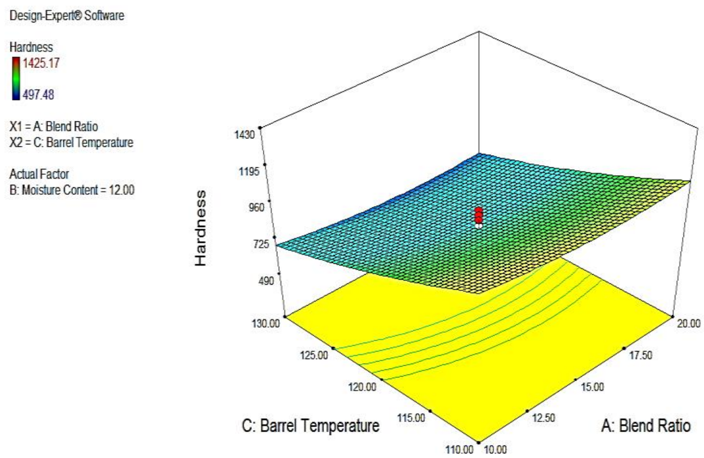


**Fig. 8. Effect of blend ratio and barrel temperature on hardness of extruded product**

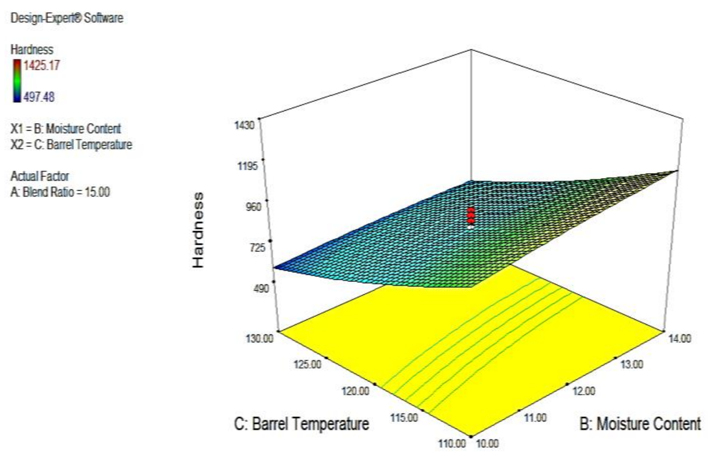


**Fig. 9. Effect of moisture content and barrel temperature on hardness of extruded product**

The response surface equation for estimating hardness for any given combination of mix component and processing parameters can be calculated by following equation:

$$\text{Hardness} = 821.6148 - 32.8481A + 43.07188B - 243.399C^{*} - 11.0713AB - 0.87375AC - 20.1063BC44.19739A^2 - 10.8664B^2 + 33.26114C^2 \quad (3)$$

(* Significant at 5% level of significance)

Where,

A-Blend Ratio (%)

B-Feed Moisture Content (%)

C-Barrel Temperature ($^0$C)

It was anticipated that higher temperatures will reduce melt viscosity, which promotes bubble growth and results in low density products with smaller, thinner cells, thereby enhancing the crispness of the extruded product. This led to a reduced bulk density, which in turn decreased the hardness of the extruded product [21]. A low-density product typically results in low hardness. A strong correlation between bulk density and hardness had been established [22, 23].

### 3.3 Optimization of Process Parameters for the Development of Extruded Product

The optimum values of extrusion condition obtained through numerical optimization for development of brown rice flour: germinated amaranth flour: moringa seed powder blend based extruded product were blend ratio 50:30:20, feed moisture content 12 per cent, barrel temperature (130 $^0$C) (Table 9).The corresponding predicted values of responses obtained were bulk density of 0.0964 g/cm$^3$, expansion ratio 3.33 and hardness of 617.16 g with desirability 0.912 (Table 9). The study also revealed that the quality of the extruded product can be enhanced by controlling the extrusion processing variables.

**Table 9. Optimum values of independent variables and product characteristics**

| **Optimized independent variables** | **Predicted Values** |
|---|---|
| Blend Ratio% (BRF: GAF:DMSP) | 50:30:20 |
| Moisture Content (% wb) | 12 |
| Barrel Temperature ($^0$C) | 130 |
| **Dependent variable** | **Predicted Values** |
| Bulk Density (g/cm$^3$) | 0.0964 |
| Expansion Ratio | 3.3348 |
| Hardness (g) | 617.16 |
| **Particular** | **Predicted Values** |
| Desirability | 0.912 |
| Where; **BRF**-Brown rice flour, **GAF**- Germinated amaranth flour, **DMSP**- Defatted moringa seed powder | |

### 3.4 Validation of model with numerical optimum solution

The experimental results for all the extruded product characteristics (bulk density, expansion ratio and hardness) were compared with predicted values.

**Table 10 Predicted response levels and experimental response levels**

| S. No. | Factors /Responses | Predicted Values | Experimental values | Variation (%) |
|---|---|---|---|---|
| 1. | Bulk Density (g/cm$^3$) | 0.0964 | 0.0939* | -2.66 |
| 2. | Expansion Ratio (%) | 3.33 | 3.35* | 0.59 |
| 3. | Hardness (g) | 617.16 | 635.56* | 2.89 |

**Values are mean ± SD of 3 replicates (n=3)*

The experimental values were found to be less than 5 per cent variation of the predicted values which confirmed that the model was adequate and in accordance with predicted responses.

## 4. CONCLUSION

The regression coefficient indicated that bulk density was linear significantly affected by feed moisture content and barrel temperature. The quadratic effect of feed moisture content and barrel temperature had significant effect on bulk density. Regression analyses indicated that bulk density increased with increase in feed moisture content and decreased with the increase in barrel temperature. The barrel temperature had negative significant effect while feed moisture content had positive significant effect on bulk density of extruded product.

ANOVA showed that expansion ratio was linear significantly affected by barrel temperature. Further quadratic effect of barrel temperature had significant effect on expansion ratio. Regression analyses indicated that expansion ratio increased with increase in barrel temperature. The barrel temperature had positive significant effect on expansion ratio of extruded product. Regression analysis showed that hardness was significantly affected by linear effect of barrel temperature.

It has been concluded from present study that brown rice flour, germinated amaranth flour and defatted moringa seed powder can be processed to prepare ready- to-eat extruded snack for value addition. Results from present study indicated that brown rice flour (50%), germinated amaranth flour (30%) and defatted moringa seed powder (20%) with process parameters such as 12 per cent feed moisture content and 130 °C barrel temperature can be utilized to prepare extruded snacks having acceptable quality. Thus, the utilization of brown rice flour, germinated amaranth flour and defatted moringa seed powder for product development will help in diversifying its use for achieving food and nutritional security.

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