International Journal of Applied Food Science and Nutrition

PRIME OPEN ACCESS

Volume 2, Issue 1

Research Article

Date of Submission: 14 July, 2026
Date of Acceptance: 14 August, 2026
Date of Publication: 25 August, 2026

Optimization Of Sweet Potato Flour And Black Cumin Seed Blending Ratios With Wheat Flour To Produce Quality Bread

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Citation: Zenebe, K., Tsegay, Z. T., Weldeabezgi, L., GebremedhinKidane, F., Gebrekrstos, G., (2026). Optimization Of Sweet Potato Flour And Black Cumin Seed Blending Ratios With Wheat Flour To Produce Quality Bread. *Int J Appl Food Sci Nutr, 2*(1), 01-16.

Abstract

This study aimed to optimize the incorporation levels of sweet potato flour and black cumin seed in wheat bread and evaluate their effects on physicochemical properties and sensory acceptability. Response Surface Methodology (RSM) coupled with Central Composite Rotatable Design (CCRD) was employed to optimize the blending ratios of sweet potato flour (8–22 g) and black cumin seed (0.59–3.89 g). A total of 13 experimental formulations were prepared and evaluated for carbohydrate content, protein content, and sensory acceptability. The results showed that the blend ratios significantly affected the nutritional and sensory qualities of the bread ($p < 0.05$). Increasing the level of sweet potato flour enhanced carbohydrate content, reaching a maximum value of 85.03%, whereas higher incorporation of black cumin seed improved protein content up to 8.0%. Sensory acceptability was highest (4.75) at intermediate substitution levels, indicating favorable consumer preference. The optimized formulation consisted of 11.8 g sweet potato flour and 3.49 g black cumin seed, producing bread with 82.22% carbohydrate, 7.9% protein, and an overall sensory score of 4.41. The optimized bread also showed appreciable levels of calcium, iron, and zinc. Experimental and predicted values showed no significant difference ($p > 0.05$), confirming the adequacy and predictive capability of the developed models. These findings demonstrate that sweet potato flour and black cumin seed can be effectively utilized to produce nutritionally improved bread with acceptable sensory quality.

Keywords: Wheat Bread, Sweet Potato Flour, Black Cumin Seed, Composite Flour, Proximate Composition, Sensory Acceptability, Response Surface Methodology

Introduction

Bread is one of the most widely consumed fermented bakery products worldwide, with wheat flour serving as the principal raw material because of its gluten proteins, which provide dough elasticity, gas retention, and desirable loaf structure [1]. Despite its technological advantages, wheat flour is relatively low in dietary fiber, minerals, and some essential nutrients. Moreover, the increasing dependence on imported wheat in many developing countries has encouraged the exploration of locally available crops as partial substitutes or fortifying ingredients in bread production.

Sweet potato (Ipomoea batatas) is an important tuber crop cultivated in more than 115 countries and contributes significantly to food security in tropical and developing regions [2,3]. Orange-fleshed sweet potato is particularly valued for its high β-carotene content, natural sweetness, and attractive color [4]. In addition, sweet potato flour is a rich source of carbohydrates, dietary fiber, vitamins, and essential minerals, making it a promising ingredient for enhancing the nutritional quality of wheat-based products [5]. Consequently, several studies have investigated the development of composite flours from tubers, cereals, and protein-rich sources as alternatives to conventional wheat flour [6].

Black cumin (Nigella sativa) is widely used as a spice and flavoring agent in food products [7]. Beyond its culinary applications, black cumin contains appreciable amounts of protein and antioxidant compounds and exhibits functional properties, such as foaming capacity, that may positively influence dough characteristics and bread quality [8]. Previous studies have reported the incorporation of black cumin into wheat-based products to improve their nutritional value [9]. However, limited information is available regarding the combined use of sweet potato flour and black cumin seed flour in bread formulations, particularly in relation to optimizing product quality and sensory acceptability [10]. Therefore, this study aimed to evaluate the effects of substituting wheat flour with sweet potato flour and black cumin seed flour on bread quality and to optimize blending ratios for improved proximate composition and sensory properties.

Materials And Methods

Sample Collection and Preparation Technique

Sweet potato samples were washed, peeled, sliced, dried, and milled into flour using a laboratory hammer mill (Model: HM-210, Thomas Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ, USA). The flour was sieved through a 250 µm mesh sieve to obtain a uniform particle size and then stored in airtight polyethylene bags at ambient temperature until analysis. Black cumin seeds were manually cleaned to remove impurities and washed thoroughly with tap water to eliminate adhering soil and dust particles. The seeds were subsequently sun-dried for 1 h based on baseline survey information. After drying, the seeds were packed in sealed plastic bags and stored in a cool, dry place until further use.

Proximate and mineral compositions were determined according to standard AACC procedures. Sample weights were measured using an analytical balance (Model: AU220, Shimadzu Corporation, Kyoto, Japan). Ash content was determined using a muffle furnace (Model: ELF 11/6B, Ca rbolite Gero, Sheffield, UK) following preliminary carbonization. Mineral contents, including iron (Fe), zinc (Zn), and calcium (Ca), were analyzed using an Atomic Absorption Spectrophotometer (AAS) (Model: AA-7000, Shimadzu Corporation, Kyoto, Japan) at wavelengths of 248.3, 213.8, and 422.7 nm, respectively. Hydrochloric acid (HCl) and distilled water were used for sample digestion and preparation of standard solutions. Calibration standards were prepared using appropriate analytical-grade reference compounds.

Data Collection Method

Primary data were collected through direct interviews with randomly selected respondents from Tahatay Koraro Woreda, North Western Zone. A structured questionnaire prepared in English was administered in Tigrigna to obtain information on commonly used spices and their incorporation levels in traditional bread making. Based on the minimum, average, and maximum quantities reported by the respondents, three levels of black cumin incorporation were established: B1 (low), B2 (medium), and B3 (high). These levels were subsequently used to determine the experimental range for bread formulation and optimization.

Experimental Design

The blending ratios of sweet potato flour and black cumin to wheat composite flours for the bread making employed RSM coupled with CCD (Central composite design),and the RSM coupled with CCD of the independent variables was designed as the $-\alpha$ = 8 g, -1 = 10 g, 0= 15, 1 = 20, and α = 22 for sweet potato flour blend and $-\alpha$ = 0.59 g, -1 = 1.09 g, 0= 2.29 g, 1 = 3.49 g, and α = 3.89 g for black cumin blend. Response variables (carbohydrate content, protein content and sensory quality) of the produced bread were predicted using the following polynomial equation (Equation 1-3). If the experimental data was suitable to linear Equation 1, for second-order model Equation 2, or for quadratic terms Equation 3 was tested according to [11].

$$\boldsymbol{y = \beta_0 \sum_{i=1}^{k} \beta_i x_i + \varepsilon} \qquad (1)$$

Where k represents the number of variables, β_0 is the constant term, β_i represents the coefficients of the linear parameters, x_i represents the variables, and ε refers to the residual associated with the experiments.

$$\boldsymbol{y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{1 \le i \le j}^{k} \beta_{ij} x_i x_j + \varepsilon} \qquad (2)$$

$$\boldsymbol{y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{1 \le i \le j}^{k} \beta_{ij} x_i x_j + \varepsilon} \qquad (3)$$

Where: β_{ij} and β_{ii} refer to the regression coefficients of interactive parameters and quadratic parameters, respectively. SPB = sweet potato blend, BCB = black cumin blend, CBH = carbohydrate. Other proximate composition and functional properties of the bread were analyzed for the bread produced at the optimum points.

Bread Making Process

Bread samples were prepared using the straight dough method described by [12] with slight modifications. Composite flour blends containing sweet potato flour (8–22 g) and black cumin seed flour (0.59–3.89 g) were formulated with wheat flour according to the experimental design (Table 4). For each formulation, 500 g flour, 10 g yeast, 5 g salt, and 65–70% water were used based on traditional baking practices and previous studies [13,14]. Dry ingredients were weighed using a digital analytical balance (Model: ME204, Mettler Toledo, China). The ingredients were mixed with yeast and salt dissolved in warm water (30–35°C) and kneaded into cohesive dough. Fermentation was conducted at 30°C and 85% relative humidity with intermittent punching. The dough was divided into 100 g portions, molded, proofed for 30 min, and baked at 220°C for 20 min in an electric oven (Model: MS2535GISW, France). The baked loaves were cooled, dried at 60°C for 9 h, and milled for physicochemical analyses.

