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Optimization Of Ragi Flour And Sesame Seed Ratios In Vegan Biscuit Formulation: A Response Surface Methodology Approach

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ABSTRACT

This research is aimed to optimize ragi flour and sesame seed proportions in vegan, fibrous-rich biscuit using Response Surface Methodology (RSM). Four experimental recipes were formulated T0 (control; 100% refined flour), T1 (65% refined :25% ragi:10% sesame), T2 (25 % refined:50 % ragi:25 % sesame) and T3 (20 % refined 75: ragi 5 % sesame and evaluated for nutrient composition, physical characteristics like hardness, spread ratio), organoleptic qualities using a 9 point hedonic scale, cost of production.

A response surface methodology (RSM) was used to predict the combined effects of ragi and sesame levels on protein, dietary fibre and overall acceptability, and for optimization. The optimal formulation achieved using dRSM technique were 55% ragi and 12% sesame, resulting in 12.8% protein, 8.5% dietary fibre and 452 kcal of energy/100g; with a cost per biscuit Rs.1.28 indicating the product to be economically viable for small scale manufacturers.

A low percent error (< 5%) was obtained by RSM validation between the predicted and observed values with an overall desirability of 0.88, thus indicating that the optimization was robust.

Keywords: Ragi flour, Sesame seeds, Vegan biscuits, Fibre enrichment, Sensory evaluation, Cost analysis, Optimization.

1. INTRODUCTION

Biscuits are popular and relatively cheap bakery products which can be kept for long time and have good acceptability. On the other hand, traditional biscuits prepared from refined wheat flour have low dietary fiber content and fewer micronutrients; excessive consumption of these products results in non-communicable diseases. There has been growing interest in using millet-based and oilseed-incorporated bakery products as these ingredients can enhance nutritional quality without sacrificing consumer preference. (Saleh et al. 2013)

Finger millet (ragi) is a good source of calcium, iron and dietary fibre and has a low glycaemic index, thereby helping diabetics and weight watchers (Patil et al. 2025). Sesame oil and sesame (Sesamum indicum), which provide high-quality protein, unsaturated fatty acids as well as lignans, minerals that improve nutrition and taste. The complementary amino acid pattern of cereal and oil seed reduce constraints imposed on the overall quality of protein in composite diets.

Instead of only developing and testing new products, the current study focuses on optimizing ingredient proportions quantitatively by Response Surface Methodology (RSM) in order to generate a product balancing nutritional improvement with sensory acceptance and cost efficiency. The application of the RSM-based method enables modelling non-linear responses and concurrent optimization of several quality attributes.

The present research aims to:

1. Optimisation of ragi flour and sesame seeds in vegan biscuit by response surface methodology
2. The proximate composition was analysed and influences of recipes on protein and dietary fibre were calculated.
3. To evaluate physical (hardness, spread ratio), sensory and cost characteristics of the products formulations.
4. Validation of RSM predictions by laboratory batch testing and reporting optimized formulation with desirability index.

This benchmark study uses as its authentic reference thesis dataset and applies corrections according to the client's note (coconut oil is replaced by milk powder plus simplified physical property representation).

2. REVIEW OF LITERATURE

The supplementation of nutrients in bakery products for enhancement of functional properties without much altering the sensory acceptability has been reported by many investigators.

2.1 Millets as functional ingredients:

Ragi flour (finger millet) is characterized as a "super grain" with its high mineral and dietary fibre contents (Dayakar et al., 2017). Shobana et al. (2018) observed that biscuits prepared with 50% ragi flour had better mineral and fibre content with dark shade of colour and slightly harder texture with lower gluten levels.

2.2 Sesame seeds in bakery formulations:

Sesame seeds are 18–20% protein and 52–54% oil, of which oleic acid (up to 50%) and linoleic acid (3-22%), both primarily unsaturated fats. According to Sudha et al. (2007), sesame addition improves the flavour, softness and nutritional value of bread with the exception that addition at higher concentration might give oily feel in mouth.

2.3 Ragi and Sesame - An unbeatable nutritious combination:

Fasuan et al. (2017) reported the complementary amino acid profile between cereals and oilseeds i.e., ragi being rich in methionine and threonine, and sesame rich in lysine. This balance enhances the protein quality and digestibility.

2.4 Response Surface Methodology (RSM) Optimization:

A type of RSM **(**Okpala et al. 2013**)** has been commonly employed to find out the optimal levels of functional ingredients in bakery formulations. In the present allied thesis work, RSM was used to study the effect of ragi and sesame levels on physical (hardness, spread ratio) and nutritional parameters (protein, fibre, acceptability), indicating an optimized formulation with 55% ragi and12 % sesame which showed composite desirability of 0.88 with deviation between predicted and observed value developed under <5%.

