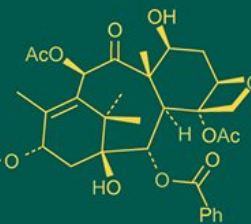
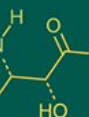
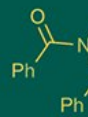


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Impact of extrusion process on sensory properties of extruded product prepared from defatted soybean meal, and broken rice fortified with moringa leaf powder

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Abstract

This study investigates the sensory properties of extruded snacks made from defatted soybean meal, broken rice (an industrial byproduct), and moringa leaf powder. A blend of these ingredients was prepared in varying proportions and conditioned to optimal moisture content before extrusion using a twin-screw extruder. The extrusion process was optimized using Response Surface Methodology (RSM) with a Central Composite Rotatable Design (CCRD) to study the effects of feed proportion, feed rate, screw speed, and barrel temperature on sensory attributes. Sensory evaluation, conducted using a 9-point hedonic scale, assessed color, hardness, crispiness, appearance, taste, odor, and overall acceptability. Second-order regression models were developed for each response variable, achieving an $R^2 > 0.60$. Statistical analysis using ANOVA confirmed the model's significance ($p < 0.0001$). The optimized conditions are feed proportion of 80:13.75:6.25, feed rate of 10 kg/h, screw speed of 250 rpm, and barrel temperature of 145 °C resulted in an extruded product with high sensory scores such as color (8.1), taste (7.56), hardness (8.2), crispiness (7.75), appearance (7.9), odor (7.0), and overall acceptability (7.75). The desirability function for predicted and optimization was 0.802 and 0.875 which is confirming the model's accuracy. The results indicate that higher moringa leaf powder levels negatively affect color and taste, while increased barrel temperature improves sensory quality. This study demonstrates the potential for utilizing industrial byproducts in nutritious extruded snack formulations with high consumer acceptability.

Keywords: Hedonic scale, sensory evaluation, optimization, response surface analysis

Introduction

Extruded snacks have gained significant popularity due to their diverse textures, shapes, and flavors, offering convenience and broad consumer appeal (Brennan *et al.*, 2013; Panak Balentić *et al.*, 2018) ^[7, 42]. Recent research has focused on developing healthier and more sustainable snacks by incorporating food industry by-products such as fruit and vegetable pomace, oilseed cakes, and cereals (Grasso, 2020) ^[21]. The food industry generates a substantial amount of by-products annually, which, if properly utilized, can be transformed into value-added products (Sirani & Ganesharanee, 2009; Kothakota, 2013; Delgado *et al.*, 2021) ^[15, 31]. Defatted soybean meal and broken rice are two such by-products, both of which are nutrient-rich and highly beneficial for the development of extruded products (Jamora *et al.*, 2001) ^[27]. These by-products can be expanded either directly or indirectly during extrusion, the latter allowing for greater ingredient versatility and nutritional enhancement (Panak Balentić *et al.*, 2018) ^[42]. While traditional extruded snacks are often energy-dense but nutritionally deficient, there is substantial potential to improve their nutritional profiles by incorporating bioactive components such as dietary fiber, proteins, and micronutrients (Brennan *et al.*, 2013; Lucas *et al.*, 2017; Coulter & Lorenz, 1991) ^[7, 12, 36]. Several studies have explored the effects of extrusion conditions and ingredient composition on snack characteristics (Yoshitomi *et al.*, 2004) ^[66]. Variables such as moisture content, barrel temperature, and the addition of by-products can significantly influence expansion, texture, and sensory properties (Ding *et al.*, 2006; Salgado. *et al.*, 2017) ^[17, 50].

Extrusion technology is widely used for producing various products, including breakfast cereals, pasta, and texturized vegetable protein (Alam *et al.*, 2016) [1].

As consumer demand for healthier snack options continues to rise, the food industry has substantial opportunities to develop nutritionally enhanced and appealing extruded products (Brennan *et al.*, 2013) [7]. Consumer preferences play a significant role in snack consumption patterns, which are also influenced by socioeconomic factors. For example, younger, single individuals with lower incomes and education levels tend to consume extruded snacks more frequently (Menis-Henrique *et al.*, 2017; Heinio *et al.*, 2003) [24, 38]. The global snack market is evolving, driven by consumer demand for healthier options and diverse textures. While traditional snacks remain popular, there is an increasing interest in products with improved nutritional profiles (Harada-Paderno *et al.*, 2021) [23]. Texture plays a crucial role in consumer acceptance, with crispy textures generally preferred across cultures (Wong *et al.*, 2020; Jakubczyk *et al.*, 2015; Luyten *et al.*, 2004) [37, 26]. However, cultural differences exist, such as Chinese and Korean consumers' preference for puffy textures (Wong *et al.*, 2020) [64]. In response, the snack industry is reformulating traditional products and developing novel snacks that balance health benefits with appealing flavors and textures (de Azeredo *et al.*, 2022) [14]. Understanding consumer preferences and leveraging insights from the global market are essential for successful product development and marketing strategies in the evolving snack food landscape (Harada-Paderno *et al.*, 2020) [23].

Extruded snacks are well-regarded in the food industry for their convenience, versatility, and appealing sensory characteristics such as crispiness, flavor, and texture (Chen *et al.*, 1991; Saeleaw *et al.*, 2012) [49, 9]. The quality of extruded snacks is directly influenced by extrusion conditions such as barrel temperature, feed moisture content, and pressure (Mohammed Ali *et al.*, 2024) [68]. The incorporation of ingredients like textured soy flour and whole wheat flour can affect textural properties, including hardness, fracturability, and crispness (Rodríguez-Vidal *et al.*, 2017) [46]. While many existing ready-to-eat snacks are high in sugar and salt, there is a clear opportunity to develop healthier alternatives that meet consumer demands for convenience without compromising sensory appeal (Brennan *et al.*, 2013) [7]. Optimizing extrusion parameters is crucial to producing nutrient-rich snacks with desirable physical, functional, and sensory properties (Mohammed Ali *et al.*, 2024) [68].