Proximate Composition Analysis of Composite Bread

The proximate composition of the composite bread was determined according to standard methods of the American Association of Cereal Chemists (AACC, 2000). Moisture content was determined by the oven-drying method, in which 5 g of sample was dried at >100°C for 6 h to constant weight, and moisture percentage was calculated from weight loss. Crude protein content was analyzed using the Kjeldahl method. Briefly, 1 g of sample was digested with concentrated H_2SO_4 in the presence of Na_2SO_4–$CuSO_4$ catalyst, followed by distillation and titration with 0.1 N HCl. Nitrogen content was converted to protein using a conversion factor of 6.25. Crude fat content was determined using Soxhlet extraction with petroleum ether for 6–8 h. Crude fiber was analyzed by sequential acid and alkaline digestion followed by drying and ashing. Total ash content was measured by incinerating samples in a muffle furnace at 550°C until complete ashing. Carbohydrate content was calculated by difference using the following equation:

Carbohydrate (%) =100−(%Moisture+%Protein+%Fat+%Fiber+%Ash) analyses were conducted in triplicate, and the results were expressed as percentage composition on a dry weight basis.

Mineral Composition Analysis of Composite Bread

The mineral contents of the composite bread, including iron (Fe), zinc (Zn), and calcium (Ca), were determined using Atomic Absorption Spectrophotometry (AAS) according to standard methods of the American Association of Cereal Chemists [15].

For mineral analysis, 2.0 g of sample was dry-ashed in a muffle furnace at 550°C until white ash was obtained. The ash was dissolved in hydrochloric acid, filtered, and diluted to a known volume with deionized water. Appropriate aliquots were aspirated into the AAS using an air–acetylene flame. Absorbance values for iron, zinc, and calcium were measured at wavelengths of 248.3, 213.8, and 422.7 nm, respectively. Standard calibration curves were prepared from 1000 ppm stock standards by serial dilution. Lanthanum chloride was added during calcium analysis to minimize interference effects. Mineral concentrations were expressed as mg/100 g dry basis and calculated from the standard calibration curves using the following equation: $\mathtt{mineral\ content}\ (mg/100g = C \times \frac{100}{samplemass(g)})$ Where C represents the concentration obtained from the calibration curve (μg/mL).

Sensory Acceptability Of Composite Bread

Sensory acceptability of the bread samples was evaluated using a five-point hedonic scale following the method described by [16] A total of 20 semi-trained panelists (male and female, aged 24–32 years) selected from the staff and undergraduate students of the Department of Food Science and Postharvest Technology, Mekelle University, participated in the evaluation. Prior to the assessment, the panelists were briefed on the evaluation procedures and scoring system. Based on the experimental design, 13 bread formulations were assessed for appearance, aroma, taste, texture, and overall acceptability using a scale ranging from 1 (very poor) to 5 (very good). The samples were randomly coded and presented on trays to minimize bias. Natural spring water was provided for mouth rinsing between evaluations, and communication among panelists was restricted during the sensory assessment.

Data Analysis

The collected survey data were analyzed using descriptive statistics, including means and standard deviations, as well as one-way and two-way analysis of variance (ANOVA). The performance of the RSM models was evaluated based on the coefficient of determination (R^2), root mean square error (RMSE), predicted values, and plots of predicted versus actual values, as described by [11] Design-Expert software version 10.1 and Microsoft Excel were used for statistical analysis of the data.

Results and Discussion

Baseline Survey

A baseline survey was conducted to assess the use of black cumin seed in traditional wheat bread production. The survey involved 29 respondents (mothers), and the quantities of black cumin seed used per 500 g of wheat flour were recorded. The results showed that the minimum, mean, and maximum amounts of black cumin seed used were 1.09 g, 2.29 g, and 3.49 g, respectively. The standard deviation (SD) of the reported values was ±1.2 g, calculated based on the overall distribution of responses. These values were used to define the experimental levels of black cumin seed for the laboratory study, where the minimum, mean, and maximum values corresponded to the low (B1), medium (B2), and high (B3) levels, respectively, in the formulation design.

Over All Experimental Design and Analyzed Results

The experiment was designed using Response Surface Methodology (RSM) coupled with a Central Composite Design (CCD) to evaluate the effects of sweet potato flour and black cumin seed on bread quality. Sweet potato flour levels ranged from 8–22 g/100 g flour blend, while black cumin seed ranged from 0.59–3.89 g/100 g flour blend. The responses investigated were carbohydrate content, protein content, and overall sensory acceptability. Control bread prepared from 100% wheat flour was included for comparison. All treatments were produced and analyzed in triplicate, while center points were replicated five times to assess model adequacy and experimental precision.

Std	Factors		Responses					
	A:SPB	B:BCB	Carbohydrate (%)		Protein (%)		Sensory value	
	Unit g	Unit g	Predicted	Measured	Predicted	Measured	Predicted	Measured
1	10	1.09	78.57	78.5	7.13	7.17	4.31	4.31
2	20	1.09	83.69	83.76	5.91	5.94	3.82	3.83
3	10	3.49	82.99	82.55	7.97	8	4.23	4.23
4	20	3.49	83.71	83.46	6.82	6.83	3.61	3.62
5	8	2.29	80.53	80.64	7.57	7.6	4.14	4.15
6	22	2.29	85.02	85.03	5.92	5.92	3.38	3.38
7	15	0.59	79.93	79.98	6.57	6.56	4.35	4.35
8	15	3.89	82.94	82.46	7.76	7.8	4.2	4.21
9	15	2.29	81.54	81.31	7.11	7.13	4.7	4.74
10	15	2.29	81.54	81.32	7.11	7.13	4.73	4.75
11	15	2.29	81.54	81.31	7.11	7.13	4.73	4.73
12	15	2.29	81.54	81.31	7.11	7.13	4.73	4.73
13	15	2.29	81.54	81.31	7.11	7.13	4.73	4.74

Table 1: Experimental Design, Measured Results, and Expected Outputs

Fitting The Response Surface Models And Model Fit Summary Of Responses

Model selection was based on the significance of model terms and the absence of aliasing. As shown in Table 2, quadratic models were selected for carbohydrate content, protein content, and sensory acceptability. Model adequacy was evaluated using ANOVA, R^2, adjusted R^2, predicted R^2, and lack-of-fit tests. The differences between adjusted R^2 and predicted R^2 values were less than 0.1 for all responses, indicating good agreement and reliable predictive performance. The lack-of-fit test revealed that the quadratic model showed a significant lack-of-fit for carbohydrate content ($p = 0.0007$), suggesting that some variability in the response was not fully explained by the model. In contrast, sensory acceptability exhibited a non-significant lack-of-fit ($p = 0.9735$), indicating an adequate model fit. Despite the significant lack-of-fit observed for some responses, the models demonstrated acceptable predictive capability due to the high R^2 values and close agreement between adjusted and predicted R^2 values.

Type of response	Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
CBH	Linear	0.0011	< 0.0001	0.6917	0.4613	
	2FI	0.0111	< 0.0001	0.8389	0.7307	
	Quadratic	**< 0.0001**	**0.0007**	**0.9998**	**0.9992**	**Suggested**
	Cubic	0.0007				**Aliased**
Protein	Linear	< 0.0001		0.932	0.8853	
	2FI	0.8639		0.9247	0.8767	
	Quadratic	**< 0.0001**		**0.9995**	**0.9981**	**Suggested**
	Cubic			1		**Aliased**
Sensory value	Linear	0.2411	< 0.0001	0.0971	-0.2509	
	2FI	0.8903	< 0.0001	-0.0009	-0.7168	
	Quadratic	**< 0.0001**	**0.9735**	**0.9998**	**0.9998**	**Suggested**
	Cubic	0.9735		0.9996		**Aliased**

Table 2: Model Fit Summary For All Responses

Anova For Quadratic Models Of The Responses

The effects of sweet potato flour and black cumin seed on protein, carbohydrate, and sensory acceptability were evaluated using ANOVA within the Response Surface Methodology (RSM) framework. The quadratic models for all responses were highly significant ($p < 0.0001$), indicating that the models adequately explained the observed variation. For sensory acceptability, linear, interaction, and quadratic terms were significant ($p < 0.05$), while the lack-of-fit was non-significant ($p = 0.9735$), confirming good model adequacy. Similarly, protein content was significantly influenced by the linear and quadratic effects of SPF and BCB ($p < 0.0001$), although the interaction effect was not significant ($p = 0.0587$).