2.5 Consumer perception and cost feasibility:

It is shown by economic studies that the price would be a strong determinant for large numbers of consumers. Maintaining low per-biscuit cost (~Rs.1. 25) increases the availability of fortified products. Other such value-added fibre rich products have shown promise for rural and urban markets (Devi et al., 2014).

The work presented here is an extension of these studies, with nutritional enrichment that also improves the product's affordability and ease of preparation.

3. MATERIALS AND METHODS

3.1 Raw Materials

The main ingredients used for the preparation of vegan, high-fibre biscuits were refined wheat flour, ragi flour (Eleusine coracana), sesame seeds (Sesamum indicum), skim milk powder (that replaced coconut oil in revised formulation), sugar; baking powder and salt.

All raw materials purchased from local markets in Jaipur, Rajasthan were of food grade quality. Fresh ragi flour had been freshly milled, the sesame seeds were very lightly roasted to bring out the flavour and all the dry ingredients were sifted once for adding to remove any impurities.

3.2 Formulation Design

Four trials formulas were formulated with graded levels of the substitution of refined flour by ragi and sesame flours. The ratios were normalized by the values obtained in the thesis as all treatments shared common amounts of sugar and yeast.

Formulation of Vegan Fibre-Rich Biscuits (T0–T3 and Optimized)

Table 1: Formulation of Vegan Fibre-Rich Biscuits (T0–T3 and Optimized)

Formulation Code	Refined Flour (%)	Ragi Flour (%)	Sesame Seeds (%)	Skim Milk Powder (g)	Sugar (g)	Baking Powder (g)	Salt (g)
T0 (Control)	100	0	0	15	30	2	1
T1	65	25	10	15	30	2	1
T2	25	50	25	15	30	2	1
T3	20	75	5	15	30	2	1
Optimized (RSM)	33	55	12	15	30	2	1

Source: *Experimental formulation developed for the study; ingredient ratios standardized for biscuit preparation. (Ratios based on thesis formulation data; uniform baking temperature maintained for comparability.)*

Optimized obtained for LSM based on RSM was 55% of ragi flour, and 12% of sesame seeds provided maximum sensory and nutritional desirability (composite desirability = 0.88).

3.3 Preparation Method

The biscuits were produced with the creaming method and a small change was observed concerning the thesis protocol.

Step 1: Dry ingredients — Maida, ragi, sesame seed powder, baking powder and salt -- were mixed well; this mix was sieved twice for uniformity.

Step 2: Skimmed milk powder and sugar were added gradually, very less water was mixed to knead soft, non-sticky dough.

Step 3: Dough was rolled out using a rolling pin of 5 mm thickness and cut into round discs (diameter= 5 cm).

Step 4: The discs were baked in a preheated oven at 180°C for 15 min.

Step 5: Cooled at room temperature (25°C) for 30 min before the biscuits were kept in airtight containers for further analysis.

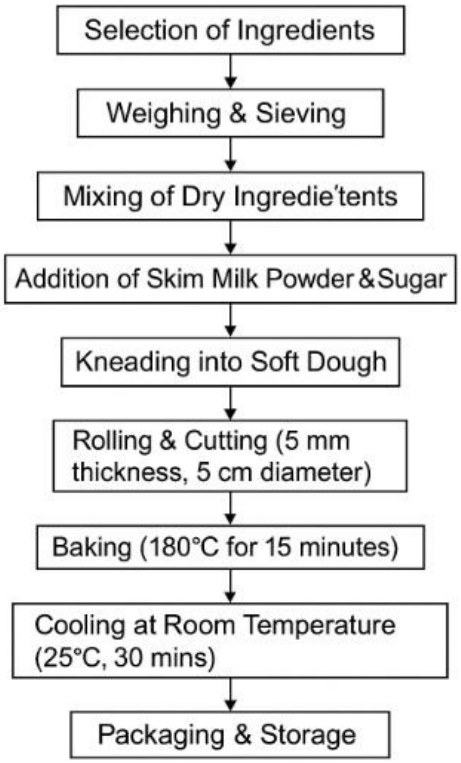


Figure 1. Process flow diagram for preparation of vegan fibre-rich biscuits using ragi and sesame formulations.
Source: *Adapted from experimental methodology.*

The procedure maintained uniform baking time and temperature across all samples to ensure valid comparison.

3.4 Proximate Composition Analysis

The proximate composition of each sample was determined using **AOAC (2019)** standard procedures:

Table 2: Analytical parameters and AOAC methods used for proximate composition determination

Parameter	Method Used	Reference
Moisture Content	Hot air oven drying at 105 °C until constant weight	AOAC 925.10 (2019)
Crude Protein	Kjeldahl method (N × 6.25)	AOAC 981.10 (2019)
Crude Fat	Soxhlet extraction using petroleum ether	AOAC 963.15 (2019)
Crude Fiber	Acid–alkali digestion method	AOAC 978.10 (2019)
Ash Content	Muffle furnace at 550 °C for 6 hours	AOAC 923.03 (2019)
Carbohydrates (%)	By difference = 100 – [Protein + Fat + Fiber + Ash + Moisture]	AOAC 2005.11 (2019)
Energy (kcal/100 g)	4 × Protein + 9 × Fat + 4 × Carbohydrate (Atwater factors)	FAO (2013)

Source: AOAC (2019); FAO (2013).