The sensory properties of extruded snacks, such as color, hardness, crispiness, appearance, taste, odor, and overall acceptability, are key determinants of consumer acceptance (Navarro-Cortez *et al.*, 2018; Elina *et al.*, 2016; Cheng *et al.*, 2007) [10, 18, 40]. These attributes are directly influenced by the extrusion process parameters, and therefore, understanding the relationships between these variables is essential for producing high-quality snacks (Delgado *et al.*, 2021) [15]. By employing response surface methodology (RSM) with central composite design (CCD), it becomes possible to quantitatively assess the impact of extrusion

parameters such as feed proportion, feed rate, screw speed, and barrel temperature on the sensory characteristics of extruded snacks (Chapanzana & Buckle, 1997; Raleng *et al.*, 2016; Awolu *et al.*, 2015) [5, 44].

This study aims to optimize the extrusion process for snacks prepared from defatted soybean meal and broken rice, fortified with moringa leaf powder on the basis of sensory attributes, by utilizing RSM and CCD. The objective is to evaluate how extrusion parameters such as feed proportion, feed rate, screw speed, and barrel temperature affect the sensory properties of the extruded products. The hypothesis is that RSM with CCD will allow for the identification of optimal extrusion conditions that enhance the sensory attributes of the final snack products. This research is expected to provide valuable insights into process optimization, potentially leading to the development of innovative, healthier, and consumer-accepted extruded snacks.

Materials and methods

Preparation of extruded product

A blend of broken rice powder, defatted soybean meal, and moringa leaf powder was prepared in different proportions and conditioned to optimal moisture content. Extrusion was performed using twin screw extruder as the process described in Fig. 1. The independent variables such as feed proportion, feed rate, screw speed, barrel temperature and levels were selected. 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). A comprehensive description of the preparation of the extruded product using defatted soybean meal, broken rice, and moringa leaf powder was provided in my previous paper Verma and Sharma (2025) [62]. Prepared extruded product of each treatment was packed in zip lock polythene bag.

Statistical Design

Response Surface Methodology (RSM) statistical design was employed to investigate the effect of process variables on the sensory properties of the extruded product. A Central Composite Rotatable Design (CCRD) was utilized, which efficiently reduced the number of experimental treatments to 30 for a 4-factor, 5-level design. The coded range, midpoint, and center point were determined based on preliminary experiments, and the levels for each factor were established within the decided range showed in coded level table 1. The interval between levels was calculated by subtracting the succeeding data point from the previous one, ensuring a systematic and precise distribution of factor levels. This approach allowed for a comprehensive analysis of the interaction effects of process variables on the sensory attributes of the extruded product, optimizing the experimental design while minimizing resource utilization.

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

Process of Sensory Evaluation

Sensory evaluation is a scientific discipline used to measure and interpret responses to product properties through the senses (Fiorentini *et al.*, 2020; Sirangelo, 2019) ^[54]. It plays a crucial role in consumer acceptance and product development, particularly for novel foods like plantbased food (Fiorentini *et al.*, 2020) ^[19]. Sensory analysis is a scientific discipline with specific purposes, which measures and explores the stimuli perceived by the senses against different variants. This integrated approach enhances the understanding of key product attributes and improves the overall quality of results in food science and consumer product industries (Sirangelo, 2019; Palmay-Paredes *et al.*, 2023) ^[41]. To the customer point of view organoleptic characteristics such as: colour, taste, hardness, crispiness, odour, appearance and overall acceptability are an important attribute for acceptability of a food product. The extrudates were tested for organoleptic attributes. A Proforma consisting of basic organoleptic characteristic was prepared and evaluated in a 9-point hedonic scale as per method (Ranganna, 1986). The primary objective of using the 9-point hedonic scale is to assess consumer acceptability or preference for a product (Lim & Green, 2009; Lawless *et al.*, 2010; Kalva *et al.*, 2014) ^[33, 29, 34].

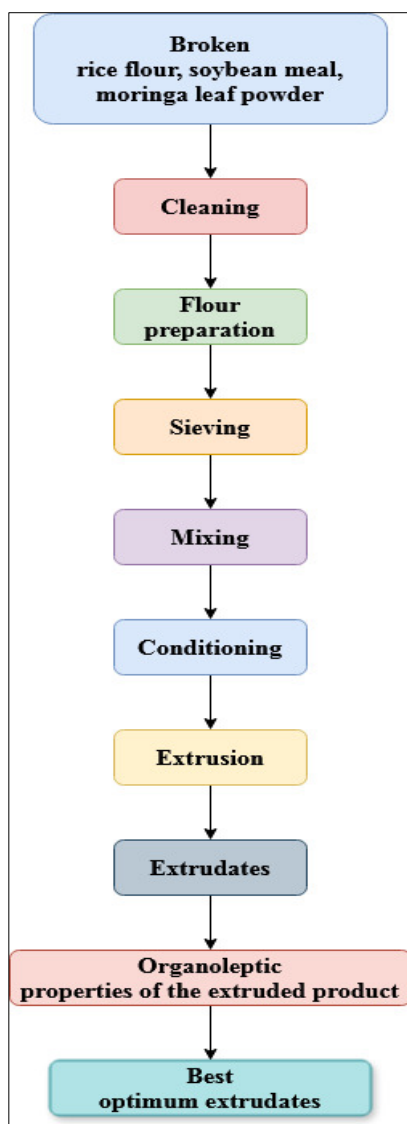


Fig 1: Flow chart representing various experimental procedures for Preparation of extruded product

It is particularly useful for the determination of the quality product and for comparing multiple products or formulations to determine which is most preferred by the target audience.

Test method

The quality of extrudates produced can be determined using different methods according to their applicability in a variety of food-industry sectors. The 9-point hedonic scale is classified as an affective test used in the sensory evaluation of extruded product. This scale specifically measures consumer preferences and acceptability of food products by allowing participants to express their degree of liking or disliking for a product. It consists of nine categories ranging from "dislike extremely" ^[1] to "like extremely" ^[9], with a neutral midpoint ^[5] indicating neither like nor dislike (Lawless *et al.*, 2010) ^[33]. This scale is widely utilized in the food industry for assessing consumer acceptance of both food and non-food products, making it one of the most popular tools for sensory testing globally. The proforma for the sensory evaluation of the extruded product is given in Fig 2.

