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Process optimization for development of horse gram (*Macrotyloma uniflorum* L.) incorporated instant cake mix

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Abstract

Aim: Horse gram (*Macrotyloma uniflorum* L.) is a nutritionally rich yet underutilized legume. The present study focused on the development and optimization of a roasted horse gram (RHG)-incorporated instant cake mix and evaluation of its nutritional, textural, and quality attributes. Instant mixes offer a convenient value-added approach to enhance dietary nutrition.

Methods: The independent variables included refined wheat flour (RWF):RHG ratio (1:1, 2:1, 3:1), milk powder (20, 25, 30 g/100 g flour), and baking time (10, 11, 12 min). Responses analyzed were moisture, ash, crude fat, crude protein, overall acceptability, color difference (ΔE), cohesiveness, hardness, and springiness.

Results: Optimization revealed that the best formulation consisted of a 2.1:1 RWF:RHG ratio, 30 g milk powder/100 g flour, and 10 min baking time. The optimized cake showed 36% moisture, 1.45% ash, 13.1% fat, 10.7% protein, 8.44 overall acceptability, 0.51 cohesiveness, 13.7 N hardness, and 0.91 springiness. All process parameters significantly ($p < 0.05$) influenced the responses. The optimized formulation was converted into an instant mix and stored for 80 days, during which moisture (6.03–7.55%) and total plate count [0.0003–0.02 colony-forming unit/g (CFU/g)] remained within safe limits. Consumer acceptability of cakes from stored mix remained high (7.8–8.5), confirming good storage stability and product potential.

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Conclusions: The study demonstrated that RHG can be successfully incorporated into an instant cake mix with improved nutritional value and acceptable sensory and textural properties. The optimized product exhibited good storage stability and high consumer acceptability, indicating its potential as a functional, value-added bakery product.

Keywords

horse gram, Instant cake mix, optimization, storage study

Introduction

The bakery industry is the largest and most organised processed food industry worldwide and has been modernising through technological upgrades over time [1]. Key ingredients for baked products include flour, sugar, eggs, water, and shortening, and these major ingredients can be combined to prepare a wide variety of baked products [2]. In India, the bakery manufacturing sector has shown productivity growth, indicating its potential contribution to the economy [3]. The visual quality of bakery products, including color and dimensions, is a key aspect of quality evaluation and production control [4]. Cakes are among the most popular bakery products and are consumed worldwide because of their sweet taste and soft texture [5]. Refined wheat flour (RWF) is a crucial ingredient in bakery products, so it cannot be completely removed because it acts as a structure builder; however, it can be fortified with vitamins and minerals or supplemented by incorporating protein-rich flours. For this purpose, pulses and legumes can be a better option, as they are rich in protein, complex carbohydrates, fibre, minerals, and vitamins, have low fat and sodium, and have a lower glycaemic index [6].

Among legumes, horse gram is one of the underutilised crops that has the capacity to be introduced into large-scale agricultural production [7]. In India, it is commonly known as Kulattha (Sanskrit) and considered the poor man's pulse. Horse gram belongs to the Fabaceae family; its botanical name, Macrotyloma, is derived from the Greek words makros, "tylos" (knob), and "loma" (margin), which describe the distinctive knobby formations along the pod edges [8].

Horse gram has a higher content of crude fibre, calcium, iron, manganese and molybdenum as compared to chickpea and pigeon pea, which are mostly consumed by the Indian population [9]. Horse gram is considered a nutrient-dense legume, providing substantial amounts of energy, protein, and dietary fibre comparable to other commonly consumed legumes. Its energy content ranges from 376.12 to 377.21 kcal per 100 g [10], which is higher than that of chickpea (347 kcal/100 g) [11]. In terms of protein, horse gram contains up to 28.8% [12], surpassing several other legumes such as kidney bean (25.23%) [13, 14], black gram (27.87%) [15], and pigeon pea (17.62–26.38%) [16–19]. With respect to dietary fibre, chickpea exhibits the highest content at 22.7% [20], followed by horse gram at 16.3% [21], indicating that horse gram is also a significant contributor of fibre in the human diet. In comparison, kidney bean (3.6%) [22], black gram (3.10–4.45%) [23], and mung bean (2.2%) [24] have lower fibre levels. Other legumes such as faba bean (13.49%) [25], pigeon pea (8.1%) [26], pea (10.30%) [27], and lentil (5.9%) [28] also contribute appreciable amounts of dietary fibre.

