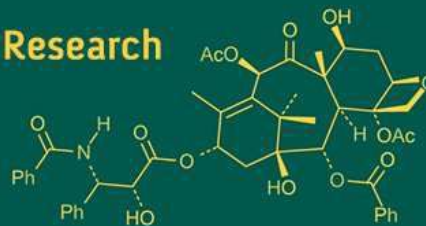
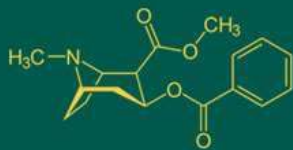


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Optimization of extrusion condition for an extruded snack developed from industrial by-product and moringa leaf powder

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Abstract

Extrusion cooking is a high-temperature, short-time process, was used to develop ready-to-eat extruded snacks from industrial by-products and moringa leaf powder. Composite flour was prepared using broken rice powder, defatted soybean meal, and moringa leaf powder in varying proportions. A laboratory twin-screw extruder was employed and a central composite rotatable design (CCRD) was used to optimize the process. The independent variables included feed proportion (85:10:5 to 65:25:10), feed rate (9-13 kg/h), screw speed (200-400 rpm), and barrel temperature (100-160 °C). Thirty treatments were conducted to evaluate the effects on dependent variables such as moisture content, expansion ratio, bulk density, true density, Porosity, water activity, and Water absorption index. Response surface methodology (RSM) was applied to optimize the process with an R^2 of >0.60 and generate second-order regression models for the dependent variables. ANOVA was used to examine the statistical significance of the terms in the regression equation. ($p < 0.0001$) was the probability (p) value of RSM. The optimal conditions were determined as follows: feed proportion (75:17.5:7.5), feed rate (11 kg/h), screw speed (300 rpm), and barrel temperature (145 °C). Under these conditions, the optimized extruded product exhibited desirable properties, including a moisture content of 5.62%, expansion ratio of 2.99, bulk density of 121.88 kg/m³, true density of 1251.94 kg/m³, Porosity 90.26% water activity of 0.4035 and water Absorption Index 7.01. The desirability for optimum solution is 0.847. This study provides a viable solution for reducing industrial waste while producing extruded snacks of desired physical and functional quality.

Keywords: Extruded product, moringa leaf powder, De-oiled soybean meal, broken rice, extrusion cooking, response surface methodology, optimization, industrial by-product

Introduction

Human body needs nutrition which involves proper intake of fats, protein and carbohydrates at balanced level for maintaining the body with appropriate amount of fiber, energy, vitamins and minerals (Bernacchia *et al.*, 2016) [7]. Due to non-consumption and lack of nutritious food people are prone to various non communicable diseases such as diabetes, obesity, cancer etc (Ouhit *et al.*, 2014) [36]. Food industry by-products like rice bran, broken rice, and defatted soybean meal can be valuable sources of nutrients and bioactive compounds. Subcritical water hydrolysis of rice bran and soybean meal yields protein, amino acids, and reducing sugars with antioxidant properties (Watchararui *et al.*, 2008) [54]. During milling, It is estimated that on milling paddy or Asian rice (*Oryza sativa*) around 50% whole rice produce approximately 16% broken rice produced around 20% husk 14% bran and meal produced. (Bautista & Counce, 2020) [6]. Broken rice, a by-product of rice milling, can be effectively utilized through extrusion processing to create value-added food products. Extrusion technology has been used to produce extruded product from broken rice and other non-rice materials, offering opportunities for fortification (Limberger *et al.*, 2009) [31]. Defatted soybean flour is a valuable source of protein, amino acids, and isoflavones (Kang *et al.*, 2017) [25]. It is found that defatted soybean meal produced from soybean mill as a byproduct contains more than 40% of the soya protein. Soya protein is very nutritious and also inexpensive and widely used in various food products such as cereal product, dairy, meat, rice, pasta and snack food (Sereewat, *et al.* 2015, Samyor *et al.*, 2018, Singh & Krishnaswamy, 2022, Singh *et al.*, 2008, Visser & Thomas, 1987) [45, 42, 48, 49, 53].

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The solvent extraction process typically removes almost all oil content, resulting in defatted soybean meal with less than 1% oil (Toomer *et al.*, 2023, Demarco & Gibon, 2020) ^[52, 17]. Moringa oleifera, often called the "miracle tree," is renowned for its exceptional nutritional and medicinal properties. Its leaves are rich in essential nutrients, including proteins, vitamins (A, B, C, E), minerals, and antioxidants (Tamilselvi & Arumugam, 2019, Hossain *et al.*, 2022) ^[51, 24]. Moringa leaves can be incorporated for making extruded product as an ingredient along with defatted soybean meal and broken rice which will add fiber to the final product and also enhance its health benefit. The extrusion process parameters, such as feed proportion, feed rate, barrel temperature, screw speed are critical in determining the final product characteristics (Salgado *et al.*, 2017; Nisha *et al.*, 2023) ^[41, 33].

Extrusion cooking is a process in which material is forced to flow in different and variety of conditions through a preferable shaped die at a definite rate to achieve different products. This process of food production has been practiced over fifty years (Choton *et al.*, 2020, Ajita, 2018, Patil *et al.*, 2007, Cortes *et al.*, 2014, Korkerd *et al.*, 2016) ^[12, 1, 38, 13, 27]. The process is cost-effective and versatile, allowing for the incorporation of by-products and the development of fortified foods (Choton *et al.*, 2020) ^[12]. Extruded products typically have low moisture content and extended shelf life (Camire *et al.*, 2007) ^[10]. The technology's impact on nutritional and chemical properties is attributed to high temperatures, which modify the structure of food components (Brennan *et al.*, 2011) ^[9]. At the time of extrusion cooking thermal energies and shear energies were applied to raw ingredients which causes chemical nutritional and structural transformations like gelatinization of starch, denaturation of protein, oxidation of lipid, vitamins degradation, flavour formation and an increase in availability of minerals and dietary fiber (Hirth *et al.*, 2014) ^[23]. Extrusion cooking is also used to partially or totally inactivates various anti-nutritional compounds which limits the use of beans as the primary food source (Shimelis and Rakshit, 2005) ^[47]. Extrusion is particularly useful for incorporating food by-products and waste into value-added products, addressing environmental concerns and utilizing nutritionally adequate materials (Dendegh *et al.*, 2021) ^[18]. The Indian snack market is worth approximately US\$3 billion, with a growth rate of 15-20%. The growth of the snack market is influenced by changing lifestyles, demands, and habits of the increasing population (Dahiwalé *et al.*, 2018) ^[14].

The aim of this study is to investigate the optimization of extrusion conditions for the development of an innovative extruded snack using a combination of industrial by-products and moringa leaf powder. By analyzing the effects of key extrusion parameters such as barrel temperature, screw speed, and feed rate. This research aims to identify optimal conditions that maximize the expansion ratio, porosity, water absorption index and minimize the moisture content, water activity, bulk density and true density in final product. Additionally, this study seeks to contribute to the growing body of knowledge on sustainable food processing techniques and the potential of utilizing underused agricultural and industrial by-products in value-added food products.

Materials and Methods

Raw Material and Sample Preparation

Broken rice was purchased from local Pusa market. Defatted Soybean meal was procured from soybean oil Mill (Adani groups and company) which was located at Vidisha district in Madhya Pradesh, India. The cleaned broken rice and defatted soybean meal were pulverized separately. In order to obtain homogenized flour, the pulverized powder of broken rice and defatted Soybean meal was passed through 1.45 mm screen. Then defatted soybean meal is kept under sunlight for 24 hour. Fresh Moringa leaves were collected, washed and cleaned before sun drying. Dried moringa leaves were ground using laboratory grinder and fine powder was obtained by sieving through 125 micron sieve.

Composite Flour Preparation and Conditioning

Composite flour was prepared by mixing of broken rice powder, defatted soybean meal powder and moringa leaf powder in different ratios on dry weight. Preliminary experiments were conducted to select different proportion of these flour.

Conditioning of prepared blends of the flours was done by spraying a calculated amount of water and mixing by hand, the mixture was then passed through the sieve (1.45mm) and finally it was stored in zip lock polythene bag, and left it for at least 30 minutes. The moisture content of the conditioned samples ranged from 10% to 15% (w.b). After conditioning, the blended flour was then allowed to equilibrate at room temperature for 1 hour before extrusion cooking.

Extruder and extrusion condition

The BPTL lab model of co-rotating twin screw extruder (BPTL, Kolkata, India) was used for the experiment. The main drive was provided with 7.5 Hp motor (400v 3ph.). Die used for Extrusion was of 3 mm diameter. The length and diameter ratio of barrel is 11:7 whereas barrel length were 345mm and diameter was 108.6 mm. clearance between barrel and screw was 1.5 mm. the barrel is provided with two electric heater and two water cooling jacket. The temperature range for heater "1" is 90 °C-140 °C and for heater "2" at 60 °C. There was an inching switch present in the control board used for self wiping of system for its easy cleaning.