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Proforma of Sensory Evaluation
DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

Name of Judge: _____
Date: _____

Please judge the following qualities of extrudates and give score/marks out of 9 based on the following:

Quality	Score/Marks
Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike Moderately	3
Dislike very much	2
Dislike Extremely	1

Extrudates samples:

Sample no.	Colour	Hardness	Crispiness	Taste	odour	Appearance	Overall Acceptability
1							
2							
3							
4							
5							
6							
..							
29							
30							

Signature of Evaluator _____

Fig 2: Proforma for sensory evaluation

Panelist selection and training

Seventeen professor were selected as panelist to conduct the test for sensory evaluation and Training program was conducted to ensure that the selected panelist were equipped with the necessary skills and knowledge required to perform accurate and consistent sensory evaluations of extruded products. Initially, participants were introduced to the scale with detailed explanations provided for assessing each sensory attribute, including color, taste, hardness, crispiness, appearance, odor, and overall acceptability which is shown in Fig 2. Blank sample (water) was provided to prevent taste contamination between evaluations. The sensory evaluation sessions were conducted in a controlled environment, ensuring optimal lighting and seating arrangements to minimize external influences. Demonstration of proper method for assessing each attribute of extruded product was provided.

Collection of data

Data collection was conducted during the final sensory evaluation session, where each professor independently rated the extruded products using the 9-point hedonic scale. All the thirty combinations of the extrudates were kept on the paper plate starting from 1 to 30 for the sensory evaluation by the panelist. The panelists were asked to evaluate and assign marks for different quality attributes out of 9. The samples were presented in a randomized order to minimize potential bias, and the evaluators assessed the sensory attributes color, taste, hardness, crispiness, appearance, odor, and overall acceptability based on their individual perceptions. Blank samples were provided between evaluations to avoid taste contamination. Ratings for each sensory attribute were systematically recorded for each product, ensuring that each attribute was evaluated independently. The mean sensory score for all the quality attributes taste, texture, colour, odour and overall acceptability is shown in table 2. The collected data was then compiled for subsequent analysis to assess the overall sensory quality of the extruded products and to optimize the process parameter.

Experimental design

To optimize the sensory attributes of the extruded products, a Response Surface Methodology (RSM) was employed. RSM allow for efficient evaluation of multiple factors and

their interactions to identify the optimal conditions for sensory quality. Central Composite Rotatable Design (CCRD) was applied to reduce the number of total experiments, which come to 30 for 4 factor 5 level design as presented under Table 2. The independent variables considered in this study included processing parameters such feed proportion, feed rate, screw speed and barrel temperature. The sensory attributes evaluated using the 9-point hedonic scale were dependent variable such as color, taste, hardness, crispiness, appearance, odor, and overall acceptability.

Statistical analysis

The sensory evaluation data were analyzed using the statistical tools provided by RSM and CCD. Descriptive statistics, such as means and standard deviations, were calculated for each sensory attribute across the product samples. The relationship between the independent variables (processing conditions) and the sensory attributes was modeled using second-order polynomial equations (Sandhu *et al.*, 2019.)^[51].

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

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). Analysis of variance (ANOVA) was applied to test the significance of the model terms and to identify the optimal levels of the processing parameters. Additionally, regression analysis was conducted to determine the effect of each factor and their interactions on the sensory attributes of the extruded products.



Fig 3: Final prepared extrudates of different treatment

Result and Discussion

The sensory evaluation of the extruded products was conducted to assess the impact of feed proportion, feed rate, screw speed, and barrel temperature on key sensory attributes, including color, taste, hardness, crispiness, appearance, odour, and overall acceptability. The results

obtained from the sensory panel were statistically analyzed using response surface methodology (RSM) with central composite design (CCD). Table 2 presents the sensory scores for different extrusion conditions. 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 ($p > 0.05$). Table 3 represents the ANOVA for all the dependent variables in relation to the independent variables. It provides an analysis of variance to assess the influence of the independent variables on the dependent variables. Second order polynomial equation was made for all dependent variable. The equation includes intercept, main effect, interaction, and quadratic terms. Main effects show the individual impact of each factor, interaction effects highlight how two factors interact to affect the response, and quadratic effects capture how the impact of each factor changes non-linearly as its level increases or decreases.

Effect on Color

It is evident from table 2 the liking of color varied from minimum 5.69 to maximum 7.99. The maximum value of

color was calculated at treatment nineteen (T-19). The composition of composite flour at treatment number nineteen 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) 9 kg/h, screw speed (C) 300 rpm and barrel temperature (D) 130 °C. The effect of variation in independent variable on color of extruded product was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

$$\begin{aligned} \text{Color} = & 7.188 - 0.183A - 0.054B + 0.073D + 0.143AC \\ & - 0.090AD - 0.124BC + 0.091BD \\ & - 0.160CD - 0.312A^2 + 0.169B^2 \\ & - 0.246D^2 \dots \dots \dots (3.1) \end{aligned}$$

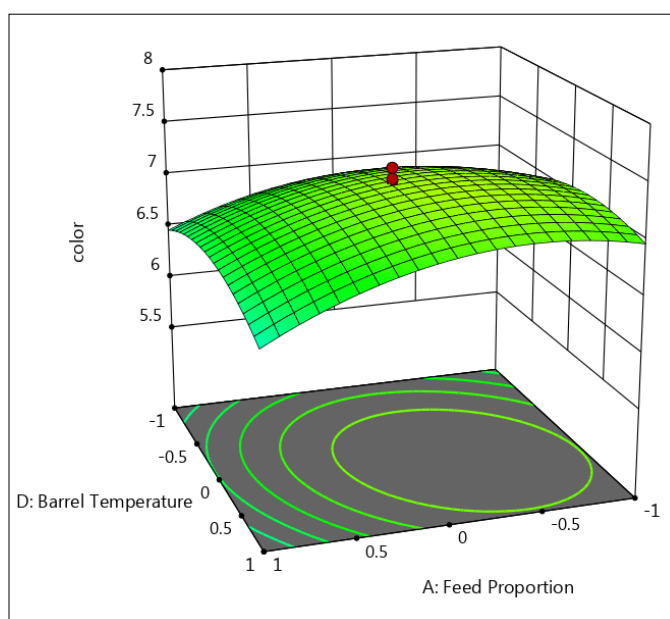


Fig 4: 3D Surface Graph Showing Effect of Feed Proportion and Barrel Temperature on Color