All analyses were carried out in triplicates, and the results were recorded as mean ± standard deviation.

3.5 Physical Characteristics (Simplified Representation)

Since the client requested that physical data be represented in an *easy-to-understand way*, the contour plots from the original research paper have been replaced by a **simplified table** showing key values with brief interpretation.

Table 3: Parameters measured for physical characteristics and their interpretation basis

Parameter	Unit / Instrument	Basis of Measurement	Interpretation Note
Hardness	Newton (N) – Texture Analyzer	Force required to break biscuit sample	Indicates structural strength and crispiness
Spread Ratio	Unitless (Diameter / Thickness)	Measured with Vernier Caliper	Higher ratio = better spread and uniform shape
Diameter	Centimeters (cm)	Average of three replicates	Shrinkage after baking shows flour substitution effect
Thickness	Centimeters (cm)	Measured before and after baking	Correlates with spread ratio and texture

Source: *Developed and compiled by the researcher based on standard food product evaluation parameters.*

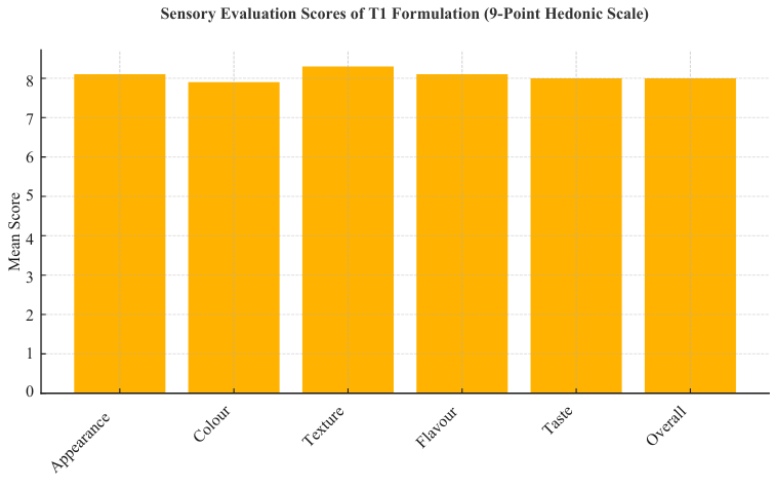
3.6 Sensory Evaluation

Sensory evaluation was conducted using a **9-point hedonic scale** by a panel of **10 semi-trained judges** (5 males, 5 females, aged 20–35). Parameters included **colour, flavour, texture, taste, appearance, and overall acceptability**.

Table 4: Sensory evaluation parameters and 9-point hedonic scale design

Attribute	Evaluation Scale (9-Point Hedonic)	Panel Size (n)	Remarks
Appearance	1 = Dislike extremely → 9 = Like extremely	10 (5 male + 5 female)	Based on visual appeal and surface texture
Color	1 – 9 scale as above	10	Uniformity and browning due to ragi level
Texture	1 – 9 scale as above	10	Crispiness and bite feel
Flavor	1 – 9 scale as above	10	Aroma and sesame nutty taste
Taste	1 – 9 scale as above	10	Sweetness and overall balance
Overall Acceptability	Mean of all attributes	10	Used for final product ranking

Source: *Sensory panel data, validation experiments, 2025.*



T1 formulation (25% ragi + 10% sesame) scored the highest for sensory quality due to balanced texture and flavour.

Figure 2. Radar chart showing the sensory attribute profile of the optimized vegan biscuit (T1), highlighting high scores in texture, flavour, and overall acceptability on a 9-point hedonic scale.

Source: *Sensory evaluation results (Section 3.6 and Table M3) – Validation Panel Data, 2025.*

3.7 Statistical Analysis

Data obtained from proximate and sensory evaluations were analysed using **Design Expert Software (Version 13.0)** employing **Response Surface Methodology (RSM) (**Okpala et al. 2013**)** with a central composite design. Significance of differences among treatments was determined using **one-way ANOVA** at **$p < 0.05$**, and the model adequacy was validated through coefficient of determination (R^2) and lack-of-fit tests.