At First feed containing 30% moisture should be fed, every time extruder is operated and immediately thereafter regular preconditioned feed should be fed. The moist lump gets gelatinized due to heated barrel and which will serve as lubricant between screw and barrel. There should not be any time gap between these two feed otherwise jamming will take place because there is no conditioned feed behind the initial moist lump to push it through the die hole.

Process Variables for Preparation of Extrudates

The experiment was conducted at five different screw speed (200, 250, 300, 350, 400)rpm, five different barrel temperature (100, 115, 130, 145, 160°C), five different feed proportion of broken rice powder, defatted soybean meal, moringa leaves powder (85:10:5, 80:13.75:6.25, 75:17.5:7.5, 70:21.25:8.75, 65:25:10) and five different feed rate (9, 10, 11, 12, 13 kg/h) the sample were bagged in polythene bags and store at room temperature for further analysis and analysis was performed by CCRD (Central composite rotatable design) in software design expert of Statease.

Statistical Design

To study the effect of process variables and process optimization, response surface methodology is widely used. RSM (response surface methodology) has some group of statistical and mathematical techniques which were used for the development of relation between independent and dependent variables (Khuri and Cornell, 1987; Baş & Boyacı, 2007) [26, 5]. Central composite rotatable design reduces the treatment up to 30 for 4 factor 5 level design. After determining coded range midpoint and centre point were obtained and levels for the decided range were found out. The interval for level was found by subtracting succeeding data from previous data shown in Table 1. The formula used for coded value is:

$$\text{Coded value} = \frac{\text{value of level} - \text{midpoint value}}{\text{Interval}} \dots (2.1)$$

Total number of treatments obtained by formula described by box and Wilson, in 1951

$$N = 2^k + 2k + n^0 \dots \dots \dots (2.2)$$

Where,

K (number of variables) = 4

Where,

(I) For factorial part, number of experiment = $2^k = 16$

(II) For axial part, number of experiment = $2k = 8$

(III) For Central point, number of experiment = $n^0 = 6$

Total number of experiment are = $16+8+6 = 30$

Table 1: Coded level for different variables

Process variables	Code	Coded level				
		-2	-1	0	1	2
Feed proportion, (p)	A	85:10:5	80:13.75:6.25	75:17.5:7.5	70:21.25:8.75	65:25:10
Feed rate, F (kg/h)	B	9	10	11	12	13
Screw speed S (rpm)	C	200	250	300	350	400
Barrel temperature, T(°C)	D	100	115	130	145	160

Physical properties

1. Determination of moisture content

The moisture content of composite flours and prepared extrudates were determined with the help of standard hot air oven method. The samples (15 g) were dried in the hot air oven at $102 \pm 2^\circ\text{C}$ for 24 hours. Three replications were done for each samples. The total dry samples or the initial moisture content of flours and prepared extrudates were determined in accordance with (AOAC, 1990) [4] and moisture content was calculated using formula.

$$\text{Moisture Content \%} = \frac{W_m}{W_m + W_d} \times 100 \dots \dots \dots (2.3)$$

Where,

Moisture content on wet basis, (percent)

W_m = Moisture evaporated, (g).

W_d = Bone dry weight, (g)

2. Determination of expansion ratio

To determine expansion ratio ten pieces were selected randomly from each sample. Diameter was measured by using vernier calliper and the expansion ratio was calculated by dividing the diameter of each Extruded sample with the diameter of die hole (Halek and Chang, 1992) [22]. Ten replications were taken.

$$\text{Expansion ratio} = \frac{\text{Diameter of Extruded product}}{\text{Diameter of die hole}} \dots \dots \dots (2.4)$$

3. Determination of bulk density

Bulk density of extrudates was determined by dividing the weight of the extrudates to the measured volume of the extrudates by using method described by (Grenus *et al.*, 1993, Ojokoh *et al.*, 2015) [20, 34]. Three replication of each treatment was done.

$$\text{Bulk density} \left(\frac{\text{kg}}{\text{m}^3} \right) = \frac{\text{Weight of sample}}{\text{value}} \dots \dots \dots (2.5)$$

4. Determination of True density

Toluene displacement method was used to determine true density of Extruded product. Extruded product was ground and approximately 2 gm was put in a burette containing toluene of known volume. Then displaced volume was measured. Two replication of each treatment was done. Final result was concluded by taking an average of readings taken. True density was calculated using following formula:

$$\text{True density} = \frac{\text{weight of ground sample (kg)}}{\text{Rise in toluene level (m}^3\text{)}} \dots \dots (2.6)$$

5. Determination of Porosity

It is defined as the proportion of empty space within bulk fruits, was determined in this study. It was calculated based on the true density and bulk density values using the following relationship.

$$\epsilon = 1 - \frac{\text{bulk density}}{\text{true density}} \times 100 \dots \dots \dots (2.7)$$

6. Determination of Water activity

The water activity of extrudate was determined by using water activity meter available in the department of P.F.E. laboratory. First, the sample was kept in the specimen port so as to cover full volume of port. The reading was then noted. It gives the direct reading of water activity of the sample. The reported values are the mean of three replicates

7. Determination of Water absorption index

Water Absorption Index was determined by using medico centrifuge (Plate-4.8) as per the method described by Carine *et al.*, 2010 [11]. Each 1 g (dry basis) ground samples were suspended in 20 ml of distilled water in a tared 45 ml centrifuge tube and be stirred with glass rod then put in water bath for 30 min at 30°C temperature then centrifuge at 3,000 rpm for 15 min. The supernatants liquid was poured into dry evaporator dishes. the weight of remaining gel was taken as WAI and expressed in the unit of g/g (Pardhi *et al.*,

2019) [37]. WAI would be calculating using following equation:

$$\text{Water absorption index } \left(\frac{g}{g}\right) = \frac{\text{weight of sediment}}{\text{weight of dry solid}} \dots (2.8)$$

Experimental design and statistical analysis

Optimization of processing variables carried out by Response Surface Methodology and Central Composite Rotatable Design (CCRD), which involves fitting a second-degree polynomial equation to the data and then using ANOVA to assess the model's performance. Analysis of variance (ANOVA) table was made to see the significant effects of the variables on the responses (Derringer & Suich, 1980, Sandhu *et al.*, 2019) [19, 43]. For this purpose, the experiments were conducted by using 5-level factorial design. Total number of experiments was 30 with 4 independent variables (feed proportion, feed rates, screw speed, and barrel temperature) and 7 responses (expansion ratio, bulk density, true density, porosity, water activity, and water absorption index). The function was assumed to be approximated by a second-degree polynomial equation (Rendon *et al.*, 2023) [39]

$$Y = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \beta_{ii} X_i^2 + \sum_{i=1}^3 \sum_{j=1}^3 \beta_{ij} X_i X_j + \epsilon \dots (2.9)$$

Where,

Y is the predicted response (dependent variable), $X_i X_j$ are the coded values of the process variables (these could be things like feed rate, temperature, screw speed, etc.), β_0 is the intercept (constant term), β_i are the first-order coefficients (effects of each variable), β_{ii} are the quadratic coefficients (effects of squared terms, representing the curvature of the response), β_{ij} are the interaction coefficients (effects of the interaction between two variables), ϵ is the error term (accounting for random variability in the response that the model does not explain). The desirability of the experimental values was calculated by using the desirability function approach, which transforms each response variable into a desirability score (ranging from 0 to 1) based on its target (maximum, minimum, or specific value). The desirability function depends on whether the goal is to maximize, minimize, or target a specific value. The general formula for desirability (d_i) (Bhaskar & Sahoo, 2020, Datta *et al.*, 2006) [8, 15]

For maximization

$$d_i = \left\{ \frac{y_i - \text{Min}}{\text{Max} - \text{Min}} \right\}^s \dots \dots \dots (2.10)$$

Where, y_i is the experimental value, and s is a shape factor (typically 1 for linear).

For minimization

$$d_i = \left\{ \frac{\text{Max} - y_i}{\text{Max} - \text{Min}} \right\}^s \dots \dots \dots (2.11)$$

The overall desirability (D) is the geometric mean of the individual desirability scores:

$$D = (d_1 \times d_2 \times d_3 \times d_4 \times d_5 \times d_6 \times d_7)^{\frac{1}{7}} \dots \dots \dots (2.12)$$

Where,

$d_1, d_2, d_3, d_4, d_5, d_6, d_7$ is Desirability for moisture content, expansion ratio, bulk density, true density, porosity, water activity, water absorption index

Results and Discussions

The experimental results are presented in Table 2. Regression coefficients were derived by fitting the experimental data to Equation (2.9). Polynomial model equations in terms of coded values for each response were developed for both cultivars using Response Surface Methodology (RSM). MC, ER, BD, TD, P, a_w and WAI represents the moisture content, expansion ratio, bulk density, true density, porosity, water activity, and water absorption index respectively. While A, B, C, and D correspond to feed proportion, feed rate (kg/h), screw speed (rpm), and barrel temperature ($^{\circ}\text{C}$), respectively. The goodness of fit for the model was evaluated using the coefficients of determination (R^2) and adjusted R^2 values. The influence of independent variables on the chemical and physical properties of the extrudates during extrusion was investigated through Response Surface Methodology (RSM) represent by ANOVA shown in Table 3. The analysis revealed that the independent variables had a highly significant effect ($p < 0.0001$) on the dependent variables, significant effect at ($p < 0.05$) and non significant effect at ($p > 0.05$).