For carbohydrate content, all model terms were significant ($p < 0.05$); however, the significant lack-of-fit ($p = 0.0007$) suggested that the model may not adequately describe the experimental data. Overall, the sensory and protein models were considered reliable for prediction and optimization within the studied range.

Source	Sum of Squares			Mean Square			F-value			p-value		
	Sensory value	Protein	CBH	Sensory value	Protein	CBH	Sensory value	Protein	CBH	Sensory value	Protein	CBH
Model	2.52	4.61	34.75	0.5034	0.9215	6.95	10469.16	5209.78	11506.9	< 0.0001*	< 0.0001*	< 0.0001*
A-SPB	0.5935	2.85	19.15	0.5935	2.85	19.15	12343.38	16118.9	31712.4	< 0.0001	< 0.0001	< 0.0001
B-BCB	0.04	1.51	6.55	0.04	1.51	6.55	832.66	8556.22	10851.6	< 0.0001	< 0.0001	< 0.0001
AB	0.0042	0.0009	4.73	0.0042	0.0009	4.73	87.88	5.09	7833.11	0.0001-	0.0587	< 0.0001
A^2	1.66	0.2365	4.11	1.66	0.2365	4.11	34596.84	1337.29	6804.64	0.0001	< 0.0001	< 0.0001
B^2	0.3785	0.0091	0.0042	0.3785	0.0091	0.0042	7872.24	51.48	6.93	0.0001	0.0002	0.0338
Residual	0.0003	0.0012	0.0042	0	0.0002	0.0006						
Lack of Fit	0	0.0012	0.0041	5.52E-06	0.0004	0.0014	0.069		69.12	0.9735**	**	0.0007*
Pure Error	0.0003	0	0.0001	0.0001		0						
* Significant at 0.5% **Not significant at 0.5%												

Table 3: Anova Of Quadratic Models For All Responses

The Model F-values confirmed that all developed models were highly significant, with only a 0.01% probability that the observed effects resulted from noise. Terms with p-values < 0.05 were considered significant. For protein content, A, B, A^2, and B^2 significantly affected the response, whereas A, B, AB, A^2, and B^2 were significant for carbohydrate content and sensory acceptability.

The interaction between sweet potato flour and black cumin blend significantly influenced carbohydrate content and overall acceptability, while its effect on protein content was less pronounced. In the ANOVA, DF represented the independent components of variation, mean square was obtained from the ratio of sum of squares to DF, and the corrected total described the overall variability around the response mean.

Summary Of Analysis Of Variance (Anova) And Validation Of Developed Quality Predictive Models

Table 4 summarizes the statistical parameters of the developed response surface models, including R^2, adjusted R^2, predicted R^2, coefficient of variation (CV), adequate precision, and PRESS values. Although high R^2 values (0.99) were obtained for carbohydrate, protein, and overall acceptability, model adequacy was primarily assessed using adjusted and predicted R^2 values. The close agreement between adjusted and predicted R^2 values indicates acceptable predictive capability of the models. In addition, adequate precision values greater than 4 demonstrated an adequate signal-to-noise ratio, confirming that the models were reliable for prediction and optimization within the studied experimental range.

Statistical parameter	Statistical value		
	CBH	Protein	Sensory value
Std. Dev.	0.0246	0.0133	0.0069
Mean	81.76	7.04	4.29
C.V. %	0.0301	0.189	0.1617

R^2	0.9999	0.9997	0.9999
Adjusted R^2	0.9998	0.9995	0.9998
Predicted R^2	0.9992	0.9981	0.9998
Adeq Precision	390.05	230.62	287.54

Table 4: Fit Statistics Of Model For All Responses

The Predicted R^2 of 0.9981 is in reasonable agreement with the Adjusted R^2 of 0.9995; i.e. the difference is less than 0.2 for the carbohydrate, protein and sensory (overall acceptability) responses. Moreover, Adeq Precision measures the signal to noise ratio in which a ratio greater than 4 is desirable. The ratios for the carbohydrate, protein and sensory (overall acceptability) responses indicate an adequate signal. These models can be used to navigate the design space. The digenesis of developed models using residual versus predicted values shown in Figure 7 indicates the predicted and actual values of the data from the developed model shown significant difference.

Final Equation Of Responses In Terms Of Actual Factors
Linear and polynomial models were assessed to determine the best fit for the experimental data. Model selection was based on significant terms ($p < 0.05$), non-significant lack-of-fit, and exclusion of aliased models, using backward elimination in Design-Expert software.

The final quadratic models for carbohydrate content, protein content, and overall sensory acceptability included significant linear, interaction, and quadratic effects. Although some black cumin blend (BCB) terms were not significant, the quadratic term was retained to preserve model hierarchy and improve predictive capability. The developed equations, expressed in actual factor levels, were used to predict responses within the experimental domain.

Equation 15: $Protein(\%) = 6.6 + 0.099SPB + 0.2BCB + 0.002SPB * BCB - 0.007SPB^2 + 0.0263BCB^2$

Equation 16: $CBH(\%) = 75.5 - 0.2SPB + 3.57BCB - 0.18SPB * BCB + 0.03SPB^2 - 0.012BCB^2$

Equation17:$Sensoryvalue = 0.16 + 0.55SPB + 0.8BCB - 0005SPB * BCB - 0.012SPB^2 - 0.17BCB^2$

Where: CBH refers to carbohydrate, BCB to black cumin blend, SPB to sweet potato blend.

Diagnosis Of Developed Models Using Actual Versus Predicted Values
Scatter plots of actual versus predicted values and residual versus predicted plots are essential diagnostic tools for evaluating model performance and adequacy. These visualizations assess the agreement between experimental and predicted values and help identify potential issues such as bias, poor fit, or the need for model refinement.

As shown in Figure 1, the actual and predicted values closely followed the 45° reference line, indicating excellent agreement between experimental and model-predicted responses. In addition, the residuals were randomly distributed and predominantly centered within the range of −1.0 to +1.0, confirming the absence of systematic error. These results demonstrate that the developed quadratic regression models were adequate for predicting the effects of ingredient blending on carbohydrate content, protein content, and sensory acceptability of the bread formulations.