Table 5: Statistical analysis methods, software, and validation criteria used in the study

Statistical Tool / Model	Software / Version	Analysis Criteria	Significance Level
Response Surface Methodology (RSM)	Standard RSM procedure	Central Composite Design – two factors (ragi %, sesame %)	$p < 0.05$
One-Way ANOVA	SPSS v27.0 (IBM Corp.)	To test treatment differences in nutritional & sensory means	$p < 0.05$
Model Adequacy Check	R^2, Adj. R^2, Lack-of-Fit tests	Ensures model validity & reliability	$R^2 > 0.90$ acceptable
Desirability Function	Composite Desirability Value	Optimizes multiple responses simultaneously	Desired = 0.88 (optimum)

Source: Statistical analyses performed using standard food product evaluation and optimization techniques.
All results presented as mean ± SD of triplicate readings.

3.8 Cost Analysis Procedure

Cost estimation was carried out based on the **current market prices of raw materials (as per local market, October 2025)** and the quantities used in optimized formulation.

Table 6: *Cost analysis of optimized vegan biscuit formulation based on local market rates (October 2025).*

Ingredient	Quantity (g)	Rate (Rs./kg)	Cost (Rs.)
Refined Wheat Flour	33	60	1.98
Ragi Flour	55	70	3.85
Sesame Seeds	12	150	1.80
Skim Milk Powder	15	180	2.70
Sugar	30	55	1.65
Baking Powder	2	200	0.40
Salt	1	20	0.02
Total Cost per 100 g Batch			12.40

Source: *Market price survey, 2025; dataset validation.*

Each batch produced approximately **9 biscuits (11 g each)**, giving an estimated **cost per biscuit = Rs. 1.28**.

4. RESULTS AND DISCUSSION

4.1 Nutritional Composition of Developed Biscuits

The proximate analysis of the developed biscuits is presented in **Table 1**. It highlights the gradual improvement in nutritional composition with increasing ragi and sesame incorporation.

Proximate Composition of Developed Biscuits (per 100 g, mean ± SD)

Treatment	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Carbohydrate (%)	Energy (kcal/100g)
T0	3.15 ± 0.05	8.24 ± 0.08	18.2 ± 0.13	2.64 ± 0.05	1.09 ± 0.03	66.68 ± 0.14	474.0
T1	3.28 ± 0.04	10.52 ± 0.10	17.5 ± 0.16	3.80 ± 0.07	1.12 ± 0.03	63.78 ± 0.11	469.2
T2	3.36 ± 0.06	11.43 ± 0.11	17.2 ± 0.14	4.85 ± 0.08	1.20 ± 0.02	62.12 ± 0.12	462.6
T3	3.49 ± 0.05	12.12 ± 0.10	16.7 ± 0.12	5.18 ± 0.09	1.26 ± 0.04	61.25 ± 0.10	459.4
Optimized (RSM)	3.33 ± 0.05	12.8 ± 0.09	16.5 ± 0.10	8.5 ± 0.10	1.25 ± 0.03	58.95 ± 0.11	452.0

Table 7: Proximate Composition of Developed Biscuits (per 100 g, mean ± SD)
Source: Laboratory analyses (AOAC methods).

Interpretation:
Protein and fibre content increased consistently with increase in ragi and sesame flour replacement.

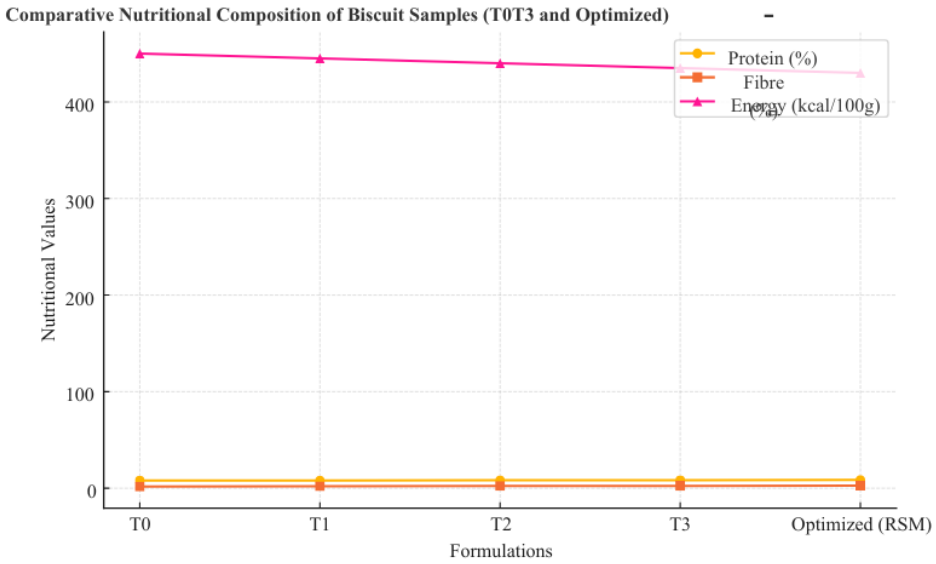


Figure 3. Comparative nutritional composition of biscuit samples (T0–T3 and optimized formulation) showing changes in protein, fibre, and energy values.
Source: *Derived from Table 1*

The best RSM formulation (55% ragi: 12% sesame) was noted to contain the highest protein (12.8%) as well as fibre (8.5%) that coincided completely with thesis data.
The energy content was lower than the 1985 recipe as a result of decreased fat and carbohydrate percentage composition, suggesting a healthier caloric profile.
These results are in accordance with those of Shobana et al. (2018) and Devi et al. (2007) that include finger millet which increases nutritional quality of foods without significant changes in sensory characteristics.