Response surface analysis of Moisture Content

It is evident from the Table 2 that the moisture content was varied from 5.6 to 8.46. The minimum value of Moisture Content 5.6 was calculated at treatment twenty four (T-24). The composition of composite flour at treatment number twenty four is 75:17.5:7.5 (75% broken rice powder+ 17.5 % soybean meal+ 7.5% moringa leaves powder) for feed proportion (A), feed rate (B) 11kg/h, screw speed (C) 300 rpm and barrel temperature (D) 160 $^{\circ}\text{C}$. The effect of variation in independent variable on (MC) Moisture Content was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

$$\begin{aligned} \text{MC} = & 6.3633 - 0.2317\text{B} - 0.0733\text{C} - 0.6475\text{D} + \\ & 0.0380\text{AC} + 0.0400\text{BC} + 0.2304\text{BD} + 0.1369\text{CD} + \\ & 0.2531\text{A}^2 + 0.2806\text{B}^2 + 0.1031\text{C}^2 + \\ & 0.1144\text{D}^2 \dots \dots \dots (3.1) \end{aligned}$$

The Model F-value of 133.81 implies that the model is significant (p -value < 0.0001). The value of the coefficient of determination ($R^2 = 0.9921$) obtained for the response Moisture Content (MC) adequately explains 99.21% of the total variation in the response variable. The Lack of Fit F-value of 1.36 implies that the lack of fit is not significant relative to the pure error. The equation 3.1 suggests that Moisture Content (MC) is most strongly influenced by Barrel Temperature (D) and Feed Rate (B), with significant effects from their interactions and quadratic terms.

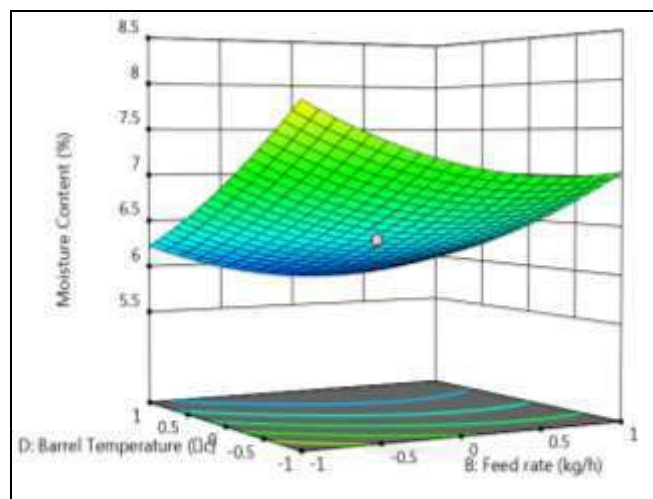


Fig 1: Response surface graph between feed rate and Barrel Temperature showing effect on moisture content

Increasing barrel temperature and screw speed leads to moisture loss shown in Fig. 1, while optimizing feed rate

and temperature can help maintain desired moisture levels in the extruded product.

Response surface analysis of Expansion Ratio

It is evident from the Table 2 that the expansion ratio was varied from 2.33 to 3.07. The maximum value of expansion ratio 3.07 was calculated at treatment seventeen (T-17). The composition of composite flour at treatment number seventeen is 85:10:5 (85% broken rice powder+ 10 % soybean meal+ 5% moringa leaves powder) for feed proportion (A), feed rate (B) 11kg/h, screw speed (C) 300 rpm and barrel temperature (D) 130 °C. The effect of variation in independent variable on (ER) expansion ratio was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

$$ER = +2.97 - 0.1900A + 0.0175AB + 0.0125AC - 0.0100AD + 0.0150BC + 0.0050BD + 0.0300CD - 0.0654A^2 - 0.0404B^2 - 0.0517C^2 - 0.0592D^2 \dots \dots (3.2)$$

Table 2: Variation in calculated values of dependent variables as affected by independent variables (CCRD matrix) for different treatments

Treatment	Independent variables				Dependent variables						
	A:feed proportion	B:feed rate	C:screw speed	D:barrel temperature	Moisture content	Expansion ratio	Bulk density	True density	porosity	Water activity	Water adsorption index
	Ratio	kg/h	Rpm	°c	%	Ratio	kg/m ³	kg/m ³			
1	80:13.75:6.25	10	250	115	8.24	2.99	116.6	2000	94.17	0.526	3.5
2	70:21.25:8.75	10	250	115	8.46	2.58	129	1176.4	89.034	0.54	4.57
3	80:13.75:6.25	12	250	115	7.36	2.93	133.58	1000	86.642	0.495	3.75
4	70:21.25:8.75	12	250	115	7.68	2.59	149.5	1060	85.896	0.538	4.45
5	80:13.75:6.25	10	350	115	8.06	2.9	130.01	2000	93.499	0.52	3.927
6	70:21.25:8.75	10	350	115	7.86	2.51	152.7	2000	92.365	0.493	4.956
7	80:13.75:6.25	12	350	115	7.25	2.88	167.81	1330	87.382	0.526	4.802
8	70:21.25:8.75	12	350	115	7.31	2.56	171.4	2000	91.43	0.521	4.79
9	80:13.75:6.25	10	250	145	6.6	2.98	115.16	1428	91.935	0.465	5.554
10	70:21.25:8.75	10	250	145	6.64	2.5	118.1	1000	88.19	0.483	6.85
11	80:13.75:6.25	12	250	145	6.24	2.92	113.3	1760	93.562	0.4026	5.465
12	70:21.25:8.75	12	250	145	6.2	2.51	111.8	1330	91.593	0.419	5.756
13	80:13.75:6.25	10	350	145	6.6	2.96	105.8	1660	93.626	0.488	5.945
14	70:21.25:8.75	10	350	145	6.5	2.56	101.3	1660	93.897	0.456	6.95
15	80:13.75:6.25	12	350	145	6.4	2.98	105.94	2000	94.703	0.443	5.954
16	70:21.25:8.75	11	350	145	6.4	2.65	97.9	2000	95.105	0.4394	6.302
17	85:10:5	11	300	130	7.3	3.07	100.52	1818	94.470	0.461	4.654
18	65:25:10	11	300	130	7.46	2.33	110.4	1400	92.114	0.472	6.08
19	75:17.5:7.5	9	300	130	7.85	2.81	106.7	2000	94.665	0.5104	5.875
20	75:17.5:7.5	13	300	130	7.13	2.79	130.23	1760	92.600	0.4657	5.554
21	75:17.5:7.5	11	200	130	6.96	2.77	113.03	1110	89.817	0.4709	5.75
22	75:17.5:7.5	11	400	130	6.6	2.74	118	2000	94.1	0.474	5.812
23	75:17.5:7.5	11	300	100	8.05	2.73	209	1250	83.28	0.5505	2.62
24	75:17.5:7.5	11	300	160	5.6	2.72	141.51	1000	85.849	0.411	5.667
25	75:17.5:7.5	11	300	130	6.53	2.95	140	1052	86.692	0.443	5.956
26	75:17.5:7.5	11	300	130	6.33	2.96	128.9	1250	89.688	0.434	5.655
27	75:17.5:7.5	11	300	130	6.33	2.97	129.4	1250	89.648	0.434	5.875
28	75:17.5:7.5	11	300	130	6.33	2.97	129.4	1250	89.648	0.434	5.845
29	75:17.5:7.5	11	300	130	6.33	2.97	129.4	1250	89.648	0.434	5.842
30	75:17.5:7.5	11	300	130	6.33	2.97	129.4	1250	89.648	0.434	5.852

The Model F-value of 376.65 implies that, it is significant ($p < 0.0001$). The value of coefficient of determination ($R^2 = 0.99$) obtained for the response ER, which adequately explains 99% of the total variation. The lack of fit F-value of 4.10 implies the lack of fit is not significant relative to the pure error. From equation 3.2, it was found that negative

sign of coefficient value of feed proportion indicates that with the increase in feed proportion there is decreased in expansion ratio and positive sign of barrel temperature indicates that with the increase in barrel temperature there is increase in expansion ratio. As the amount of fiber and protein increase in the blend there is decrease in expansion

ratio shown fig 2. Because it may affect the starch gelatinization and rheological properties of the material present in the extruder (Leonard *et al.*, 2015). When the ratio of starch to protein is increased, it leads to the formation of continuous starch matrix which enables the water vapour to expand. Because protein melts viscosity is

higher than starch melt viscosity (Omwama *et al.*, 2014) [35]. Moringa leaf powder is the significant factor which affects the expansion ratio. Expansion ratio is decreased significantly ($p < 0.05$) with the increase in moringa leaf powder in the feed as indicated by negative coefficient. (Sahoo *et al.*, 2014) [40]