Beyond its nutritional benefits, it has been reported to have medicinal properties that help prevent or treat various health issues, such as weight loss, skin disorders, cardiovascular problems, kidney stones, and some types of cancer [29]. Horse gram is characterized by a relatively low fat content, ranging from 0.58% to 2.06% [30], with values of about 1.9% also reported [31], along with a moderate starch level of approximately 31.86% [32] to 47.5% [33]. Owing to this nutritional profile, it is often considered beneficial for individuals with diabetes. In addition to its dietary advantages, horse gram exhibits notable therapeutic properties, including anti-urolithiatic activity against calcium oxalate, calcium phosphate, and uric acid crystals, which distinguishes it from many other legumes. Furthermore, it is a drought-tolerant crop, well adapted to arid and water-scarce environments [11]. Thus, horse gram-based products could help meet the body's nutritional needs while promoting the use of underutilised crops.

The utilisation of horse gram remains limited, possibly because of its poor cooking quality, poor digestibility, presence of enzyme inhibitors and hemagglutinin activity [34]. Some anti-nutritional compounds have also been reported, which could limit the absorption of certain minerals by forming insoluble/soluble complexes and further reducing protein digestibility [35]. Traditional processing methods such as roasting, soaking, germination, fermentation, and dehulling can reduce these anti-nutritional properties, improving protein utilisation and enhancing acceptability and nutritional quality [36]. The limited availability of horse gram products and the underdeveloped market also make it commercially unviable, despite its high nutritional and remedial properties. Thus, horse gram can be a good fit for preparing fortified baked products. Therefore, this study aimed to optimise the process for developing an instant cake mix incorporating horse gram flour, based on the cake's nutritional and organoleptic properties, and to study the microbial properties of the instant cake mix and the organoleptic properties of the developed cake during storage.

Materials and methods

For the development of a roasted horse gram (RHG)-incorporated instant cake mix, horse gram was procured from Almora, Uttarakhand, India. The seeds were cleaned to remove extraneous materials, including dirt, dust, straws, etc., and packed properly in airtight packets until use. RWF, sugar, oil, milk powder, baking powder, vanilla powder, salt, and baking soda were purchased from the local market. All analytical-grade chemicals were purchased from Hi-Media Laboratories Pvt. Ltd., Mumbai, India.

Experimental plan and methodology

The complete experimental systematic plan incorporating all applicable unit operations used in the development of instant cake mix is shown in Figure 1. This work was accomplished in three phases: the first was the physical analysis of raw materials and RHG, the second was the milling of raw materials and RHG, their nutritional, functional, and anti-nutritional analysis, and the last phase was the preparation of RHG incorporated into instant cake mix and its analysis.

Experimental design

Box-Behnken design (BBD) of response surface methodology (RSM) was selected for its efficiency in evaluating quadratic response surfaces with fewer experimental runs. The three process parameters, each evaluated at three levels, including RWF:RHG flour (1:1, 2:1, and 3:1), milk powder per 100 g flour (20, 25, and 30), and baking time (10, 11, and 12 min), were selected. A total of seventeen experiments with five central points were conducted, and responses, i.e., moisture content, total ash, crude fat, crude protein, color difference, cohesiveness, hardness, springiness, and overall acceptability, were analysed. The obtained data were analyzed by fitting a second-order model equation.

Design-Expert software was used to conduct analysis of variance (ANOVA) and assess the statistical significance of each model parameter. The model's suitability was evaluated based on Fisher's F-value, R^2, adjusted R^2, and the lack-of-fit test. Each term in the second-order model was examined for statistical significance using its corresponding F-value across multiple significance levels.