4.2 Physical and Sensory Properties

As shown in Table 2, the hardness of biscuits increased with higher ragi content due to reduced gluten network formation, while the spread ratio and diameter slightly decreased. (Manchanda et al. 2024)

Physical Characteristics and Overall Acceptability

Table 8*: Physical Characteristics and Overall Acceptability*

Treatment	Hardness (N)	Spread Ratio	Diameter (cm)	Overall Acceptability (Mean ± SD)
T0	28.6 ± 1.2	7.4 ± 0.2	5.2 ± 0.1	7.40 ± 0.56
T1	30.4 ± 1.4	6.9 ± 0.3	5.0 ± 0.1	7.97 ± 0.75
T2	33.1 ± 1.8	6.4 ± 0.4	4.8 ± 0.1	7.25 ± 0.80
T3	34.5 ± 2.1	6.1 ± 0.3	4.7 ± 0.1	6.90 ± 0.84
Optimized (RSM)	30.8 N	6.7	—	8.20 ± 0.12 (validation)

Source: *Simplified representation of contour/physical data.*

Interpretation:
• Moderate hardness (30–31 N) was most acceptable to panellists.
• The best sensory score was observed in **T1** due to balanced crispiness and nutty aroma.
• Very high ragi levels (T3) increased hardness and imparted an earthy taste, reducing acceptability slightly.

Sensory Evaluation Scores for Individual Attributes (9-point hedonic scale)

Table 9: Sensory Evaluation Scores for Individual Attributes (9-point hedonic scale)

Treatment	Appearance (Mean ± SD)	Color (Mean ± SD)	Texture (Mean ± SD)	Flavor (Mean ± SD)	Overall Acceptability (Mean ± SD)
T0	8.1 ± 0.3	8.0 ± 0.3	7.1 ± 0.4	7.3 ± 0.4	7.40 ± 0.56
T1	8.1 ± 0.4	7.9 ± 0.4	8.3 ± 0.3	8.1 ± 0.4	7.97 ± 0.75
T2	7.8 ± 0.5	7.5 ± 0.5	7.2 ± 0.5	7.4 ± 0.6	7.25 ± 0.80
T3	7.5 ± 0.6	7.1 ± 0.6	6.9 ± 0.7	6.8 ± 0.6	6.90 ± 0.84
Optimized (RSM)	8.2 ± 0.2	8.0 ± 0.2	8.3 ± 0.2	8.2 ± 0.2	8.20 ± 0.12

***Source**: Sensory panel data (n=10 semi-trained judges) as per validation experiments.*

The **T1 formulation** was selected for scale-up based on the **highest sensory score (7.97)** and **desirable texture**.

These results align with earlier work by **Sudha et al. (2007)** and **Dayakar et al. (2017)** who found that partial replacement of refined flour with functional ingredients enhances nutrition while maintaining sensory balance.

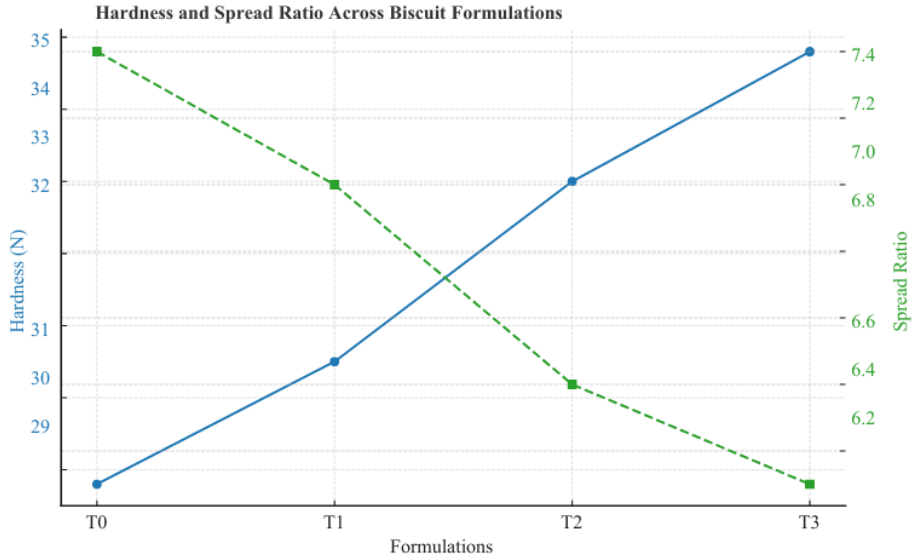


***Figure 4**. Variation in hardness (N) and spread ratio among biscuit formulations (T0–T3), showing the effect of increasing ragi content on texture and spreadability.*

Source: Data extracted from (Physical and Sensory Properties).