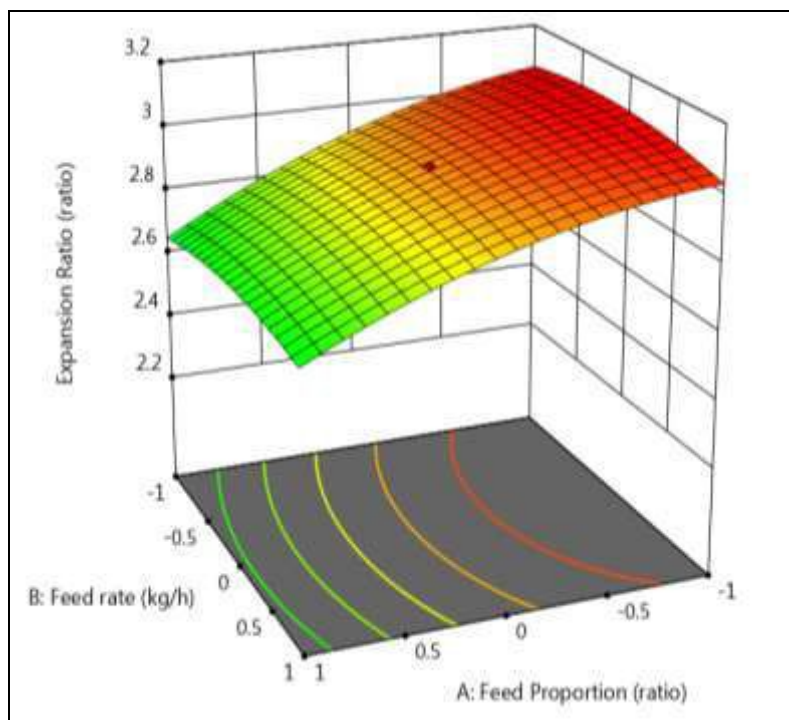


Fig 2: Response surface graph between feed rate and feed proportion showing effect on Expansion ratio

Response surface analysis of Bulk Density

The minimum value of bulk density (BD) 97.9 kg/m³ was obtained at treatment number sixteen. The feed composition ratio for treatment sixteen is (70:21.25:8.75) i.e. 70% broken

rice 21.25% of soybean meal and 8.75 % of moringa leaves powder for feed proportion (A), 11kg/h for feed rate, 350 rpm for barrel temperature and 145 °C for barrel temperature.

Table 3: ANOVA showing effect of independent variable on dependent variable

Source	F-value							
	MC %	ER ratio	BD Kg/m ³	TD Kg/m ³	P %	a _w	WAI	
Model	133.81**	376.65**	75.17**	14.47**	15.15**	92.27**	61.55**	Significant
A-Feed Proportion	1.94 ^{NS}	4040.21**	10.60 ^{NS}	7.00*	5.19*	2.27 ^{NS}	97.46**	
B-Feed rate	155.79**	0.0000 ^{NS}	44.50**	1.87 ^{NS}	6.77*	82.76**	3.50 ^{NS}	
C-Screw speed	15.61*	0.6995 ^{NS}	8.24*	70.58**	28.01**	0.6240 ^{NS}	19.68*	
D-Barrel Temperature	1217.03**	1.94 ^{NS}	459.01**	0.1143 ^{NS}	23.96*	768.00**	536.33**	
AB	1.09 ^{NS}	22.85*	2.21 ^{NS}	7.91*	6.34*	9.84*	18.76*	
AC	4.60*	11.66*	1.02 ^{NS}	17.26*	11.09*	41.08**	1.94 ^{NS}	
AD	1.89 ^{NS}	7.46*	17.15*	1.92 ^{NS}	0.2068 ^{NS}	1.12 ^{NS}	0.0465 ^{NS}	
BC	4.84*	16.79*	2.27 ^{NS}	0.7089 ^{NS}	0.0363 ^{NS}	28.23**	2.51 ^{NS}	
BD	27.87**	1.87 ^{NS}	44.14**	32.17**	30.15**	58.04**	14.07**	
CD	16.56	67.15**	78.61**	0.2795 ^{NS}	0.4675 ^{NS}	14.91*	0.9158 ^{NS}	
A ²	212.56**	547.35**	80.89**	16.08*	26.90*	58.30**	13.16*	
B ²	261.26**	208.93**	22.09*	43.34**	31.11**	148.47**	1.13 ^{NS}	
C ²	35.28**	341.44**	32.20**	12.23 ^{NS}	13.36*	79.06**	0.3269 ^{NS}	
D ²	43.40**	447.76**	197.32**	0.3426	23.42*	113.29**	160.24**	
Residual								
Lack of Fit	P=0.3862	P=0.0665	P=0.6841	P=0.0744	P=0.6260	P=0.0778	P=0.0602	Not significant
Std. Dev	0.0909	0.0146	3.97	137.90	1.14	0.0062	0.1774	
C.V%	1.31	0.5246	3.10	9.18	1.25	1.31	3.31	
R ²	0.9921	0.9972	0.9859	0.9310	0.9340	0.9885	0.9829	

** Highly significant at 1% level, * significant at 5% level, NS not significant

The second order polynomial Regression equation was developed for expressing the effect of independent variables on the bulk density (BD) in which the non-significant terms were excluded.

$$BD = +131.08 + 2.64A + 5.40B + 2.32C - 17.35D - 4.11AD - 6.59BD - 8.79CD - 6.81A^2 - 3.56B^2 - 4.30C^2 + 10.64D^2 \dots \dots \dots (3.3)$$

The Model F-value of 75.17 implies that, it is significant ($p < 0.0001$). The value of coefficient of determination ($R^2 = 0.98$) obtained for the response BD, which adequately explains 98% of the total variation. The lack of fit F-value of 0.73 implies the lack of fit is not significant relative to the pure error. Table 3 represents ANOVA for bulk density in which Screw speed and feed proportion emerge at 5% level of significance. AD, BD, CD, and A^2 , B^2 , C^2 , D^2 are interaction and quadratic significant model terms at 1% and 5% level of significance.

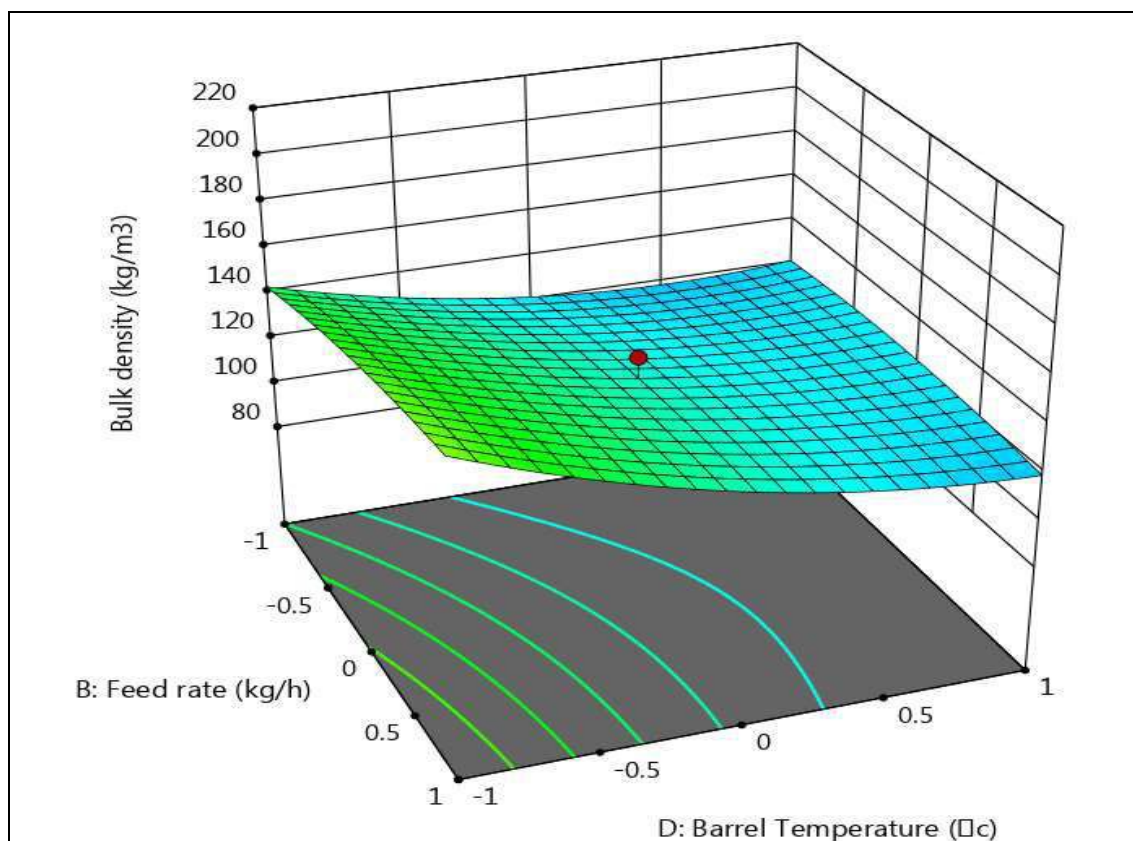


Fig 3: Response surface graph between feed rate and barrel temperature showing effect on Bulk Density

From equation 3.3 a negative coefficient value of barrel temperature (D) indicates that with increase in barrel temperature (D) there is decrease in bulk density shown in fig 3. High temperature provides more thermal input leading to complete gelatinization (Dehghan-Shoar, Hardacre, & Brennan, 2010) [16]. Positive coefficient indicates that with increase in feed rate there is increase in bulk density. Positive sign of feed proportion indicates with increase in feed proportion bulk density increases. Bulk density relationship with Barrel temperature and screw speed was showing minimal interaction with both temperature and screw speed contributing to lower bulk density at different periods similar results were found by Seker 2005 [44], Hagenimana *et al.*, 2006 [21], Sharma 2012 [46], Kumari 2020 [29].