The Model F-value of 39.53 implies that the model is significant ($p < 0.0001$). The coefficient of determination ($R^2 = 0.974$) indicates that the model explains 97.36% of the total variation. The lack of fit F-value of 1.26 suggests that the lack of fit is not significant relative to the pure error. In Equation 3.1 the negative sign associated with the feed proportion (A) and feed rate (B) indicates that increasing the levels of defatted soybean meal and moringa leaf powder results in a decrease in the color preference of the extruded product shown in Fig 3. This may be due to the dark green

color contributed by moringa leaf powder, which negatively impacts the overall color perception of the product (Govender & Siwela, 2020; Liu *et al.*, 2000) [20, 35]. Barrel temperature has a positive sign, indicating that higher temperatures improve color preference. This is likely due to the Maillard reaction, which enhances browning and visual appeal, making the product more desirable to consumers. Increased temperatures also improve color and overall acceptability (Coțovanu *et al.*, 2023; Starowicz & Zieliński, 2019, Suknark *et al.*, 2019) [56, 11]

Table 2: Variation in calculated values of dependent variables as affected by independent variables

Treatment	Independent variables				Dependent variables						Overall acceptability
	A:feed proportion	B:feed rate	C:screw speed	D:barrel temperature	Color	Taste	Hardness	Crispiness	Appearance	Odour	
	Ratio	kg/h	Rpm	°c							
1	80:13.75:6.25	10	250	115	6.66	6.99	7.31	6.88	7.1	6.76	6.95
2	70:21.25:8.75	10	250	115	6.32	6.45	6.44	5.81	6.11	6.23	6.23
3	80:13.75:6.25	12	250	115	6.84	6.71	7.46	7.08	6.99	6.85	6.99
4	70:21.25:8.75	12	250	115	6.22	5.92	6.64	5.88	6.8	6.21	6.28
5	80:13.75:6.25	10	350	115	7.16	7.43	6.9	6.65	6.71	7.18	7.01
6	70:21.25:8.75	10	350	115	7.28	6.9	5.67	6.89	6.31	7.17	6.70
7	80:13.75:6.25	12	350	115	6.53	6.71	7.48	7.17	6.86	6.54	6.88
8	70:21.25:8.75	12	350	115	6.55	6.65	6.34	6.9	7.36	6.63	6.74
9	80:13.75:6.25	10	250	145	7.25	7.62	8.31	7.61	7.39	7.27	7.58

10	70:21.25:8.75	10	250	145	6.5	6.49	7.26	6.75	6.71	6.5	6.70
11	80:13.75:6.25	12	250	145	7.54	7.18	7.48	7.38	6.59	7.51	7.28
12	70:21.25:8.75	12	250	145	6.57	6.76	6.46	6.39	6.87	6.67	6.62
13	80:13.75:6.25	10	350	145	6.79	7.18	7.86	6.22	6.78	6.79	6.94
14	70:21.25:8.75	10	350	145	6.69	6.98	6.45	6.96	6.51	6.69	6.71
15	80:13.75:6.25	12	350	145	6.87	6.91	7.65	6.47	6.11	6.97	6.83
16	70:21.25:8.75	11	350	145	6.43	6.65	6.19	6.54	6.84	6.43	6.51
17	85:10:05	11	300	130	6.34	6.82	7.42	6.69	6.43	6.24	6.66
18	65:25:10	11	300	130	5.69	5.92	5.2	5.99	6.21	5.59	5.77
19	75:17.5:7.5	9	300	130	7.99	8.3	7.97	7.27	7.46	8.02	7.84
20	75:17.5:7.5	13	300	130	7.89	7.69	7.76	7.39	7.91	7.99	7.77
21	75:17.5:7.5	11	200	130	7.29	6.56	7.52	7.27	7.18	7.19	7.17
22	75:17.5:7.5	11	400	130	7.25	6.91	6.75	7.22	6.88	7.15	7.03
23	75:17.5:7.5	11	300	100	6.11	5.73	6.21	5.79	6.47	6.01	6.05
24	75:17.5:7.5	11	300	160	6.45	6.75	7	5.95	6.1	6.35	6.43
25	75:17.5:7.5	11	300	130	7.1	7.36	7.18	6.74	6.84	7.05	7.05
26	75:17.5:7.5	11	300	130	7.23	7.32	7.26	6.97	6.78	7.21	7.13
27	75:17.5:7.5	11	300	130	7.15	7.43	7.25	6.77	6.92	7.15	7.11
28	75:17.5:7.5	11	300	130	7.05	7.87	7.22	6.72	6.86	7.08	7.13
29	75:17.5:7.5	11	300	130	7.35	7.19	7.11	6.99	6.98	7.05	7.06
30	75:17.5:7.5	11	300	130	7.25	7.22	7.26	6.82	6.89	7.15	7.10

Effect on Taste

It is evident from table 2 the liking of Taste varied from minimum 5.73 to maximum 8.3. The maximum value of color was calculated at treatment nineteen (T-19). The composition of composite flour at treatment number nineteen 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) 9 kg/h, screw speed (C) 300 rpm and barrel temperature (D) 130 °C. The effect of variation in independent variable on taste of extruded product was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

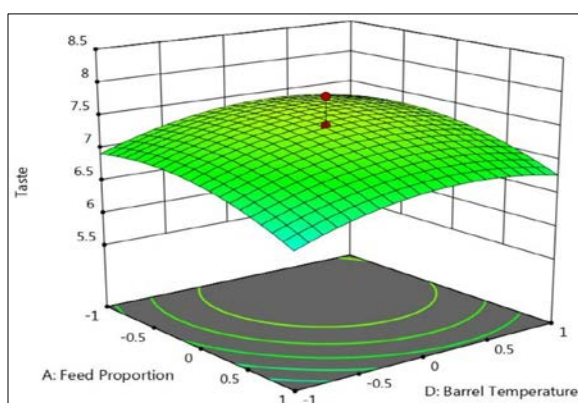


Fig 5: 3D Surface Graph Showing Effect of Feed Proportion and Barrel Temperature on Taste

The Model F-value of 16.65 implies that the model is significant ($p < 0.0001$). The coefficient of determination ($R^2 = 0.940$) indicates that the model explains 93.95% of the total variation. The Lack of Fit F-value of 0.42 suggests that the lack of fit is not significant relative to the pure error.