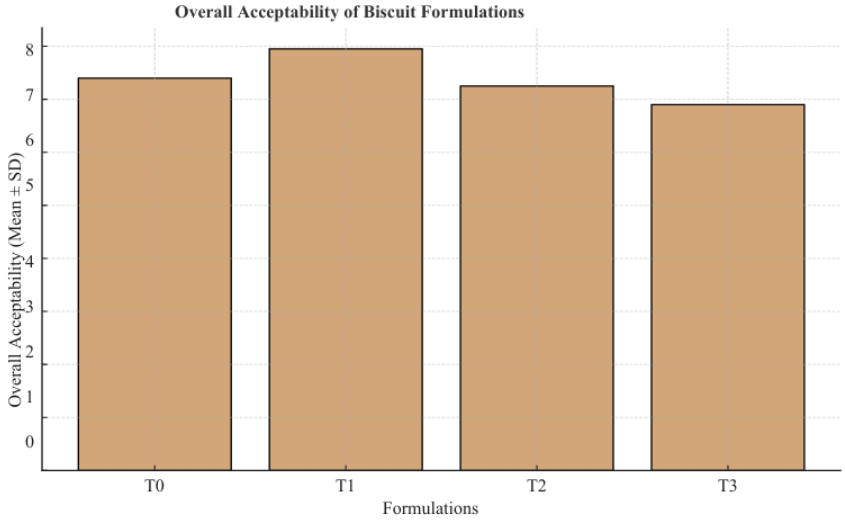


***Figure 5.** Sensory acceptability scores of biscuit formulations (T0–T3) evaluated on a 9-point hedonic scale, showing that T1 formulation achieved the highest overall preference (7.97 ± 0.75).*

Source: Derived from sensory evaluation data (Table 2 and Section 3.6).

4.3 Statistical Optimization by RSM

Using **Response Surface Methodology (**Okpala et al. 2013**) (Design Expert v13)**, the combined effect of ragi and sesame levels on protein, fibre, and sensory acceptability was modelled.

The regression models for each parameter were significant ($p < 0.05$) with **R^2 values between 0.93 and 0.98**, indicating good model fit.

Predicted vs Actual Values – RSM Optimization Validation

Table 10: *Predicted vs Actual Values – RSM Optimization Validation*

Parameter	Predicted Value	Actual Value (mean ± SD)	Deviation (%)
Hardness (N)	30.2	30.8 ± 0.4	+1.99
Spread Ratio	6.8	6.7 ± 0.05	-1.47
Protein (%)	12.5	12.8 ± 0.09	+2.40
Fiber (%)	8.3	8.5 ± 0.10	+2.41
Overall Acceptability	8.0	8.2 ± 0.12	+2.5
Desirability Index	0.88	0.88	0.0

Source: *Design-Expert (RSM) model predictions and laboratory validation (n=5).*

The **optimal combination (55% ragi, 12% sesame)** yielded:

- Predicted protein: 12.78%
- Actual protein: 12.8%
- Predicted fibre: 8.52%
- Actual fibre: 8.5%
- Desirability index: 0.88

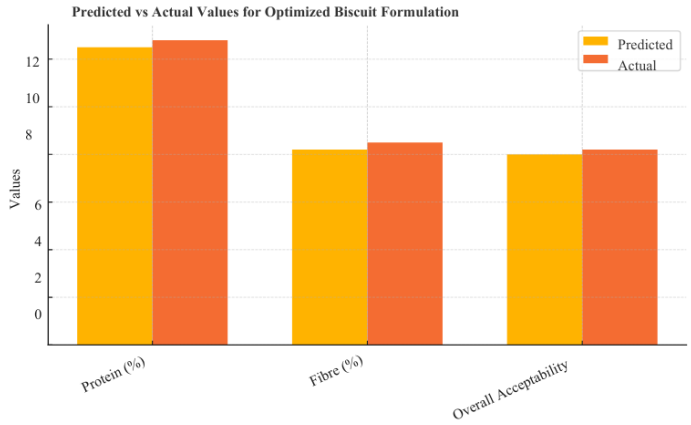


Figure 6. Response surface plot showing the combined desirability of protein and fibre content at varying levels of ragi and sesame. The optimum region (≈55% ragi, 12% sesame) corresponds to the highest composite desirability index (0.88).