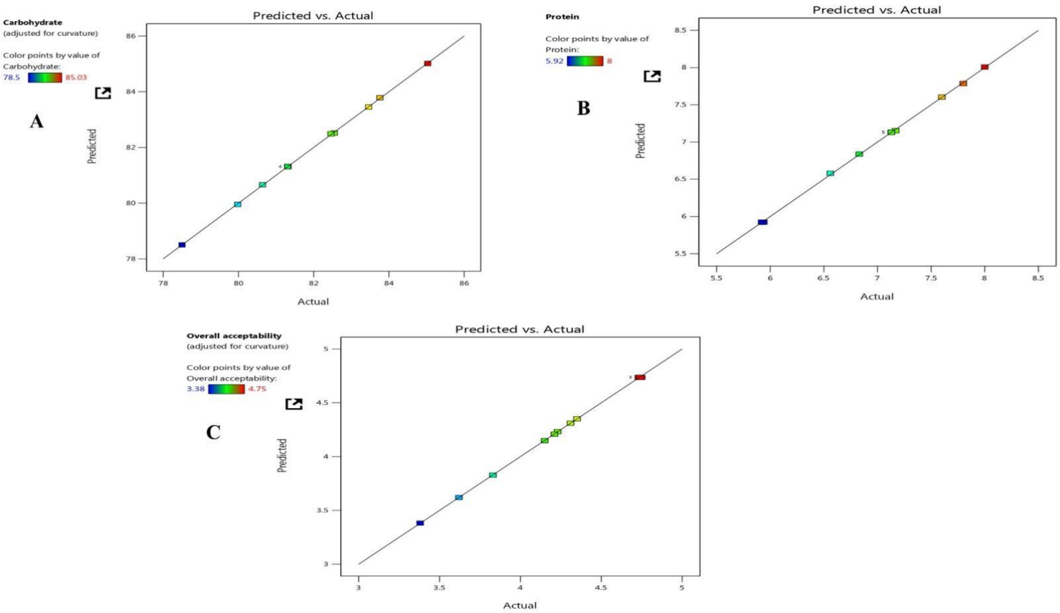

Figure 1: Actual Versus Predicted Plots Of (Protein, Carbohydrate And Overall Acceptability

Interaction Effect Of Sweet Potato Flour And Black Cumin Seed Blend On The Protein Content Of Bread

Protein content varied significantly among the bread formulations. ANOVA results (Table 3) showed that the linear and quadratic effects of sweet potato blend (SPB) and black cumin blend (BCB) significantly influenced protein content ($p < 0.05$), whereas the interaction effect (SPB × BCB) was weak ($p < 0.1$). The nearly parallel contour lines observed in the response surface plots further confirmed the minimal interaction between SPB and BCB, indicating that their effects on protein content were largely independent rather than synergistic. Although the interaction coefficient was positive (SPB × BCB = +0.002), its contribution was negligible compared with the main effects.

The significant linear effects were mainly associated with the inherent protein composition of sweet potato and black cumin flours. Black cumin flour contains relatively higher protein levels than sweet potato flour; therefore, increasing the proportion of BCB enhanced the overall protein content of the composite bread. In contrast, increasing SPB reduced protein content due to the comparatively lower protein concentration of sweet potato flour, resulting in a dilution effect within the flour mixture. The weak interaction effect suggests that the combined incorporation of SPB and BCB had limited influence on protein modification during dough development and baking. Similar findings were reported by [17] who observed improved crude protein content following the incorporation of black cumin flour into wheat-based bread. Likewise, [18] highlighted the protein-enhancing potential of black cumin in bakery products. The highest protein content was obtained in the formulation containing 10 g SPB and 3.49 g BCB, whereas the lowest value was recorded at 22 g SPB and 2.29 g BCB. The combined effects of SPB and BCB on protein content are presented in Figure 2.

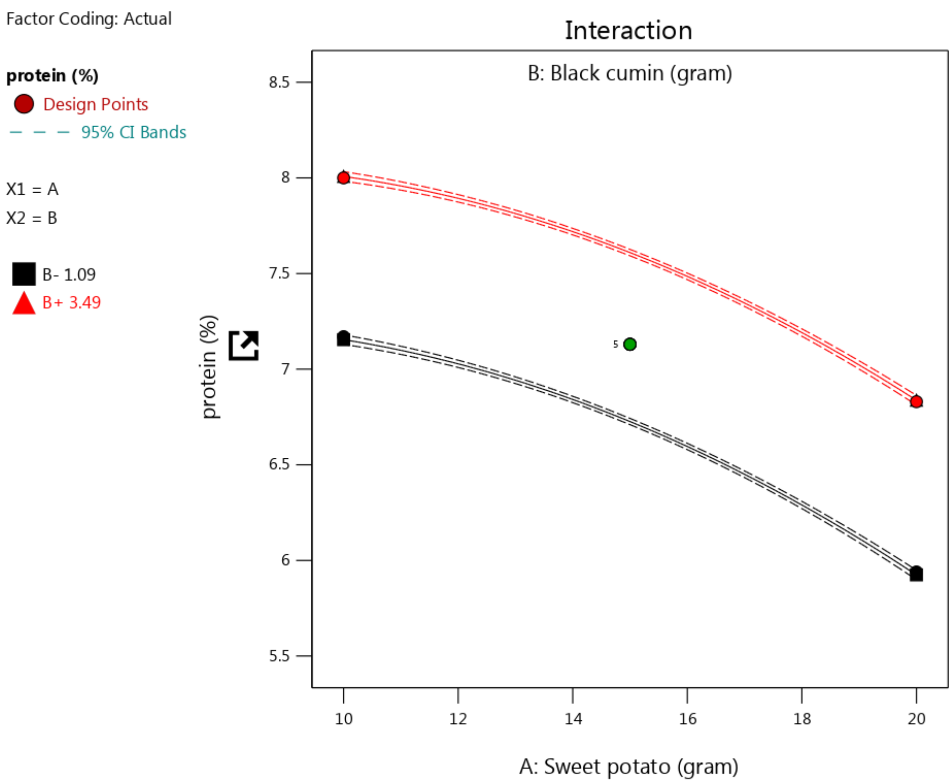

Figure 2: Interaction Effect Of Sweet Potato Flour And Black Cumin On Protein

Contour Effect Of Black Cumin And Sweet Potato On Protein

Protein content of the bread significantly ($p < 0.05$) varied with the blending ratios of sweet potato flour and black cumin, ranging from 5.92–8.0%. Higher substitution levels of sweet potato flour resulted in lower protein content, whereas black cumin incorporation improved protein levels. The developed model showed excellent predictive performance with high R^2 (0.9997) and adjusted R^2 (0.9995) values, significant linear and quadratic terms (A, B, A^2, B^2; $p \leq 0.05$), and a non-significant lack-of-fit. Similar observations were reported by Awolu et al., who noted that high R^2 values indicate good model fitness and predictive reliability. The contour plot (Figure 3) further demonstrated that regions with higher black cumin incorporation corresponded to increased protein content.