Physio-chemical characteristics of raw and RHG

Seed weight, volume, and density

Seed weight for raw and RHG was determined by weighing 100 seeds randomly selected from the sample [37]. The volume was calculated using the toluene displacement method [37]. Seed density was calculated by dividing the seed weight of raw and RHG by the seed volume of 100 seeds.

Hydration capacity and hydration index

One hundred randomly selected raw and RHG seeds of known weight were transferred into a 250 mL conical flask, followed by the addition of 100 mL of water. After soaking overnight, the water was drained

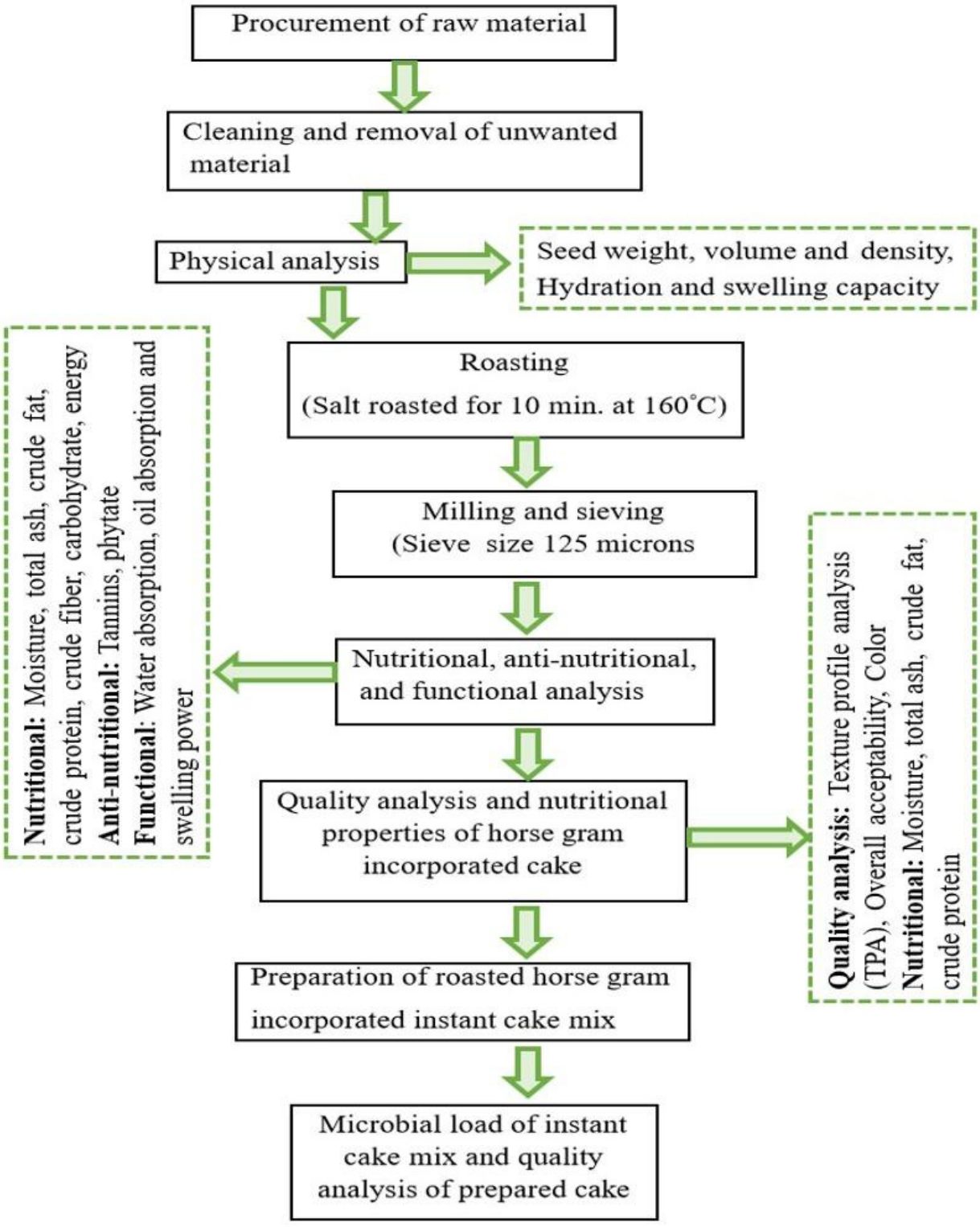

Figure 1. Flow chart describing the experimental plan.