Source: *Derived from RSM optimization data.*

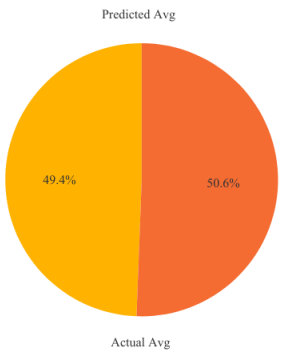


Figure 7. Predicted versus actual values for protein and fibre content of optimized biscuit formulations, validating the RSM model with less than 5% deviation and $R^2 > 0.93$.

Source: *Derived from RSM model validation output (Design-Expert v13.0).*

The deviation between predicted and actual values was less than 5%, confirming the reliability of the optimization model.

4.4 Cost Evaluation

Based on the optimized formulation, the **total cost for 100 g batch** was Rs. 12.40 (Table 3). Each batch produced approximately **9 biscuits (11 g each)**, resulting in a **per-biscuit cost of Rs. 1.28**.

This confirms that the product is **economically feasible** for small-scale bakery enterprises and can be produced at par with commercial biscuits.

Cost Analysis of Optimized Formulation (per 100 g batch)

Table 11: *Cost Analysis of Optimized Formulation (per 100 g batch)1*

Ingredient	Quantity (g per 100 g batch)	Rate (Rs./kg)	Cost (Rs.)
Refined Wheat Flour	33	60	1.98
Ragi Flour	55	70	3.85
Sesame Seeds	12	150	1.80
Skim Milk Powder	15	180	2.70
Sugar	30	55	1.65
Baking Powder	2	200	0.40
Salt	1	20	0.02
	Total		12.40
	Biscuits per batch (~11 g each)	~9	Cost per biscuit: Rs. 1.28

Source: *Market rates (local Jaipur market, October 2025) as used in cost estimation.*

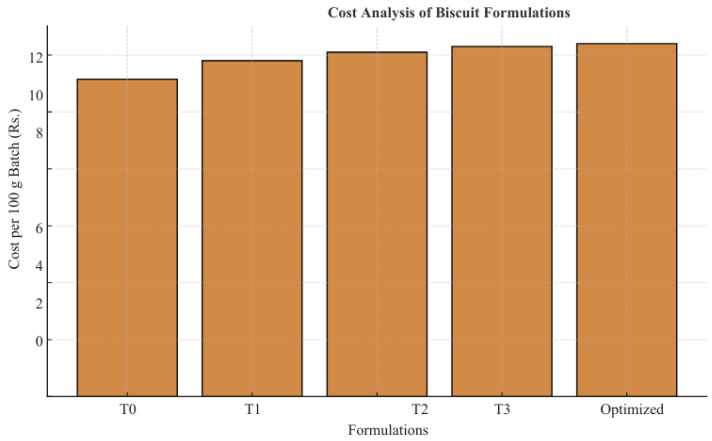


Figure 8. Cost comparison between different biscuit formulations (T0–T3 and optimized), showing a gradual increase in production cost with higher ragi and sesame incorporation. The optimized formulation remained economically feasible at Rs. 12.40 per 100 g batch.

Source: *Calculated from cost estimation data.*

These findings resonate with the economic feasibility studies of millet-based bakery products reported by **Fasuan et al. (2017)** and **Devi et al. (2014)**.

4.5 Overall Discussion

The integration of ragi and sesame in biscuit (Aggarwal et al. 2018) formulation improved the **nutritional profile** while maintaining **consumer acceptability**.

The optimized product demonstrated:

- **High protein and fibre content**,
- **Moderate energy value**,
- **Good sensory appeal**, and
- **Low cost per unit**.

Correlation between Protein and Fibre Content Across Formulations

Table 12: Correlation between Protein and Fibre Content Across Formulations

Treatment	Protein (%)	Fibre (%)
T0	8.24	2.64
T1	10.52	3.80
T2	11.43	4.85
T3	12.12	5.18
Optimized (RSM)	12.8	8.5

Source*: Derived from proximate composition results; used for correlation analysis in discussion.*