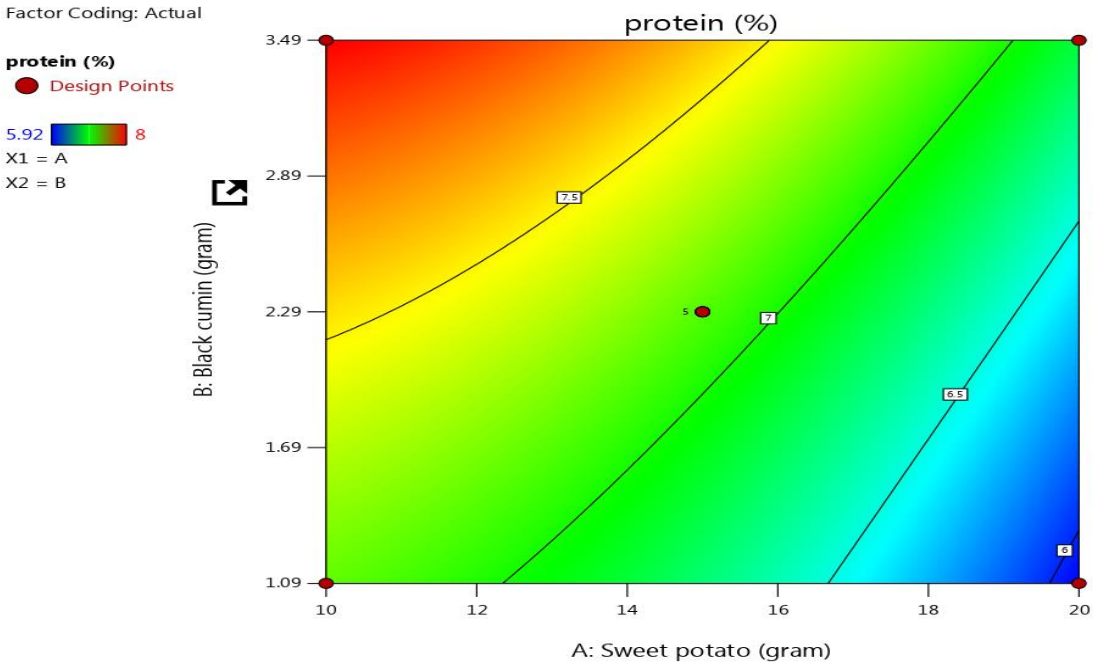

Figure 3: Contour Plot Effect Of Sweet Potato and Black Cumin On Protein

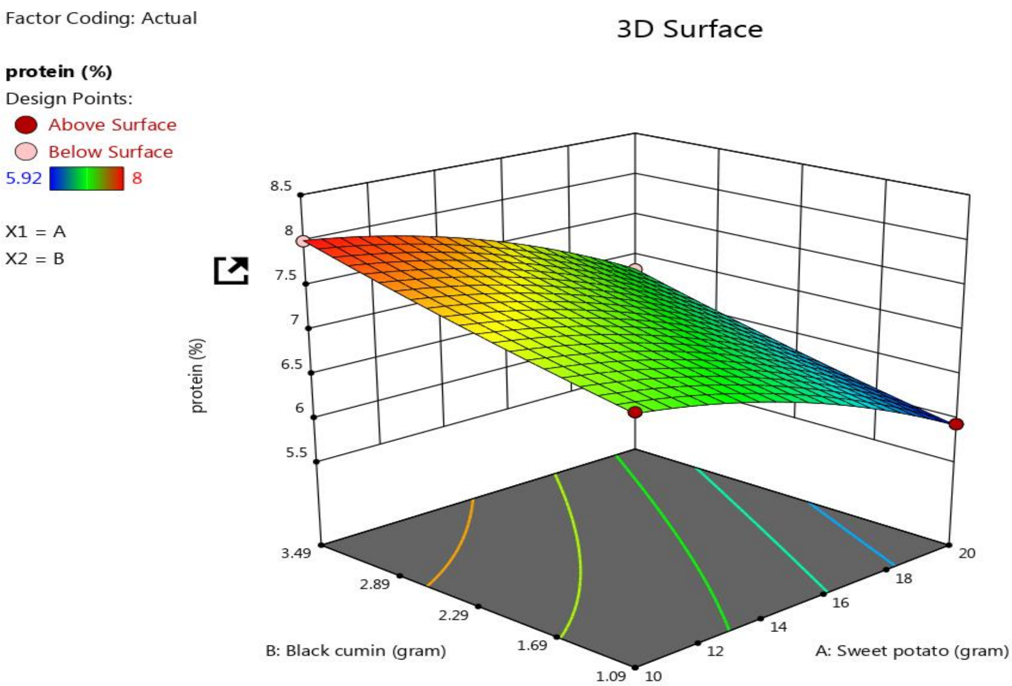

Figure 4: 3d Plot Effect Of Sweet Potato Flour and Black Cumin On Protein

Interaction Effects Of Sweet Potato Flour And Black Cumin Blend On Carbohydrate Content Of The Bread
ANOVA results (Table 3) showed that the linear and quadratic effects of sweet potato blend (SPB) and black cumin blend (BCB) significantly influenced the carbohydrate content of the bread ($p < 0.05$). A significant interaction effect between SPB and BCB was also observed, as indicated by the non-parallel contour plots, suggesting that the effect of SPB on carbohydrate content depended on the level of BCB. Increasing SPB markedly increased carbohydrate content at lower BCB levels, whereas this effect became weaker at higher BCB concentrations.

Although the interaction was statistically significant, the main effects of SPB and BCB were more dominant, indicating that each factor independently contributed more to carbohydrate variation within the studied range. The highest carbohydrate content was recorded in bread containing 22 g SPB and 2.29 g BCB, while the lowest was observed at 10 g SPB and 1.09 g BCB. This variation may be attributed to the higher starch contribution of sweet potato and wheat flours relative to the lower starch content of black cumin.

These findings are consistent with the study by (Qianqian et al.,2020), who reported reduced carbohydrate content in bread enriched with black cumin flour due to its relatively low starch composition.

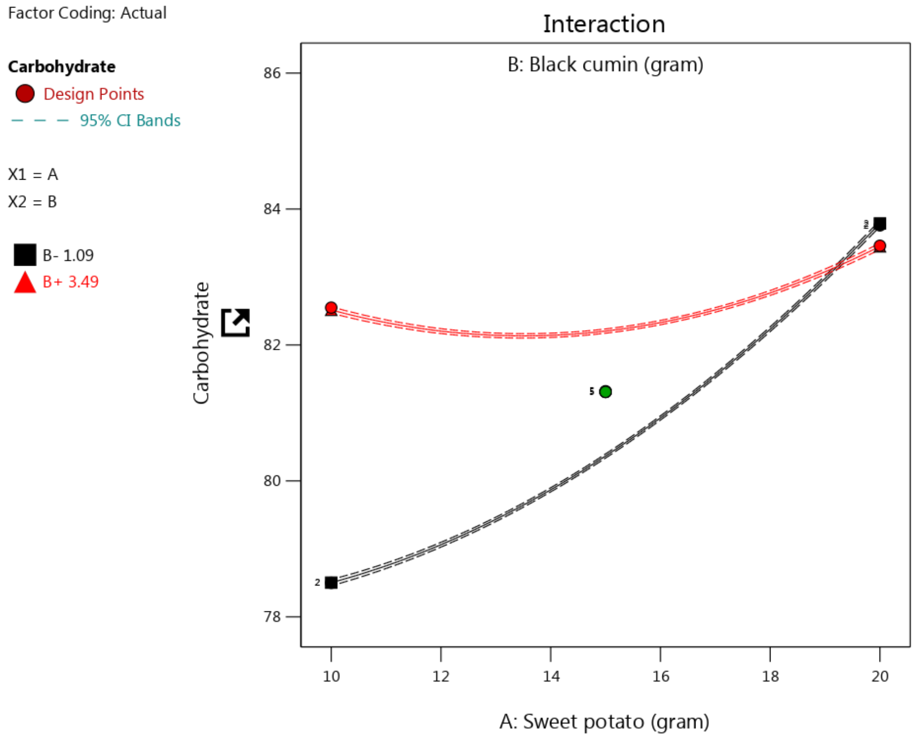

Figure 5: Interaction Effect Of Sweet Potato Flour And Black Cumin On Carbohydrate

Contour Effect Of Black Cumin And Sweet Potato On Carbohydrate

Carbohydrate content significantly ($p < 0.05$) increased with higher proportions of sweet potato flour and decreased with increasing black cumin incorporation, ranging from 78.5–85.03%. The developed model demonstrated excellent predictive accuracy, with high R^2 (0.9999) and adjusted R^2 (0.9998) values, significant linear and quadratic terms (A, B, AB, A^2, B^2; $p \leq 0.05$), and a non-significant lack-of-fit.

The contour plot (Figure 6) further confirmed that the composite flour composition significantly influenced carbohydrate content, with the yellow-shaded regions representing formulations with the highest carbohydrate levels. These regions were mainly associated with higher sweet potato incorporation, likely due to its relatively high starch contribution compared to black cumin flour.