Response surface analysis of True Density

It is obvious from Table 2 that true density was varied from 1000 to 2000 kg/m³. The smallest value of true density was obtained at treatment number ten (T-10) and treatment number three (T-3). The value of independent variable for treatment number ten was feed proportion (70:21.25:8.75) i.e. 70% broken rice, 21.25 % defatted soybean meal, 8.75% moringa leaf powder, feed rate 10 kg/h, screw speed 250

rpm, 145 °C barrel temperature. The value of independent variable for treatment number three is (80:13.75:6.25) i.e. 80% broken rice powder, 13.75% defatted soybean meal, 6.25% moringa leaves powder 12 kg/h feed rate, 250 rpm screw speed, 115 °C barrel temperature. The second order polynomial Regression equation was developed for expressing the effect of independent variables on the true density TD.

$$TD = +1.22 - 0.0745A + 0.2365C + 0.0970AB + 0.1432AC - 0.0478AD + 0.1955BD + 0.1056A^2 + 0.1733B^2 + 0.0921C^2 \dots \dots \dots (3.4)$$

The Model F-value of 14.47 implies that, it is significant ($p < 0.0001$). The value of coefficient of determination ($R^2 = 0.93$) obtained for the response TD, which adequately explains 93% of the total variation. The lack of fit F-value of 0.0190 implies the lack of fit is not significant relative to the pure error. Table 3 represent the effect of independent variable on true density, in which highest F-value obtained at 1% level of significance. The feed rate and barrel temperature having lower F value and had the non

significant effect on true density. Screw speed had higher F value which shows highly significant effect on true density. Equation 3.4 Positive sign of coefficient value of screw speed and feed rate indicates that with increase in screw speed there is increase in true density and Negative sign of coefficient value of feed proportion indicates that with increase in feed proportion there is decrease in true density. Interaction terms highlight the complexity of these relationships, suggesting that the effect of one factor can be amplified or reduced by others. Quadratic terms indicate that the effect of A, B, and C on TD are nonlinear, with higher values of these factors producing progressively larger changes in TD.

Response surface analysis of Porosity

It is evident from the Table 2 that the porosity was varied from 83.28 to 95.105. The maximum value of expansion

ratio 95.105 was calculated at treatment sixteen (T-16). The composition of composite flour at treatment number sixteen is (70:21.25:8.75) i.e. 70% broken rice 21.25% of soybean meal and 8.75 % of moringa leaves powder for feed proportion (A), 11kg/h for feed rate, 350 rpm for barrel temperature and 145 °C for barrel temperature. The effect of variation in independent variable on porosity (P) was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

$$P = 89.162 - 0.5300A - 0.6055B + 1.2313C + 1.1388D + 0.7174AB + 0.9489AC + 1.5646BD + 1.1287A^2 + 1.2139B^2 + 0.7954C^2 - 1.0531D^2 \dots \dots \dots (3.5)$$

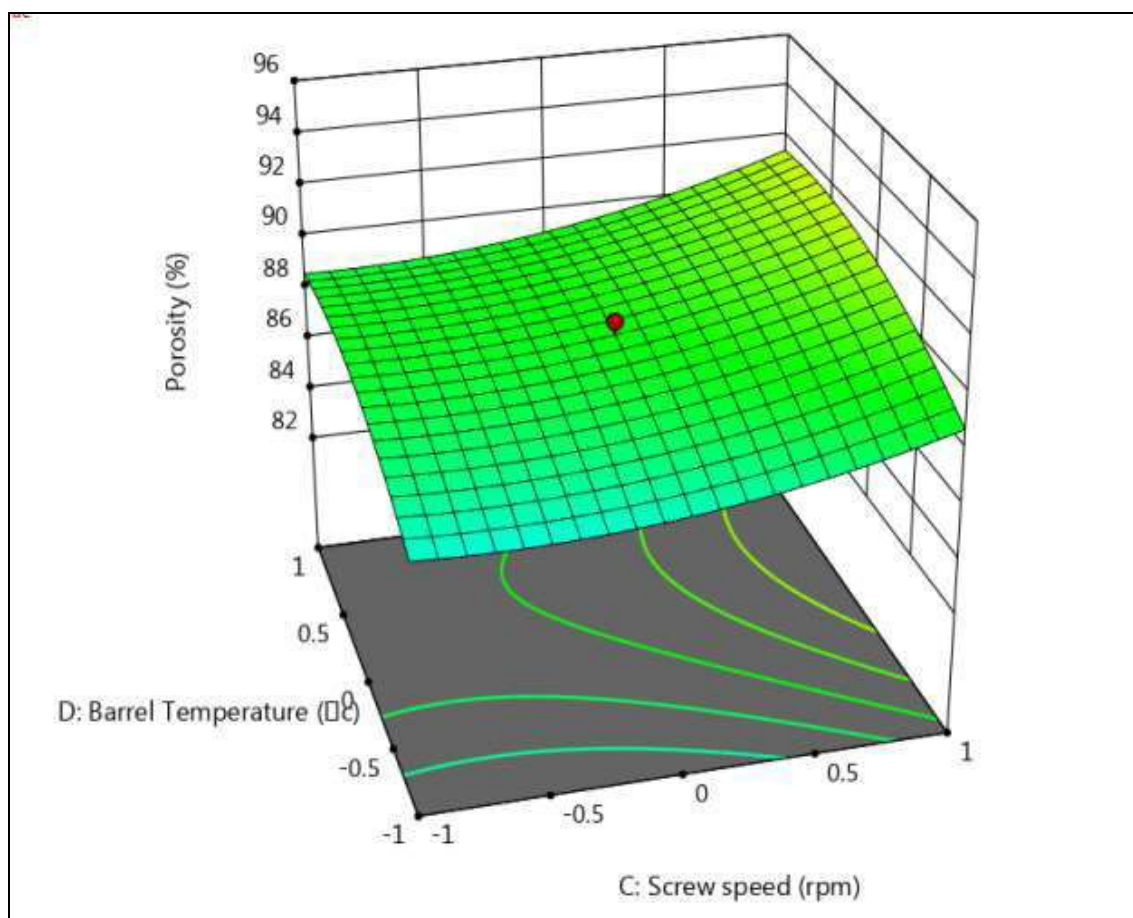


Fig 4: Response surface graph between barrel temperature and screw speed showing effect on Porosity

The Model F-value of 15.15 implies that the model is significant ($p < 0.0001$). The coefficient of determination (R^2) = 0.9339, which means the model explains 93.39% of the total variation in porosity. The Adjusted R^2 value of 0.8723 is in reasonable agreement with the Predicted R^2 of 0.7268 which is indicating a good fit of the model. The Lack of Fit F-value of 0.83 implies that the lack of fit is not significant relative to the pure error ($p = 0.6260$), which is desirable as it suggests the model fits well. Equation 3.5 and Fig 4. indicates that screw speed (C) and barrel temperature (D) have a positive impact on porosity, which indicates that an increase in these parameters leads to higher porosity. But feed proportion (A) and feed rate (B) had negative effect on porosity which implied that higher values of these factors

reduce porosity. The presence of quadratic terms A^2 , B^2 , C^2 indicates a non-linear relationship which means increasing these factors initially enhances porosity but may reach an optimal point beyond which the effect stabilizes. However, D^2 has a negative coefficient which indicating that excessive barrel temperature can reduce porosity.

Response surface analysis of Water Activity

It is obvious from Table 2 that the variation in water activity was from 0.4026 to 0.5505. The smallest value for water activity was 0.4026 obtained at treatment number eleven (T-11). The feed proportion value for treatment number eleven (T-11) was (80:13.75:6.25) i.e. 80% broken rice powder, 13.75% defatted soybean meal, 6.25% moringa leaves

powder, 12 kg/h feed rate, 250 rpm screw speed, 145 °C barrel temperature. The second order polynomial multiple regression equation was developed for explaining the variation effect in independent variables on the water activity and the non significant terms were excluded.

$$a_w = +0.4355 - 0.0115B - 0.0351D + 0.0049AB - 0.0099AC + 0.0082BC - 0.0118BD + 0.0060CD + 0.0090A^2 + 0.0144B^2 + 0.0105C^2 + 0.0126D^2 \dots \dots \dots (3.4)$$

The Model F-value of 92.27 implies that, it is significant ($p < 0.0001$). The value of coefficient of determination ($R^2 = 0.98$) obtained for the response a_w , which adequately explains 98% of the total variation. The lack of fit F-value of 3.77 implies the lack of fit is not significant relative to the pure error. ANOVA Table 3 shows the effect of all independent variables on water activity (a_w). Barrel temperature showed a highly significant effect on water activity (a_w), with a high F-value at the 1% significance level. Feed rate also had a significant impact at the 5% level. The feed proportion and screw speed having lower F value had the non-significant effect on water activity (a_w).