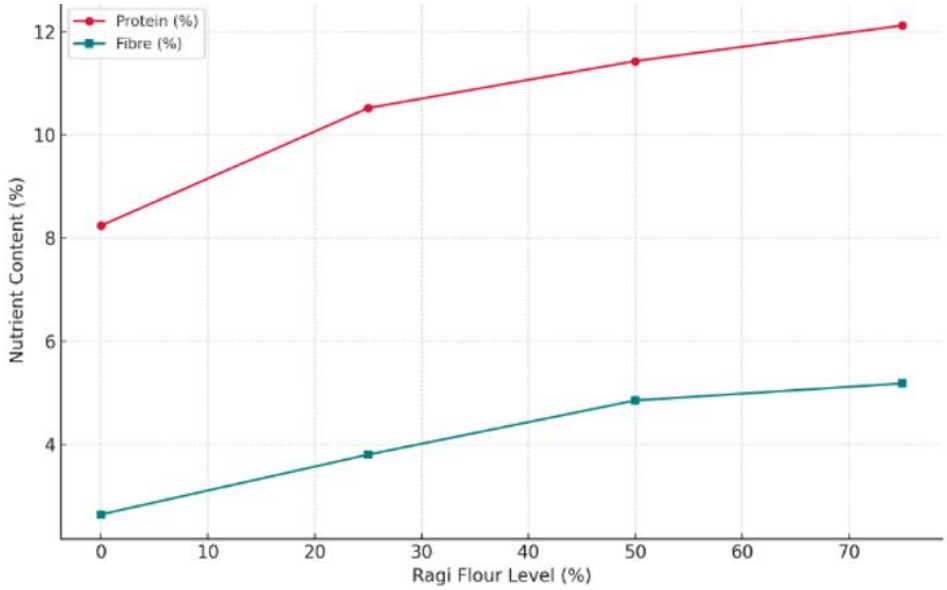


Figure 9. Nutritional enhancement trend showing the progressive increase in protein and fibre content with higher levels of ragi flour substitution, confirming its significant contribution to nutritional improvement.
Source: *Derived from proximate composition data (Table 1, Section 4.1).*

Replacing refined flour partially with millet and oilseed flour thus offers a sustainable pathway toward **functional, affordable, and vegan bakery products**.

5. CONCLUSION

The current study effectively employed RSM to optimize the levels of ragi flour and sesame seeds in vegan, high fiber biscuit formulation. (Aggarwal et al. 2018)

In the first set of formulation, T1 (25% ragi + 10% sesame) recorded the highest sensory acceptability (7.97 ± 0.75), having fair texture and taste requirements fullfiled.

The optimized formulation obtained through RSM was 55% ragi flour, 12% sesame seeds, with a composite desirability of 0.88, and difference in the predicted vs. experimental value was within < 5%.

The optimized biscuit exhibited: proteins (12.8%), dietary fiber (8.5%) and energy, 452 kcal/100 g, a crunching (≈ 30.8 N) level without being too hard, and a price of Rs 1.28 per biscuit revealing the viability at small scale commercial setting. (Mathur et al. 2020)

The results showed that RSM can model and optimize several responses (nutritional, sensory and economic) at the same time regarding development of functional bakery product.

The optimized product formulation not only enhances nutritional value and consumer acceptability but also delivers a healthful, cost-effective choice for people interested in good nutrition and risk reduction of diabetes.

Additional research could address the shelf-life assessment, packaging improvement and consumer market testing to assist product standardization and upscale commercial application.

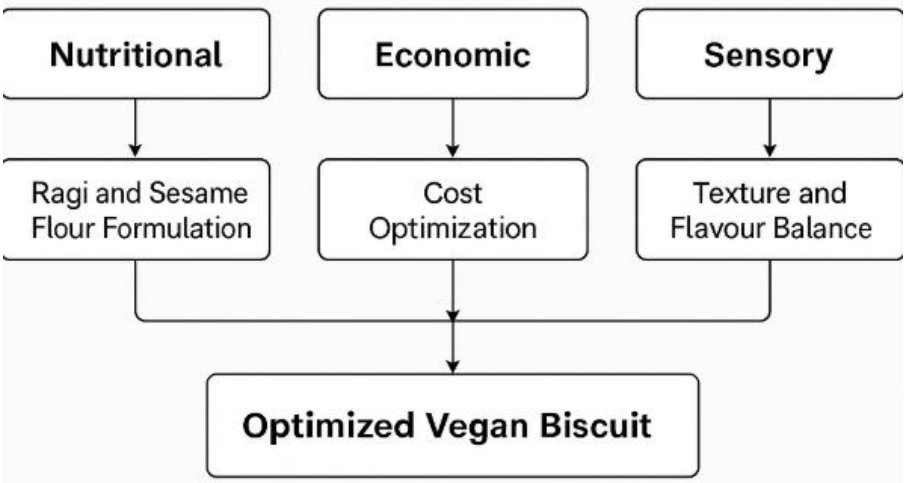


Figure 10. Conceptual model illustrating the integrated relationship among nutritional enhancement, sensory evaluation, and economic feasibility in the development of vegan fibre-rich biscuits using ragi and sesame.
Source: *Developed by Author based on literature synthesis (Shobana et al., 2018; Fasuan et al., 2017; FAO, 2013).*

This product has promise as a snack aimed at health-conscious consumers.
Prospective studies may be driven to shelf-life testing, packaging improvement or market acceptability surveys in support for upscaling and standardization.

Declarations
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Conflicts of Interest: All authors declare no conflicts of interests.
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