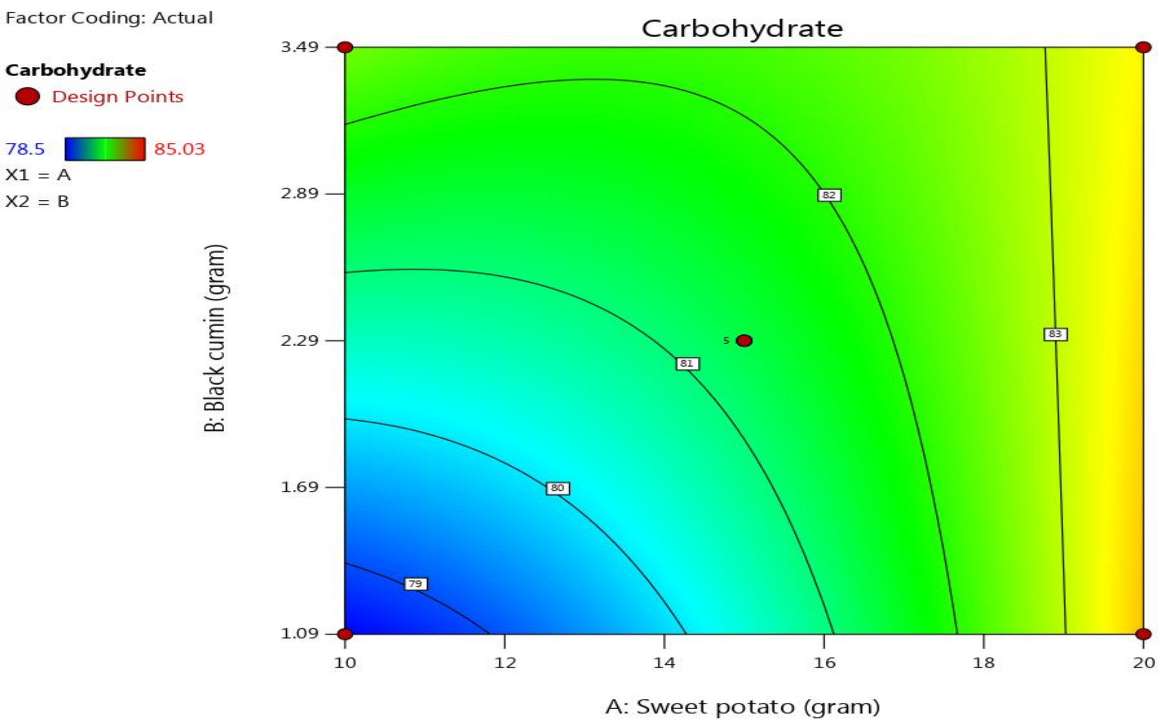

Figure 6: Contour Plot Effect of Sweet Potato And Black Cumin on Carbohydrate

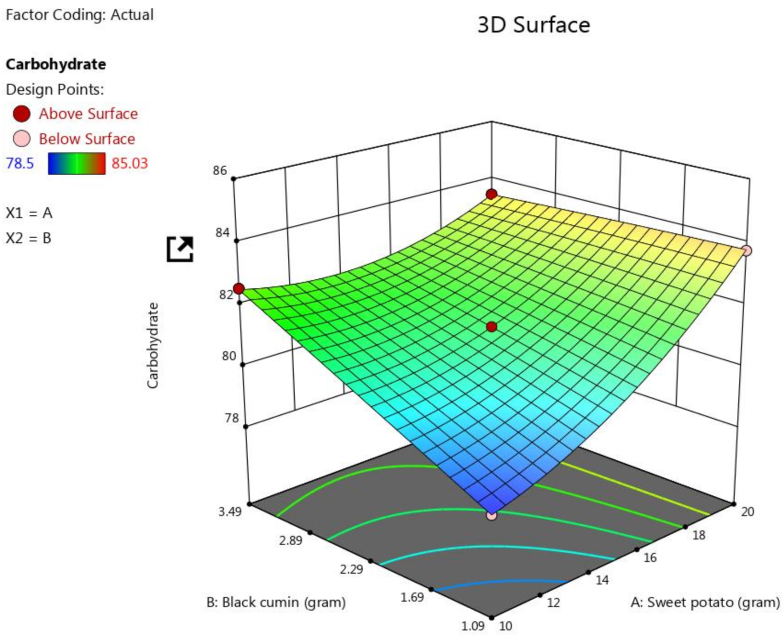

Figure7: 3d Plot Effect of Sweet Potato Flour And Black Cumin on Carbohydrate

Interaction Effects Of Sweet Potato Flour And Black Cumin Blend On Overall Sensory Value Of The Produced Bread

Although the interaction between sweet potato flour (SPF) and black cumin blend (BCB) was statistically significant ($p < 0.0001$), the response surface plots showed a near-parallel pattern with minimal curvature, indicating that the practical interaction effect on sensory acceptability was relatively weak. This suggests that the effects of SPF and BCB on overall acceptability were mainly additive rather than strongly interactive. The statistical significance may be attributed to the sensitivity of the model and low experimental error.

Sensory acceptability varied significantly among formulations ($p < 0.05$), with higher scores obtained at moderate incorporation levels of SPF and BCB. The highest sensory score was recorded for Sample 10 (15 g SPF and 2.29 g BCB) with a value of 4.75, followed by the optimized formulation containing 11.8 g SPF and 3.49 g BCB (4.41). In contrast, higher substitution levels reduced acceptability, likely due to intensified flavor, darker color, and textural changes.

These findings agree with previous studies by . Who reported that moderate black cumin incorporation improves aroma and texture, while excessive levels negatively affect acceptability because of its strong flavor Similar improvements in bread softness and sensory quality were also reported by [19-21] Attributing these effects to the moisture retention capacity and the fat and protein content of black cumin flour.

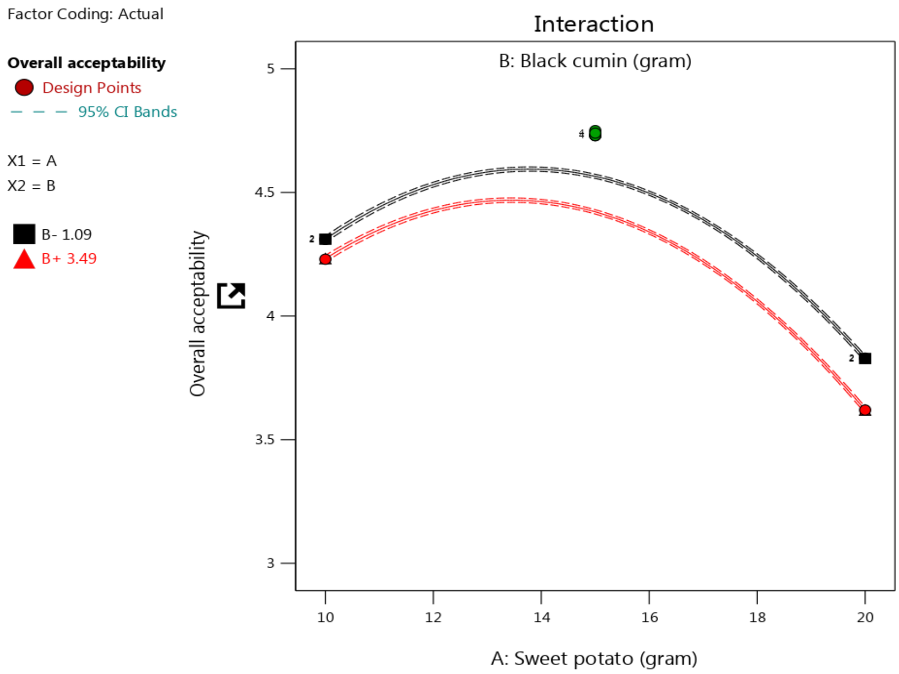

Figure 8: Interaction Effect Of Sweet Potato Flour And Black Cumin On Overall Acceptability

Contour Plot Effect Of Sweet Potato And Black Cumin On Overall Acceptability

Overall acceptability was significantly ($p < 0.05$) influenced by the blending ratios, increasing moderately with higher black cumin incorporation and decreasing with increasing sweet potato flour levels. The developed model showed excellent predictive performance, with high R^2 (0.9999) and adjusted R^2 (0.9998) values, significant linear and quadratic terms (A, B, AB, A^2, B^2; $p \leq 0.05$), and a non-significant lack-of-fit.

The contour plot (Figure 9) confirmed that composite flour composition significantly affected sensory acceptability, with the red-shaded regions representing formulations with the highest acceptability. These regions were mainly associated with moderate black cumin incorporation.