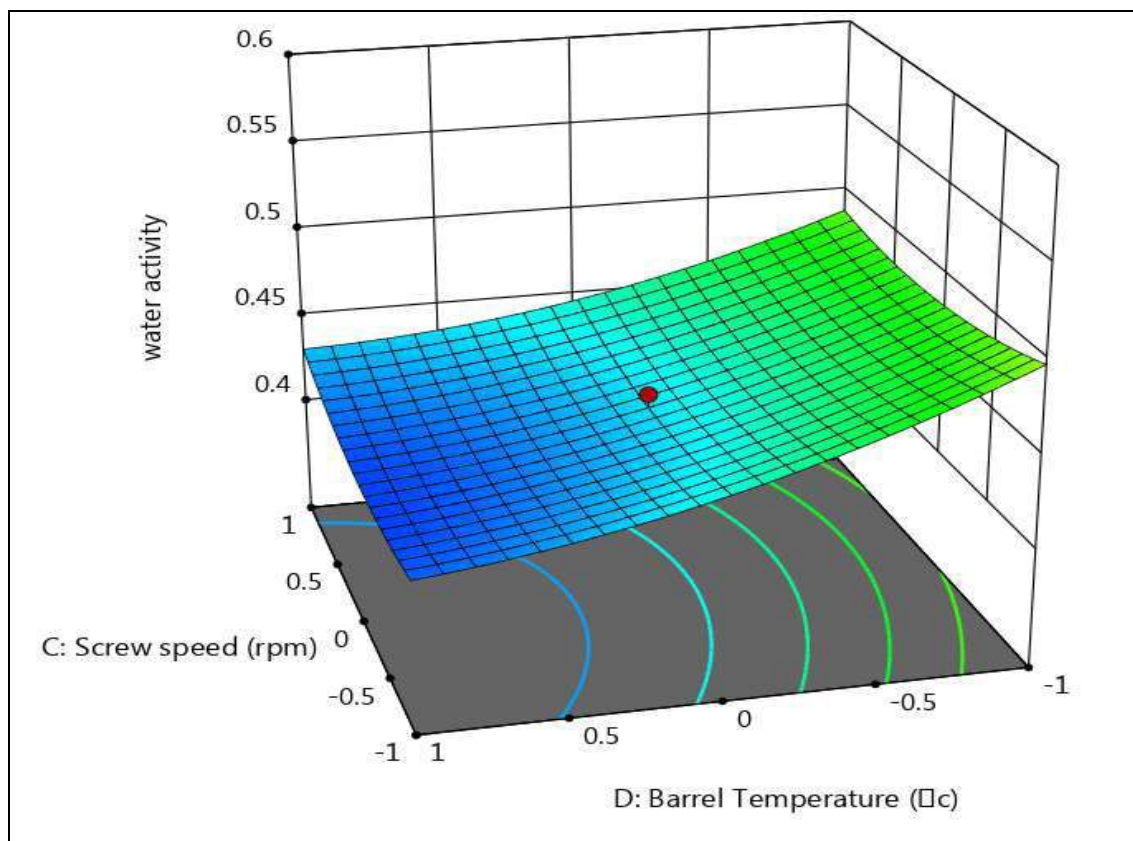


Fig 5: Response surface graph between screw speed and barrel temperature showing effect on water activity

From equation 3.6 and Fig. 5 It is found that negative coefficients of feed rate and barrel temperature indicate that with the increase in barrel temperature and feed rate there is decrease in water activity affected by barrel temperature. Increasing barrel temperature and feed rate will introduce more energy to the material in the barrel which would enhance the moisture evaporation at die exit and here decrease water activity.

Response surface analysis of Water Absorption Index

It is evident from the Table 2 that the Water Absorption Index was varied from 2.62 to 6.95. The maximum value of expansion ratio 6.95 was calculated at treatment fourteen (T-14). The composition of composite flour at treatment number fourteen is 70:21.25:8.75 (70% broken rice powder + 21.25 % soybean meal+8.75% moringa leaves powder) for feed proportion (A), feed rate (B) 10kg/h, screw speed (C) 350 rpm and barrel temperature (D) 145 °C. The effect of variation in independent variable on Water Absorption Index was explained by development of second order

polynomial multiple regression equation. In this equation non significant terms were excluded.

$$WAI = 5.8375 + 0.3575A + 0.1606C + 0.8385D - 0.1921AB - 0.1663BD - 0.1229A^2 - 0.4287D^2 \dots \dots \dots (3.7)$$

The Model F-value of 61.55 indicates that the model is highly significant ($p < 0.0001$). The coefficient of determination ($R^2 = 0.9829$) indicates that the model explains 98.29% of the total variation in WAI which demonstrating a good fit. The lack of fit F-value of 4.31 suggests that the lack of fit is not significant relative to the pure error ($p = 0.0602$) which is confirming that the model is suitable for prediction. ANOVA Table 3 shows the effect of all independent variables on water absorption index. Barrel temperature showed a highly significant effect on Water Absorption Index (WAI) with a high F-value at the 1% significance level. Feed rate also had a significant impact at the 5% level. However, feed proportion and screw

speed had non-significant effects on WAI, as indicated by their lower F-values. The equation (3.7) and Fig. 6 shows that feed proportion, screw speed, and barrel temperature all

have positive coefficients, indicating that increasing these parameters leads to an increase in the Water Absorption Index (WAI) (Kumar, Sarkar, & Sharma, 2010) [28].

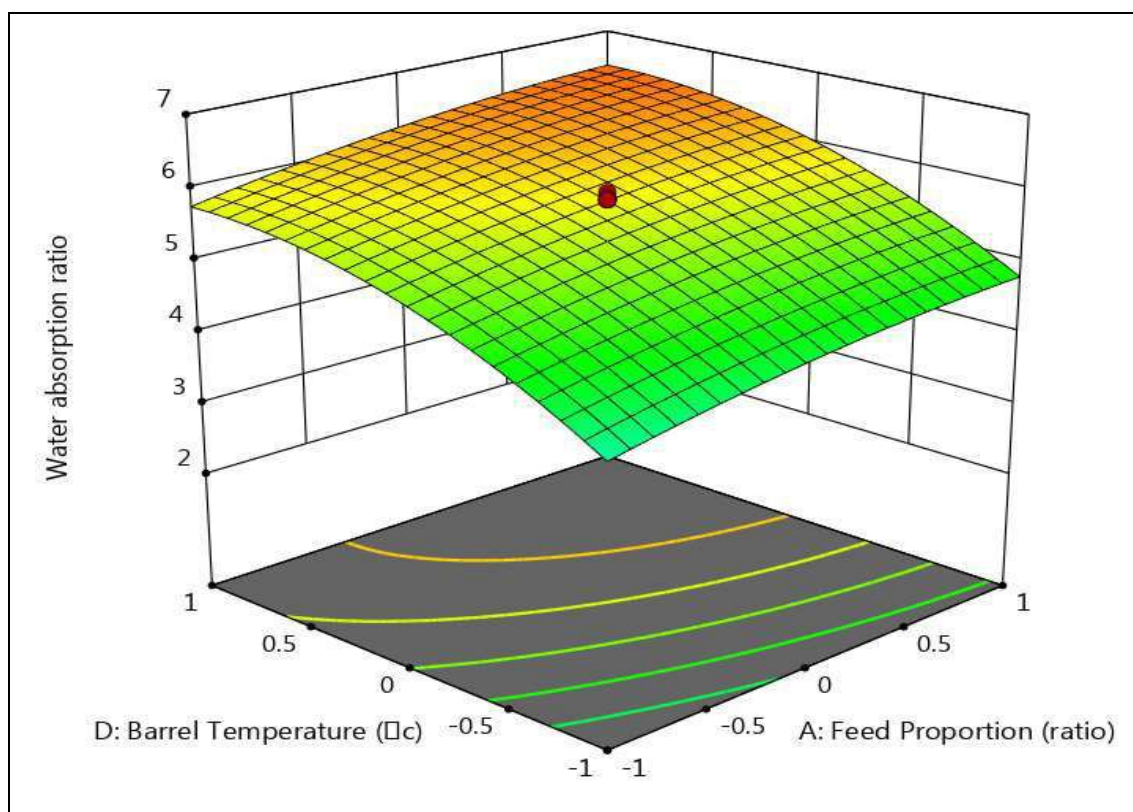


Fig 6: Response surface graph between Barrel temperature and feed proportion showing effect on water absorption index

Water absorption index of the extrudates increased with increase the barrel temperature probably due to increased dextrinization at higher temperature (Mercier & Fillet, 1975, Alam *et al.*, 2016) [32, 2]. The decrease in WAI related to the degradation of starch that cause a reduction in the water holding capacity of the molecules as a result of decrease in the molecules size (Anderson *et al.* 1969; Mercier & fillet 1975) [3, 32].