In Equation 3.2, the negative sign associated with the feed proportion (A) and feed rate (B) indicates that increasing the levels of defatted soybean meal and moringa leaf powder leads to a decrease in the taste preference of the extruded product, as shown in Fig. 4. While moringa is known to enhance the nutritional profile of foods, its strong flavor and green coloration can negatively impact sensory characteristics and consumer acceptance (Trigo *et al.*, 2023)^[60]. Research suggests that lower levels of fortification (less than 10%) may help minimize adverse effects on taste and texture (Ariani *et al.*, 2023)^[3]. Studies on bread, muffins, noodles, and ice cream fortified with MOLP consistently show that increasing MOLP concentration tends to decrease taste acceptability (Govender & Siwela, 2020; Jung, 2016; Mpalanzi *et al.*, 2023; Handayani *et al.*, 2022)^[22, 39, 20, 28]. Barrel temperature exhibits a positive effect, indicating that higher temperatures enhance taste preference. This is attributed to the elevated temperatures during extrusion promoting the Maillard reaction, which generates flavor compounds such as pyrazines and furans. These compounds contribute to the development of desirable toasted cereal flavors, improving overall taste acceptance (Coțovanu *et al.*, 2023)^[11].

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

Source	Color	Taste	Hardness	Crispiness	Appearance	Odour	OA	
value	F	F	F	F	F	F	F	
Model	39.53**	16.65**	460.24**	47.75**	43.37**	64.31**	167.23**	Significant
A-Feed Proportion	56.78**	36.54**	3529.84**	89.73**	10.84*	98.03**	523.82**	
B-Feed rate	5.00*	15.82*	16.54*	0.313 ^{NS}	14.70*	3.21*	10.60 ^{NS}	
C-Screw speed	0.3031 ^{NS}	4.41*	371.47**	0.0256 ^{NS}	14.35*	0.4663 ^{NS}	5.49*	
D-Barrel Temperature	9.17*	18.25*	488.54**	7.61*	7.08*	17.14*	75.55**	
AB	3.92 ^{NS}	1.26 ^{NS}	0.4221 ^{NS}	12.42*	102.19**	1.85 ^{NS}	2.07 ^{NS}	
AC	23.08*	5.59*	64.21**	143.83**	34.94**	33.66**	95.54**	
AD	9.21*	0.0135 ^{NS}	22.70*	9.51*	9.91*	9.19*	0.9251 ^{NS}	
BC	17.41*	0.5811 ^{NS}	124.39**	2.77 ^{NS}	6.46*	20.68*	0.2855 ^{NS}	
BD	9.46*	1.70 ^{NS}	401.28**	14.58*	58.11**	14.16*	11.42*	

CD	29.10**	6.35*	0.2931 ^{NS}	91.11**	18.57*	44.07**	104.08**	
A ²	190.02**	47.75**	641.62**	37.33**	77.86**	282.6**	546.28**	
B ²	55.62**	16.69*	351.99**	43.30**	119.27**	139.10**	314.83**	
C ²	0.0041 ^{NS}	19.72*	3.75 ^{NS}	30.15**	2.09 ^{NS}	0.1332 ^{NS}	6.2398 ^{NS}	
D ²	117.95**	60.68**	287.83**	147.25**	87.05**	173.86**	508.71**	
Residual								
Lack of Fit	1.26	0.416	0.412	0.6349	2.09	2.74	2.48	Not significant
Std. Dev	0.1186	0.1935	0.0462	0.1021	0.0905	0.0957	0.0507	
C.V%	1.73	2.78	0.6565	1.52	1.33	1.4	0.7373	
R ²	0.9736	0.9395	0.9977	0.9781	0.9759	0.9836	0.9936	

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

Effect on Hardness

It is evident from table 2 the liking of Hardness varied from minimum 5.2 to maximum 8.31. The maximum value of Hardness was calculated at treatment ten (T-9). The composition of composite flour at treatment number nine is 80:13.75:6.25 (80% broken rice powder+ 13.75% soybean meal+ 6.25% moringa leaves powder) for feed proportion (A), feed rate (B) 9 kg/h, screw speed (C) 250 rpm and barrel temperature (D) 145 °C. The effect of variation in independent variable on Hardness of extruded product was explained by development of second order polynomial multiple regression equation. In this equation non-significant terms were excluded.

$$\begin{aligned} \text{Hardness} = & 7.213 - 0.560A - 0.038B - 0.182C \\ & + 0.208D + 0.008AB - 0.093AC \\ & - 0.055AD + 0.129BC - 0.231BD \\ & - 0.223A^2 + 0.165B^2 \\ & - 0.150D^2 \dots \dots \dots (3.3) \end{aligned}$$

In equation 3.3, The negative coefficients for factors A, B, and C suggest that increasing the levels of feed proportion (i.e., an increase in the percentage of defatted soybean meal and moringa leaf powder, and a decrease in the percentage of broken rice), feed rate, and screw speed leads to a decrease in hardness acceptability shown in Fig.5. This can be attributed to the fact that higher levels of soybean meal and moringa leaf powder, along with elevated feed rates and screw speeds, may result in softer, less cohesive products with reduced texture quality. Previous studies have shown that increased screw speeds in soy-based extrudates lead to softer and lighter products (Ribeiro *et al.*, 2024) [45].

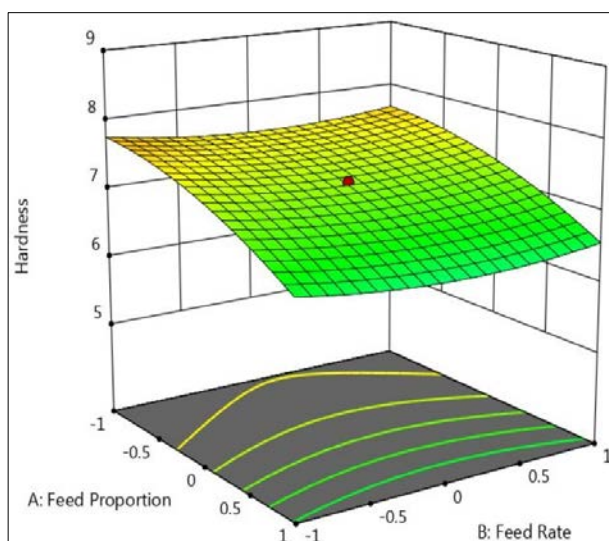


Fig 6: 3D Surface Graph Showing Effect of Feed Proportion and Feed Rate on Hardness

Besides the positive coefficient for barrel temperature indicates that increasing the barrel temperature enhances hardness acceptability. This effect may be due to the fact that higher temperatures during extrusion improve processing efficiency, leading to a firmer, more desirable texture in the final product (Coțovanu *et al.*, 2023; Dar *et al.*, 2014) [13, 11].