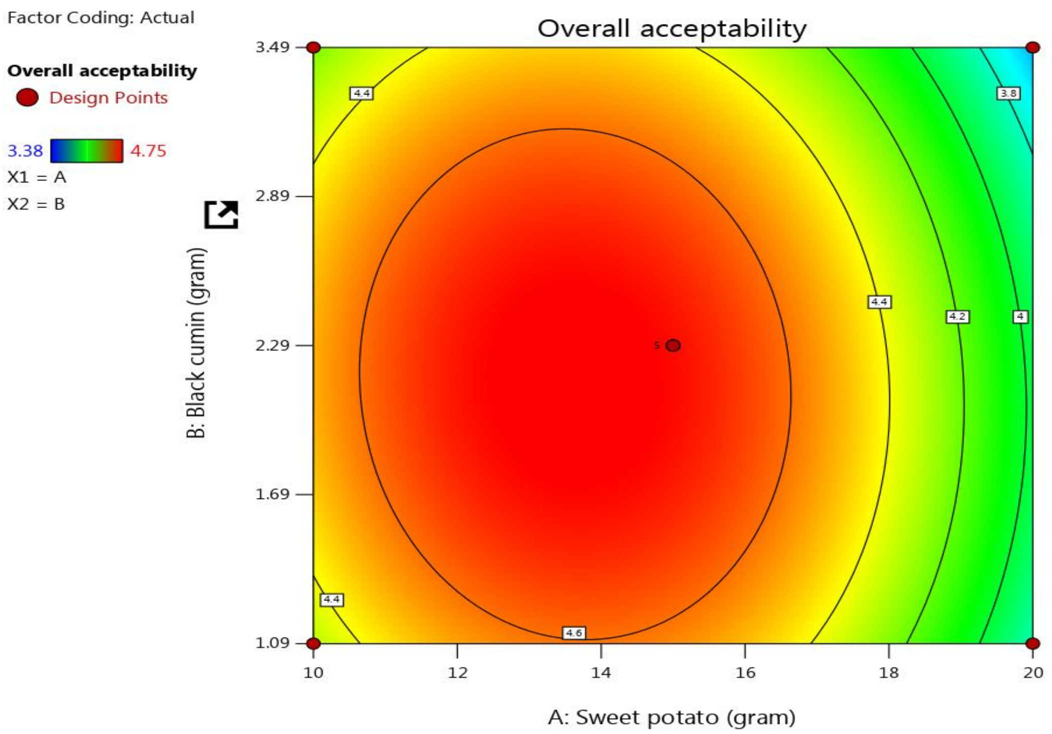

Figure 9: Contour Plot Effect Of Sweet Potato And Black Cumin On Overall Acceptability

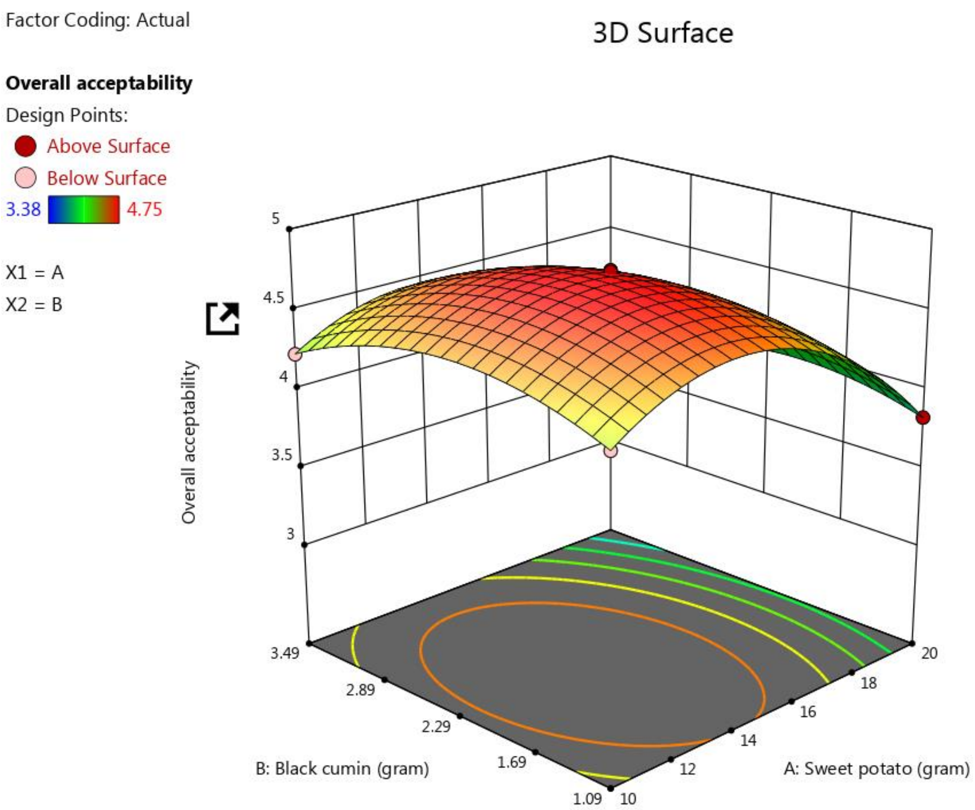

Figure 10: 3d Plot Effect Of Sweet Potato Flour And Black Cumin On Overall Acceptability

Confirmation Report To Validate The Combination Of Factors On The Carbohydrate, Protein And Overall Acceptability

The mean values for protein content (7.9%) total carbohydrate content (82.2%) and overall acceptability (4.41) were analyzed through Design Expert Software. The selected formulations (with desirability >0.744) of sweet potato flour were prepared and further evaluated for validating predicted values. Overall acceptability was evaluated by same panel of judges. Based upon the validation experiments, the formulation with optimized levels for sweet potato flour and black cumin as 11.8 g and 3.49 g respectively was found most suitable for preparation of composite bread. At the optimum values of SPB (11.8 g) and BCB (3.49 g) five experimental tests were conducted and the observed mean values are shown in Table 5.

Factor	**Name**	**Level**	**Low Level**	**High Level**	**Std. Dev.**	**Coding**		
A	SPB	11.8	10	20	0	Actual		
B	BCB	3.49	1.09	3.49	0	Actual		
Analysis	**Predicted Mean**	**Predicted Median**	**Observed data**	**StdDev**	**N**	**SE Pred**	**95% PI low**	**Data Mean**
CBH (%)	80.62	80.62	**82.2**	0.02457	5	0.0268497	80.5576	**82.2**
Protein (%)	7.18	7.18	**7.9**	0.0133	5	0.0145309	7.14524	**7.9**
Overall acceptability	4.774	4.774	**4.41**	0.00693	5	0.0075758	4.75634	**4.41**

Table 5: Confirmation Report At The Optimized Values Of Spb And Bcb And The Predicted Values

Overall Optimization Of The Blending Process

The parameters like sweet potato flour and black cumin ratio were optimized within a range, while the responses protein, carbohydrate, and overall acceptability were set to maximize. If the value ranges from 0 to 1, in which as it approaches to 1 best solution. However, if it approaches to 0 it does not meet the best goal. In this study it meets the best goal at desirability of 0.744.Generally, during the optimization of the process parameters factors sweet potato flour and black cumin ratio were optimized in range but the responses protein, carbohydrate, and overall acceptability were set to be maximized in the study

Name	**Goal**	**Lower Limit**	**Upper Limit**	**Lower Weight**	**Upper Weight**	**Importance**
A:Sweet potato	in range	10	20	1	1	3
B:Black cumin	in range	1.09	3.49	1	1	3
Protein	Maximize	5.92	8	1	1	5
Carbohydrate	Maximize	78.5	85.03	1	1	5
Overall acceptability	Maximize	3.38	4.75	1	1	5

Table 6: Constraints For Optimization Process Parameters Form Doe Software

Numerical Optimization

The optimization analysis performed using Design-Expert software identified 11.8 g sweet potato flour and 3.49 g black cumin seed flour as the optimal formulation, with a desirability value of 0.744. The desirability function is a numerical optimization approach used to simultaneously evaluate multiple responses, where values closer to 1 indicate better optimization performance (Montgomery, 2017). The optimized formulation was predicted to produce bread containing 7.9% protein, 82.2% carbohydrate, and an overall sensory acceptability score of 4.41, indicating a suitable balance between nutritional quality and consumer acceptability.