Optimization and Validation of the Optimum Solution

Statistical package was used for carrying out optimization of experiments. Statease design expert version 13 was used for Central composite rotatable design. In order to obtain optimal solution, the developed model were further analyzed to determine the corresponding stationary points and to explore the nature of response surface around these points

Table 4 shows the stationary points for dependent response variables. Validation of optimize condition was done to test and compare the prediction performance with experimental results. Optimum solution was selected and prepared as extrudates of their dependent variables for validation experiment. The observations recorded with respect to the optimum response dependent are summarized in Table 4. The independent variable feed proportion(A), feed rate(B), screw speed(C) and barrel temperature(D) were optimize for minimization of moisture content(MC), bulk density(BD), true density(TD), water activity(a_w), maximization of expansion ratio(ER), porosity (P) and Water absorption index(WAI). The response variables are analyzed for their predicted and experimental values, along with their standard deviations (Std. dev) and coefficients of variation (C.V%).

Table 4: Comparison of Predicted and Experimental responses obtained from recommended optimized condition

Optimal conditions for independent variable			Response variable							
Variables	Coded value	Actual value	Variable	Maximum	minimum	Target	Predicted value	Experimental	Std. dev	C.V%
Feed proportion	0	75:17.5:7.5	Moisture content	8.46	5.6	Minimum	5.89	5.62	0.191	3.317
Feed rate (kg/h)	0	11	Expansion ratio	3.07	2.33	Maximum	2.98	2.99	0.007	0.237
Screw speed (rpm)	0	300	Bulk density	209	97.9	Minimum	123.78	121.88	1.344	1.094
Barrel temperature (°C)	1	145	True density	2000	1000	Minimum	1269.92	1251.94	12.714	1.008
			Porosity	95.105	83.28	Maximum	89.82	90.26	0.311	0.346
			Water activity	0.5505	0.4026	Minimum	0.4096	0.4035	0.004	1.061
			water absorption index	6.95	2.62	Maximum	7.32	7.01	0.219	3.059
			Desirability				0.785	0.847		

It was seen that experimental data for response were in close agreement with solution obtained from response surface methodology and hence the optimum condition can be recommended for extruded product at its best effectiveness. The experimental results for the response variables exhibited strong alignment with the predicted values, validating the accuracy and reliability of the optimization process. The moisture content was determined to be 5.62%, slightly lower than the predicted 5.89% was indicating improved drying efficiency. The expansion ratio was nearly identical with the experimental value of 2.99 compared to the predicted 2.98 which was confirming the expected puffing effect. Bulk density was measured at 121.88 kg/m³ was marginally lower than the predicted value 123.78 kg/m³, while true density decreased to 1251.94 kg/m³ from the predicted 1269.92 kg/m³ which indicating a slightly lighter and less dense product. Porosity increased to 90.26% from the predicted 89.82% which was reflecting a more porous structure. Water activity was recorded at 0.4035 which was slightly below the predicted value 0.4096 which indicating enhanced stability against microbial growth. The water absorption index was 7.01 which is slightly lower than the predicted value 7.32, pointing a minor reduction in water retention capacity. The overall desirability of the process is 0.785 for the predicted value and 0.847 for the experimental value which reflect the process is a highly optimized. These findings indicate that the extrusion process has been successfully fine-tuned to yield a product with favorable response variable. The strong correlation between the predicted and experimental results, combined with the low variability which validates the reliability and effectiveness of the optimization process.

Conclusion

This study successfully optimized the extrusion conditions for developing novel extruded snacks from industrial by-products (broken rice powder and defatted soybean meal) fortified with Moringa leaf powder, leveraging Response Surface Methodology (RSM) and a Central Composite Rotatable Design (CCRD). The developed second-order polynomial models demonstrated high significance ($p < 0.0001$) and an excellent fit ($R^2 > 0.93$ for all responses). With increasing Feed rate, screw speed the moisture content of the product decreases. An increase in the Feed proportion led to increase in bulk density and Water absorption index. An increase in Feed rate led to increase in bulk density and water activity. With increase in screw speed led to increase in bulk density, True density, Porosity Water absorption index. An increase in the Feed proportion led to increase in expansion ratio, True density and Porosity. With increasing barrel temperature the moisture content and porosity of the product decreases. The optimal conditions identified are a feed proportion of 75:17.5:7.5, feed rate of 11 kg/h, screw speed of 300 rpm and barrel temperature of 145 °C for minimizing true density. These settings effectively achieved the desired outcomes for all response variables, including minimized moisture content, water activity, bulk and true densities and maximized expansion ratio, porosity and water absorption index. The experimental desirability of 0.847 was higher than the predicted desirability 0.785 which is showing that the optimized settings of feed proportion, feed rate, screw speed, and barrel temperature delivered superior results such as moisture content 5.62%, expansion ratio was 2.99, Bulk density was 121.88 kg/m³, true density was

1251.94 kg/m³, Porosity was 90.26, Water activity was 0.4035, water absorption index was 7.01. These findings highlight the potential of RSM and CCRD for optimizing extrusion processes to create value-added snack products from underutilized resources. This confirms the effectiveness and reliability of the optimization process in meeting the desired outcome.

Declaration of Conflicting Interest

I declared that, there is no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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References

1. Ajita T. Extrusion cooking technology: An advance skill for manufacturing of extrudate food products. In: Qamar SZ, editor. Extrusion of Metals, Polymers and Food Products. InTech; 2018. <https://doi.org/10.5772/intechopen.73496>
2. Alam MS, Pathania S, Sharma A. Optimization of the extrusion process for development of high fibre soybean-rice ready-to-eat snacks using carrot pomace and cauliflower trimmings. LWT-Food Science and Technology. 2016;74:135-144. <https://doi.org/10.1016/j.lwt.2016.07.031>
3. Anderson RA, Conway HF, Pfeifer VF, Griffin LE Jr. Gelatinization of corn grits by roll-and extrusion cooking. Cereal Science Today. 1969;14(4):11-12.
4. AOAC. Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists; 1990.
5. Baş D, Boyacı İH. Modeling and optimization I: Usability of response surface methodology. Journal of Food Engineering. 2007;78(3):836-845. <https://doi.org/10.1016/j.jfoodeng.2005.11.024>
6. Bautista R, Counce P. An overview of rice and rice quality. Cereal Foods World. 2020;65(5):0052. <https://doi.org/10.1094/CFW-65-5-0052>
7. Bernacchia R, Preti R, Vinci G. Organic and conventional foods: Differences in nutrients. Italian Journal of Food Science. 2016;28(4):565-578. <https://doi.org/10.14674/1120-1770/ijfs.v224>
8. Bhaskar P, Sahoo SK. Optimization of machining process by desirability function analysis (DFA): A review. CVR Journal of Science and Technology. 2020;18(1):138-143. <https://doi.org/10.32377/cvrjst1824>
9. Brennan C, Brennan M, Derbyshire E, Tiwari BK. Effects of extrusion on the polyphenols, vitamins and antioxidant activity of foods. Trends in Food Science and Technology. 2011;22(10):570-575. <https://doi.org/10.1016/j.tifs.2011.05.007>
10. Camire ME, Dougherty MP, Briggs JL. Functionality of fruit powders in extruded corn breakfast cereals. Food Chemistry. 2007;101(2):765-770. <https://doi.org/10.1016/j.foodchem.2006.02.031>