Effect on Crispiness

It is evident from table 2 the liking of Crispiness varied from minimum 5.79 to maximum 7.61. The maximum value of Crispiness was calculated at treatment nine (T-9). The composition of composite flour at treatment number nine is 80:13.75:6.25 (80% broken rice powder+ 13.75% soybean meal+ 6.25% moringa leaves powder) for feed proportion (A), feed rate (B) 9 kg/h, screw speed (C) 250 rpm and barrel temperature (D) 145 °C. The effect of variation in independent variable on Crispiness of extruded product was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

$$\begin{aligned} \text{Crispiness} = & 6.835 - 0.198A + 0.058D - 0.090AB + 0.306AC \\ & + 0.079AD - 0.098BD - 0.244CD - 0.119A^2 + 0.128B^2 \\ & + 0.107C^2 - 0.237D^2 \dots \dots \dots (3.4) \end{aligned}$$

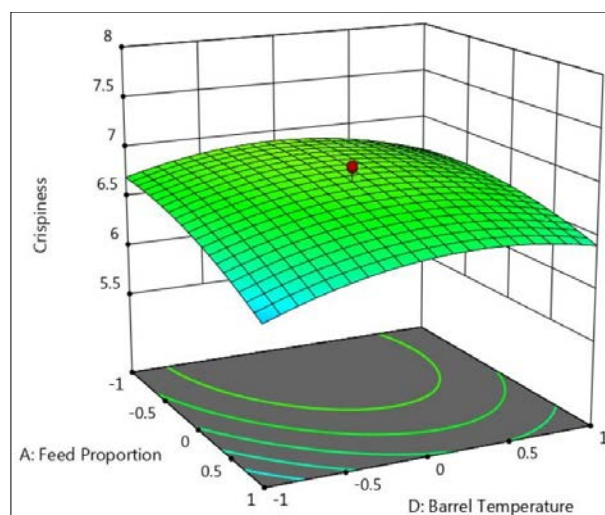


Fig 7: 3D Surface Graph Showing Effect of Feed Proportion and Barrel Temperature on Hardness

In Equation 3.4, the negative coefficient for factor A indicates that an increase in the feed proportion (i.e., higher percentages of defatted soybean meal and moringa leaf powder) results in a decrease in the crispiness of the product. This may be because research on soybean incorporation in extruded products has shown that higher

soybean content increases bulk density and reduces the expansion ratio, which leads to a less crispy texture (Sun & Muthukumarappan, 2002; Kim & Aldrich, 2022; Aussanasuwannakul *et al.*, 2022) [4, 58]. Similarly, higher levels of moringa leaf powder can increase product density and decrease the expansion ratio, resulting in a less crisp texture (Liu *et al.*, 2000; Rweyemamu *et al.*, 2015) [35, 47]. On the other hand, the positive coefficient for barrel temperature (D) suggests that as the barrel temperature increases, the crispiness of the product improves. Higher temperatures during extrusion enhance the drying and expansion processes, leading to a crispier texture in the final product (Skierkowski *et al.*, 1990; Ryu & Walker, 1995) [48, 55] as shown in Fig 6.

Effect on Appearance

It is evident from table 2 the liking of Appearance varied from minimum 6.1 to maximum 7.91. The maximum value of Appearance was calculated at treatment twenty (T-20). The composition of composite flour at treatment number twenty 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) 13 kg/h, screw speed (C) 300 rpm and barrel temperature (D) 130 °C. The effect of variation in independent variable on Appearance of extruded product was explained by development of second order polynomial multiple regression equation. It include A, B, C, D, AB, AC, AD, BC, BD, CD, A², B², D² are significant model terms.

$$\begin{aligned} \text{Appearance} = & 6.878 - 0.061A + 0.071B - 0.070C \\ & - 0.049D + 0.229AB + 0.134AC \\ & + 0.071AD + 0.058BC - 0.173BD \\ & - 0.098CD - 0.153A^2 + 0.189B^2 \\ & + 0.025C^2 \\ & - 0.161D^2 \dots \dots \dots (3.5) \end{aligned}$$

A negative or positive coefficient tells the direction of the effect. If a factor has a negative coefficient, appearance score decreases with increasing that factor, while a positive coefficient indicates that increasing the factor improves the appearance. The negative coefficient of feed proportion indicates that increasing the levels of defatted soybean meal and moringa leaf powder leads to a decrease in the appearance score of the extruded product. Conversely, an increase in broken rice content enhances the appearance score. This improvement may be attributed to the higher starch content in broken rice. Higher starch content in broken rice promotes greater expansion in extruded products (Vanier *et al.*, 2016) [61], which is resulting in a more desirable product appearance. Similarly, the negative coefficient for C suggests that higher screw speed can lead to reduced appearance score, possibly due to overprocessing or uneven mixing of ingredient. The negative coefficient for D indicates that increasing barrel temperature also decrease appearance score as shown in fig.7 because, higher temperatures might cause overcooking or change in color of extruded product.

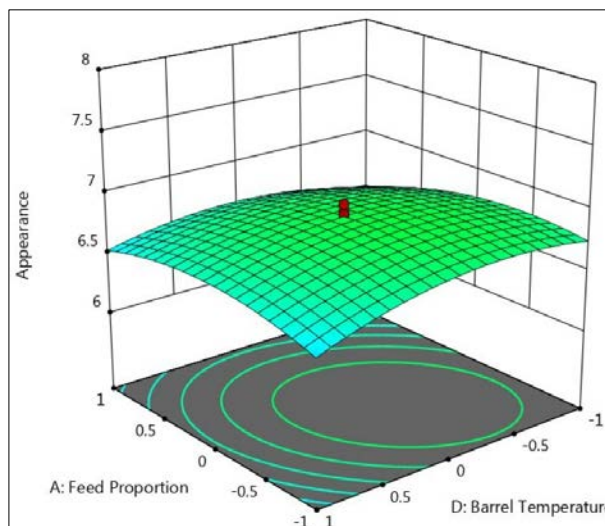


Fig 8: 3D Surface Graph Showing Effect of Feed Proportion and Barrel Temperature on Appearance

Effect on Odour

It is evident from table 2 the liking of Odour varied from minimum 5.59 to maximum 8.02. The maximum value of Odour was calculated at treatment nineteen (T-19). The composition of composite flour at treatment number nineteen 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) 9 kg/h, screw speed (C) 300 rpm and barrel temperature (D) 130 °C. The effect of variation in independent variable on Odour of extruded product was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

$$\begin{aligned} \text{Odour} = & 7.115 - 0.193A - 0.035B + 0.081D + 0.139AC \\ & - 0.073AD - 0.109BC + 0.090BD \\ & - 0.159CD - 0.307A^2 + 0.215B^2 \\ & - 0.241D^2 \dots \dots \dots (3.6) \end{aligned}$$