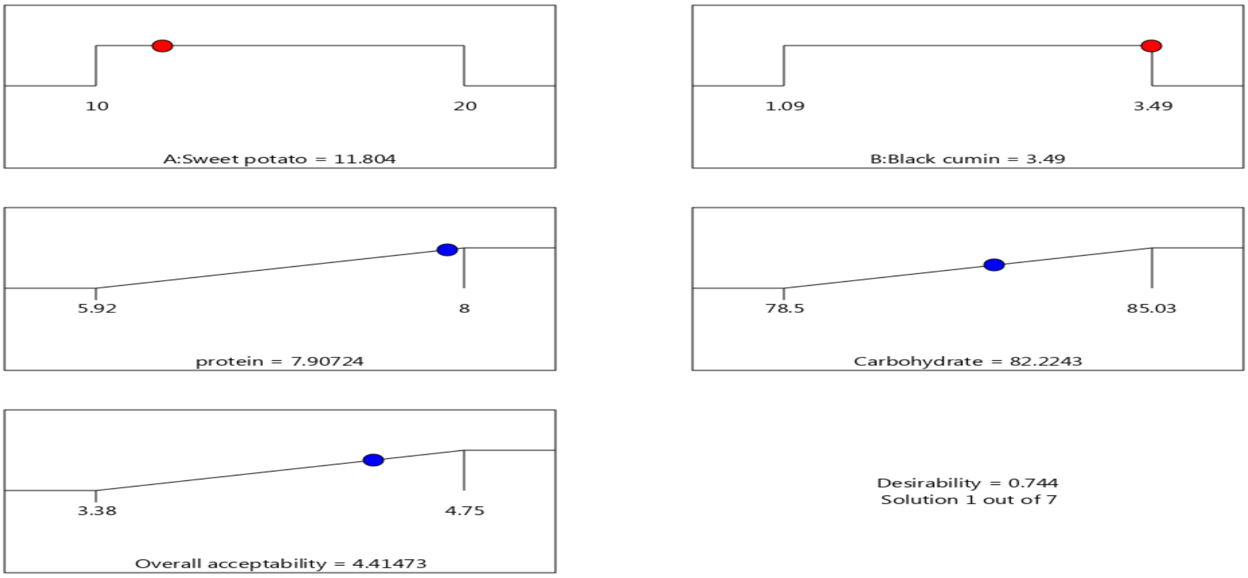

Figure 11: Ramps Plot For Numerical Optimization At Desirability 0.744

Physicochemical Properties Of The Bread Produced At The Overall Optimum Values

The optimized SPB and BCB were also used to evaluate proximate composition, mineral content and functional properties of the developed bread. Moisture, protein, fat, crude fiber, total carbohydrate, iron, zinc and calcium content in most acceptable range for the bread made at the optimized SPB and BCB. The present study concluded that the optimized sample of composite bread containing 11.8g sweet potato flour and 3.49 g black cumin was found the best combination with respect to overall acceptability and nutritional value.

Proximate composition			**Optimized sample (11.8g sweet potato flour and 3.49 g black cumin on bread**			
Protein%			7.9			
Carbohydrate%			82.2			
Overall acceptability			4.41			
Fiber%			1.49			
Ash%			2.59			
Fat%			2.43			
Moisture%			5.72			
Mineral content (mg/100g)						
Ca			16.12			
Fe			12.45			
Zn			3			
Control						
Protein%	**CHO%**	**Over all Acceptability**	**Fiber%**	**Ash%**	**Fat%**	**Moisture%**
6.2	86.71	3.9	0.75	1.98	2.30	5.21
Ca(mg/100g)		**Fe(mg/100g)**		**Zn(mg/100g)**		
15.37		3.99		1.61		

Table 7: Proximate Composition Of Optimized Sample Of Sweet Potato Flour And Black Cumin

Protein content increased with increasing black cumin seed incorporation because of its higher protein concentration compared with wheat flour, indicating compositional enrichment rather than protein denaturation. Protein content increased from 7.17% to 8.00% as black cumin seed increased from 1.09 g to 3.49 g, which is consistent with the findings of [22] The optimized formulation (11.8 g SPF and 3.49 g BCB) contained 7.9% protein, demonstrating that moderate substitution can improve nutritional quality without adversely affecting sensory acceptability. In contrast, carbohydrate content decreased in the composite bread due to partial replacement of starch-rich wheat flour with sweet potato flour and black cumin seed, which contain higher levels of protein, fiber, and other non-starch components. The optimized formulation contained 82.2% carbohydrate, and the reduction observed with increasing black cumin seed agrees with the findings of Mohammad et al. (2016) and Qianqian et al. (2020).

Sensory evaluation indicated that balanced incorporation of sweet potato flour and black cumin seed improved overall acceptability. The highest sensory score (4.75) was obtained at 15 g SPF and 2.29 g BCB, whereas the optimized formulation achieved a score of 4.41. Higher substitution levels reduced acceptability because of stronger flavor, darker color, and weakening of the gluten network caused by increased fiber and non-gluten components. Similar observations were reported by [19].

The optimized bread exhibited acceptable moisture (5.72%), ash (2.59%), fat (2.43%), and crude fiber (1.49%) contents, indicating improved nutritional quality and storage stability. The increases in ash, fat, and fiber contents were attributed to the mineral, lipid, and dietary fiber contributions of black cumin seed and sweet potato flour, in agreement with the findings of and Moisture content remained within the recommended limit force real-based products, supporting microbial stability and shelf life, as reported by [23-27].

Mineral analysis showed enhanced calcium (16.12 mg/100 g), iron (12.45 mg/100 g), and zinc (3.00 mg/100 g) contents compared with conventional wheat bread, confirming the micronutrient enrichment potential of composite flour incorporation. Similar compositional trends were reported by [22,28] highlighting the nutritional advantages of sweet potato and black cumin seed supplementation in bakery products.

Conclusions

The incorporation of sweet potato flour and black cumin seed into wheat bread significantly enhanced the nutritional and sensory qualities compared with the control bread. Sweet potato flour primarily increased carbohydrate content, whereas black cumin seed improved protein of the composite bread. Sensory evaluation showed that moderate substitution levels resulted in greater consumer acceptability, while excessive incorporation negatively affected product quality. This indicates the importance of balanced formulation for achieving desirable nutritional and sensory attributes. The optimized formulation produced bread with higher overall acceptability, enhanced protein content, and improved micronutrient composition compared with conventional wheat bread. The close agreement between predicted and experimental values confirmed the adequacy and reliability of the developed model. Overall, partial substitution of wheat flour with sweet potato flour and black cumin seed can be effectively applied in the development of nutritionally enriched and consumer-acceptable bread products. The findings highlight the potential of composite flour technology for producing practical bakery products with improved nutritional value.

Acknowledgments

The authors would like to acknowledge Adigrat University for fianicial support. College of Agriculture and enviromental scienceand Mekelle University is also kindly acknowledge for space and laboratory facility allowance.

Statements and Declarations

Author Contributions

All authors contributed to the study's conception and design. Material preparation, data collection were performed by (Kidanemariam Tesfay ,Zenebe Tadesse,LijalemTareke,], Ftwi Gebremedhin , GebrehiwotGidey. Data was analyzed by [Zenebe Tadesse and LijalemTareke]. The first draft of the manuscript was written by [Kidanemariam Tesfay and Zenebe Tadesse]and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding

The work was financially supported by Adigrat University during 2021-2023 recurrent budgets with the Grant project Registration Number of CRPO/ADU/Medium/CoDANR/26/2021-2023.

Competing Interests

The authors declare that there are no financial or non-financial competing interests regarding the publication of this article.

Data Availability

The datasets generated during and/or analyzed during the current study are available in the manuscript.

Clinical Trial Number

Not applicable

Ethics

The, ethical approval was reviewed by the local Ethics Committee of the Mekelle University Research Academy, in accordance with its established guidelines. The reflective nature of the study and the fact that all procedures performed were part of standard care contributed to this decision. The research protocol for this study was approved by the University Research Ethics Committee of Mekelle University Research Academy). All procedures were conducted in accordance with the ethical standards of the committee Mekelle University Research Academy Declaration and Informed consent was obtained from all participants prior to data collection. The study adhered strictly to the ethical guidelines set by the Mekelle University Research Academy.

Consent To Publish
Not applicable

Plant Guide Line
I have used local plant guideline

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