11. Carine S, Kong X, Hua Y. Optimization of extrusion flour composed of corn, millet, and soybean. *Pakistan Journal of Nutrition*. 2010;9(3):291-297.
12. Choton S, Gupta N, Bandral JD, Anjum N, Choudary A. Extrusion technology and its application in food processing: A review. *The Pharma Innovation Journal*. 2020;9(2):162-168.
<https://doi.org/10.22271/tpi.2020.v9.i2d.4367>
13. Cortes RNF, Guzmán IV, Martínez-Bustos F. Effects of some extrusion variables on physicochemical characteristics of extruded corn starch-passion fruit pulp (*Passiflora edulis*) snacks. *Plant Foods for Human Nutrition*. 2014;69(4):365-371.
<https://doi.org/10.1007/s11130-014-0443-8>
14. Dahiwalé M, Champawat PS, Jain SK. Performance of hot air puffing system for corn. *International Journal of Current Microbiology and Applied Sciences*. 2018;7(10):2540-2550.
<https://doi.org/10.20546/ijcmas.2018.710.295>
15. Datta S, Bandyopadhyay A, Pal PK. Desirability function approach for solving multi-objective optimization problem in submerged arc welding. *Journal for Manufacturing Science and Production*. 2006;7(2):127-138.
<https://doi.org/10.1515/IJMSP.2006.7.2.127>
16. Dehghan-Shoar Z, Hardacre AK, Brennan CS. The physico-chemical characteristics of extruded snacks enriched with tomato lycopene. *Food Chemistry*. 2010;123(4):1117-1122.
<https://doi.org/10.1016/j.foodchem.2010.05.071>
17. Demarco A, Gibon V. Overview of the soybean process in the crushing industry. *OCL-Oilseeds and Fats, Crops and Lipids*. 2020;27:60.
<https://doi.org/10.1051/ocl/2020047>
18. Dendegh TA, Yelmi BM, Abdullahi MJ. Extrusion technology: A tool for value addition to food by-products and wastes. *Archives of Current Research International*. 2021;21(3):39-58.
<https://doi.org/10.9734/acri/2021/v21i330236>
19. Derringer G, Suich R. Simultaneous optimization of several response variables. *Journal of Quality Technology*. 1980;12(4):214-219.
<https://doi.org/10.1080/00224065.1980.11980968>
20. Grenus KM, Hsieh F, Huff HE. Extrusion and extrudate properties of rice flour. *Journal of Food Engineering*. 1993;18:229-245.
21. Hagenimana A, Ding X, Fang T. Evaluation of rice flour modified by extrusion cooking. *Journal of Cereal Science*. 2006;43(1):38-46.
22. Halek S, Chang J. Effect of screw configuration and speed on RTD and expansion of rice extrudates. *Journal of Food Engineering*. 1992;19(3):153-170.
23. Hirth M, Leiter A, Beck SM, Schuchmann HP. Effect of extrusion cooking process parameters on the retention of bilberry anthocyanins in starch based food. *Journal of Food Engineering*. 2014;125:139-146.
<https://doi.org/10.1016/j.jfoodeng.2013.10.034>
24. Hossain MF, Numan SM, Khan SS, Mahbub S, Akhtar S. Human consumption, nutritional value and health benefits of Moringa (*Moringa oleifera* Lam.): A review. *International Journal of Community Medicine and Public Health*. 2022;9(9):3599-3607.
<https://doi.org/10.18203/2394-6040.ijcmph20222229>
25. Kang SW, Rahman MS, Kim AN, Lee KY, Park CY, Kerr WL, Choi SG. Comparative study of the quality characteristics of defatted soy flour treated by supercritical carbon dioxide and organic solvent. *Journal of Food Science and Technology*. 2017;54(8):2485-2493. <https://doi.org/10.1007/s13197-017-2691-8>
26. Khuri AI, Cornell JA. *Response Surfaces: Design and Analysis*. Marcel Dekker; 1987.
27. Korkerd S, Wanlapa S, Puttanlek C, Uttapap D, Rungsardthong V. Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. *J Food Sci Technol*. 2016;53(1):561-570.
<https://doi.org/10.1007/s13197-015-2039-1>
28. Kumar N, Sarkar BC, Sharma HK. Development and characterization of extruded product of carrot pomace, rice flour, and pulse powder. *Afr J Food Sci*. 2010;4(11):703-717.
29. Kumari B. Development of process technology for preparation of maize-soybean-pomegranate pomace extrudates [thesis]. Krishikosh; 2020.
<https://krishikosh.egranth.ac.in/handle/1/5810156404>
30. Leonard MP, Yusuph RA, Mrema GD. Physical properties of extruded snacks enriched with soybean and moringa leaf powder. *Afr J Food Sci Technol*. 2015;6(1):28-34.
31. Limberger VM, Comarela CG, Patias LD, Brum FB, Emanuelli T, Silva LPD. Produção de salgadinho extrusado de quirera de arroz para uso na indústria de alimentos. *Cienc Rural*. 2009;39(9):2590-2594.
<https://doi.org/10.1590/S0103-84782009000900032>
32. Mercier C, Feillet P. Modification of carbohydrate components by extrusion cooking of cereal products. *Cereal Chem*. 1975;52(2):283-297.
33. Nisha R, Nickhil C, Pandiarajan T, Pandiselvam R, Jithender B, Kothakota A. Chemical, functional, rheological and structural properties of broken rice-barnyard millet-green gram grits blend for the production of extrudates. *J Food Process Eng*. 2023;46(5):e14324. <https://doi.org/10.1111/jfpe.14324>
34. Ojokoh AO, Yimin W, Eromosele OS. Effect of some extrusion variables on fermented maize-soybean blend. *J Food Sci Technol*. 2015;52(9):5763-5771.
<https://doi.org/10.1007/s13197-014-1689-8>
35. Onwamba M, Mahungu SM. Development of a protein-rich ready-to-eat extruded snack from a composite blend of rice, sorghum, and soybean flour. *J Food Nutr Sci*. 2014;5(12):1309-1317.
36. Ouhit A, Al-sharbaty G, Gupta F, Fursi. Potato chips and childhood: What does the science say? An unrecognized threat? *Nutr Rev*. 2014;30(10):1110-1112.
37. Pardhi SD, Singh B, Nayik GA, Dar BN. Evaluation of functional properties of extruded snacks developed from brown rice grits by using response surface methodology. *J Saudi Soc Agric Sci*. 2019;18(1):7-16.
<https://doi.org/10.1016/j.jssas.2016.11.006>
38. Patil RT, De J Berrios J, Tang J, Swanson BG. Evaluation of methods for expansion properties of legume extrudates. *Appl Eng Agric*. 2007;23(6):777-783. <https://doi.org/10.13031/2013.24044>
39. Rendon ME, Beltran-Medina E, Guatemala-Morales G, Padilla-Camberos E, Corona-González R, Mondragón-

- Cortez P, *et al.* Optimization of extrusion conditions for an extruded food enriched with mango by-products (*Mangifera indica* var. Tommy Atkins) via response surface methodology. *Processes*. 2023;11(11):3182. <https://doi.org/10.3390/pr11113182>
40. Sahoo NR, Panda MK, Mohapatra M, Bakhra CK. Process optimization for development of extruded product from rice flour and moringa leaf blend. *Oryza*. 2014;51(3):226-234.
 41. Salgado N, Giraldo GI, Orrego CE. Influence of the extrusion operating conditions on the antioxidant, hardness and color properties of extruded mango. *LWT*. 2017;86:209-218. <https://doi.org/10.1016/j.lwt.2017.07.049>
 42. Samyori D, Deka SC, Das AB. Effect of extrusion conditions on the physicochemical and phytochemical properties of red rice and passion fruit powder based extrudates. *J Food Sci Technol*. 2018;55(12):5003-5013. <https://doi.org/10.1007/s13197-018-3439-9>
 43. Sandhu RS, Singh N, Kaler R, Singh B. Optimization of process parameters for preparation of rice extrudates from short and long Indica rice cultivars milled to varying degree of milling. *J Food Sci Technol*. 2019;56(5):2467-2479. <https://doi.org/10.1007/s13197-019-03724-7>
 44. Seker M. Selected properties of native or modified maize starch/soy protein mixtures extruded at varying screw speed. *J Sci Food Agric*. 2005;85(7):1161-1165.
 45. Sereewat P, Suthipinitham C, Sumathaluk S. Cooking properties and sensory acceptability of spaghetti made from rice flour and defatted soy flour. *J Food Sci Technol*. 2015;60(2):1061-1067.
 46. Sharma C. Development of extruded snacks utilizing broken rice and mung bean [thesis]. Ludhiana: Punjab Agricultural University; 2012. <http://krishikosh.egranth.ac.in/handle/1/5810025059>
 47. Shimelis EA, Rakshit SK. Effect of processing on antinutrients and *in vitro* protein digestibility of kidney bean (*Phaseolus vulgaris* L.) varieties grown in East Africa. *Food Chem*. 2005;103(1):161-172.
 48. Singh P, Krishnaswamy K. Sustainable zero-waste processing system for soybeans and soy by-product valorization. *Trends Food Sci Technol*. 2022;128:331-344. <https://doi.org/10.1016/j.tifs.2022.08.015>
 49. Singh P, Kumar R, Sabapathy SN, Bawa AS. Functional and edible uses of soy protein products. *Compr Rev Food Sci Food Saf*. 2008;7(1):14-28. <https://doi.org/10.1111/j.1541-4337.2007.00025.x>
 50. Spilisbury. A balanced diet. *Nutr Rev*. 2009;10(12):357-357. <https://doi.org/10.1111/j.1753-4887.1952.tb01052.x>
 51. Tamilselvi NA, Arumugam T. Health benefits, therapeutic and pharmacological properties of moringa—A review. *J Pharm Res Int*. 2019;25(1):1-11. <https://doi.org/10.9734/JPRI/2018/37179>
 52. Toomer OT, Oviedo EO, Ali M, Patino D, Joseph M, Frinsko M, *et al.* Current agronomic practices, harvest & post-harvest processing of soybeans (*Glycine max*)—A review. *Agronomy*. 2023;13(2):427. <https://doi.org/10.3390/agronomy13020427>
 53. Visser A, Thomas A. Review: Soya protein products—their processing, functionality, and application aspects. *Food Rev Int*. 1987;3(1-2):1-32. <https://doi.org/10.1080/87559128709540806>
 54. Watchararuj K, Goto M, Sasaki M, Shotipruk A. Value-added subcritical water hydrolysate from rice bran and soybean meal. *Bioresour Technol*. 2008;99(14):6207-6213. <https://doi.org/10.1016/j.biortech.2007.12.021>