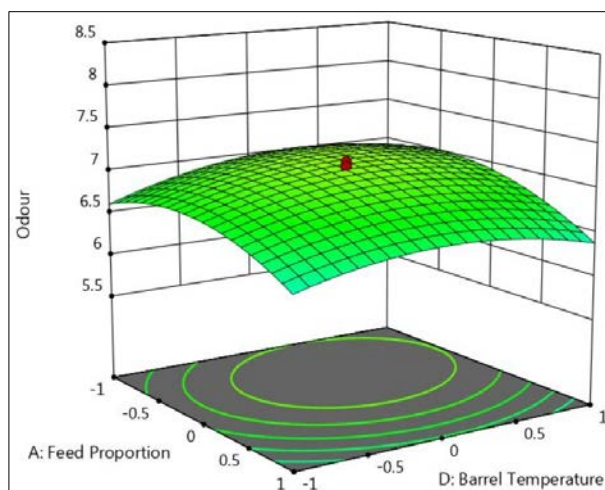


Fig 9: 3D Surface Graph Showing Effect of Feed Proportion and Barrel Temperature on Odour

In equation 3.6, the negative coefficient for A suggests that increasing the feed proportion (i.e., higher amounts of defatted soybean meal and moringa leaf powder with a reduced percentage of broken rice) lowers odor acceptability as shown in fig 8. This may be attributed to the strong, distinct aroma of moringa leaf powder, which can affect the

overall sensory appeal. Research indicates that increasing moringa leaf powder in food products negatively impacts sensory attributes, particularly odor and aroma. Studies have shown that while at least 10% moringa leaf powder is required for significant nutritional benefits, this level also begins to reduce sensory desirability (Boateng *et al.*, 2019) ^[6]. In bread production, higher moringa leaf powder concentrations resulted in lower consumer acceptance despite improved nutritional value (Sengev *et al.*, 2013) ^[52]. The negative coefficient for B (-0.035) indicates that increasing the feed rate slightly reduces odor acceptability, possibly due to inadequate mixing or inconsistent processing. The positive coefficient for D indicates that higher barrel temperatures enhance odor acceptability by promoting the formation of desirable aroma compounds through thermal reactions, releasing volatile compounds that improve the product's sensory appeal (Ibrahim Mohammed Ali *et al.*, 2024) ^[2].

Effect on Overall Acceptability

It is evident from table 2 the liking of Overall Acceptability varied from minimum 5.93 to maximum 7.74. The maximum value of Overall Acceptability was calculated at treatment nineteen (T-19). The composition of composite flour at treatment number nineteen 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) 9 kg/h, screw speed (C) 300 rpm and barrel temperature (D) 130 °C. The effect of variation in independent variable on Overall Acceptability of extruded product was explained by development of second order polynomial multiple regression equation. In this equation non significant terms were excluded.

Overall Acceptability

$$= 7.096 - 0.239A - 0.034B - 0.024C + 0.090D + 0.124AC - 0.043BD - 0.129CD - 0.226A^2 + 0.172B^2 - 0.218D^2 \dots \dots \dots (3.7)$$

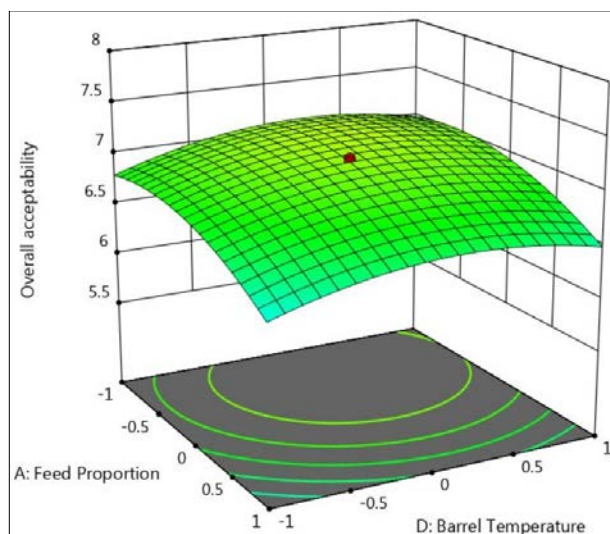


Fig 10: 3D Surface Graph Showing Effect of Feed Proportion and Barrel Temperature on Overall Acceptability

In Equation 3.7, the negative coefficient for A suggests that increasing the feed proportion, particularly with higher levels of defatted soybean meal and moringa leaf powder while reducing broken rice, negatively impacts the overall

acceptability of the extruded product. This may be attributed to the strong flavor and darker color of moringa leaf powder, which can affect sensory appeal. Researches indicate that while moringa leaf powder enhances nutritional value, its higher concentrations tend to reduce overall acceptability in various food products. Studies on bread (Govender & Siwela, 2020) ^[20], noodles (Mpalanzi *et al.*, 2023; Zula *et al.*, 2021) ^[39, 67], and ice cream (Handayani *et al.*, 2022) ^[22] demonstrate that increased moringa leaf powder levels lead to decreased sensory acceptance. However, lower concentrations, such as 5% in bread and 1% in ice cream, have been found to be acceptable while still providing nutritional benefits. Additionally, higher protein content has been associated with increased hardness, crispness, and breaking strength, while reducing the expansion ratio and contributing to a sticky mouthfeel (Devi *et al.*, 2013) ^[16]. Similarly, incorporating defatted soy meal in sorghum-based extrudates improved nutritional composition but adversely affected physical and sensory attributes (Tadesse *et al.*, 2019; Veronica *et al.*, 2006) ^[59, 63]. The negative coefficients for B and C indicate that increasing the feed rate and screw speed slightly decreases overall acceptability, possibly due to changes in texture and appearance caused by variations in processing conditions. The positive coefficient for D suggests that higher barrel temperatures improve overall acceptability shown in fig 9. In extrusion cooking the overall acceptability improve by enhancing color, texture, and aroma through thermal reactions like the Maillard reaction. The Maillard reaction significantly influences sensory properties, contributing to the development of color, taste, and aroma in thermally treated foods (Starowicz & Zieliński, 2019) ^[56].

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Optimization and Validation of the Optimum Solution

A statistical package was used to optimize the experimental design. The Central Composite Rotatable Design (CCRD) was implemented using Design-Expert software (version 13, Stat-Ease). To obtain the optimal solution, the developed models were further analyzed to determine the stationary points and explore the nature of the response surface around these points. Table 4 presents the stationary points for the dependent response variables. To validate the optimized conditions, experimental trials were conducted, and the sensory evaluation was conducted again, the trained panelist were asked to give the score to the optimized product and the predicted values were compared with the actual

experimental results. The optimum solution was selected, and extrudates were prepared to assess the dependent variables for validation. The recorded observations of the optimal response variables are summarized in Table 4. In hedonic scale the lowest score was 1 and highest score was 9. The independent variables, including feed proportion (A), feed rate (B), screw speed (C), and barrel temperature (D), were optimized to maximize the score of sensory attributes such as color, taste, hardness, crispiness, appearance, odor, and overall acceptability. The response variables were analyzed for their predicted and experimental values, along with their standard deviations (Std. Dev) and coefficients of variation (C.V%) summarized in table 4.

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	-1	80:13.75:6.25	Color	7.99	5.69	maximum	7.32	8.1	0.55	7.15
Feed rate (kg/h)	-1	10	Taste	8.33	5.73	maximum	7.62	7.56	0.04	0.56
Screw speed (rpm)	-1	250	Hardness	8.31	5.2	maximum	8.18	8.2	0.01	0.17
Barrel temperature (°C)	1	145	Crispiness	7.61	5.79	maximum	7.48	7.75	0.19	2.51
			Appearance	7.91	6.1	maximum	7.44	7.9	0.33	4.24
			Odour	8.02	5.59	maximum	7.33	7.0	0.23	3.26
			Overall Acceptability	7.84	5.77	maximum	7.56	7.75	0.13	1.76
			Desirability				0.802	0.875		

The desirability of the experimental values was calculated by using the desirability function approach. (Verma *et al.*, 2025)

• For maximization

$$d_i = \left\{ \frac{y_i - \text{Min}}{\text{Max} - \text{Min}} \right\}^s \dots \dots \dots (3.8)$$

Where,

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

To calculate the overall desirability, we use the geometric mean of individual desirability values:

$$D = (d_1 \times d_2 \times d_3 \times d_4 \times d_5 \times d_6 \times d_7)^{\frac{1}{7}} \dots \dots \dots (3.9)$$

$$D = 0.875$$

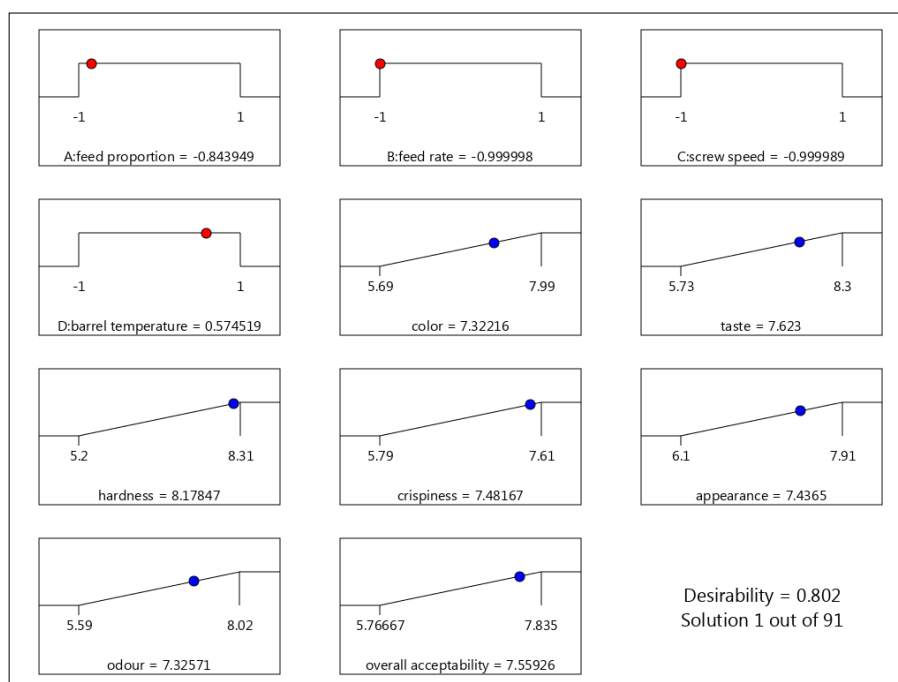


Fig 10: Showed the optimized and predicted value for independent or dependent value

Table 4 presents a comparison of the predicted and experimental values for various sensory response variables under the optimized extrusion conditions. The independent variables such as feed proportion, feed rate, screw speed, and barrel temperature were optimized to achieve the maximum sensory scores for color, taste, hardness, crispiness, appearance, odor, and overall acceptability. The results indicate a strong agreement between predicted and experimental values, with minimal deviations observed across all sensory parameters. The standard deviation values for each response variable are low, confirming the reliability and consistency of the experimental data. The coefficient of variation (C.V.%) further supports this, showing low variability in most parameters. Notably, the desirability function, which represents the overall optimization effectiveness, improved from the predicted value of 0.802 to the experimental value of 0.875. This increase suggests that the optimized extrusion conditions successfully enhanced the overall sensory quality of the extruded product. These findings validate the effectiveness of the optimization model in predicting and achieving desirable product characteristics under experimental conditions.

Conclusion

The optimization of extrusion parameters using Response Surface Methodology (RSM) successfully improved the sensory attributes of extruded snacks made from defatted soybean meal, moringa leaf powder, and broken rice. The optimized conditions of 80:13.75:6.25 feed proportion, 10 kg/h feed rate, 250 rpm screw speed, and 145 °C barrel temperature is resulted in enhanced taste, texture, and overall acceptability. While moringa leaf powder negatively affected color and taste, higher barrel temperatures improved sensory quality through the Maillard reaction. The desirability function improved from a predicted value of 0.802 to an experimental value of 0.875, demonstrating the effectiveness of the optimized conditions in enhancing the overall product quality. Sensory evaluation conducted by a trained panel validated that the optimized extrudates were well-accepted, particularly in terms of taste and overall acceptability. The strong agreement between predicted and experimental values confirms the model's reliability. These findings highlight the potential of incorporating nutrient-rich ingredients into extruded snacks while maintaining consumer appeal.

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