off the next day, and the seeds were air-dried and weighed [38]. The hydration capacity was calculated using the formula given below.

$$Hydration\ capacity\left(g\,/\,seed\right) = \frac{Weight\ after\ soaking\ (g) - Weight\ before\ soaking\ (g)}{No.\ of\ seeds} \quad (1)$$

The hydration index was determined by dividing each seed's hydration capacity by its corresponding seed weight.

Swelling capacity and swelling index

We used the methodology of Jain et al. [10] to determine the swelling capacity and swelling index. Briefly, 100 seeds (raw and RHG) of known volume were transferred into a 250 mL conical flask, followed by the addition of 100 mL of water to it. The flask was properly covered and left overnight. The water was drained off the next day, and the seeds were air-dried. The seeds were then transferred to a 100 mL measuring cylinder, 20 mL of toluene was added, and the cylinder was tapped a few times to ensure no air bubbles remained. The increase in volume was recorded, and swelling capacity was determined using the formula given below.

$$Swelling\ capacity\left(mL\ /\ seed\right) = \frac{Volume\ after\ soaking\ (mL) - Volume\ before\ soaking\ (mL)}{No.\ of\ seeds} \quad (2)$$

The swelling index was calculated by dividing the swelling capacity per seed by its volume.

Anti-nutritional factor

Tannins

Tannins were determined using the standard method described by Rosenblatt and Peluso [39]. We placed 0.5 g of sample and 75 mL of distilled water in a 250 mL conical flask, gently heated, and then boiled for 30 min. After heating, the solution was cooled and centrifuged for 20 min at 2000 rpm. The collected supernatant was made up to 100 mL in a volumetric flask. Then, 1 mL of this sample was transferred to another 100 mL volumetric flask containing 75 mL of distilled water, to which 5 mL of Folin–Denis reagent was added, followed by the addition of 10 mL of sodium carbonate solution and diluted to 100 mL with water. The solution was shaken well and left undisturbed for 30 min; then absorbance was measured at 700 nm. A blank was prepared using distilled water instead of the sample. Tannic acid (%) was calculated using the following formula.

$$Tannins\ as\ tannic\ acid\ (\%) = \frac{mg\ of\ tannic\ acid \times dilution\ factor \times 100}{mL\ of\ sample\ taken \times weight\ of\ sample \times 1{,}000} \quad (3)$$

Phytate

Phytates in the samples were estimated using the method of Wheeler and Ferrel [40]. To estimate phytate, a 5 g sample was extracted with 50 mL of 3% trichloroacetic acid for 30 min with mechanical shaking. The suspension was centrifuged at 769 g for 10 min, then a 10 mL aliquot of the supernatant was transferred to a test tube, to which 4 mL of $FeCl_3$ solution was added by rapidly blowing it from the pipette. Heat the contents of the test tube in a water bath for 45 min until the supernatant is clear, then centrifuge for 10 min at 769 g, followed by careful decantation of the clear supernatant. The precipitate left in the centrifuge tube was washed twice by dispersing it well in 25 mL of 3% trichloroacetic acid, followed by heating in boiling water for 5–10 min, then centrifuged at 769 g for 10 min. The precipitate was finally dispersed in 1 mL of water, and 3 mL of 1.5 mol/L NaOH was added by mixing the test tubes. The volume was adjusted to 30 mL with distilled water, and the mixture was heated in a boiling water bath for 30 min. Filter the hot contents through Whatman No. 2 filter paper. Wash the precipitate retained on the filter with 60–70 mL of hot water, then discard the filtrate. Dissolve the precipitate directly from the filter paper in 40 mL of hot 3.2 mol/L HNO_3 in a 100 mL volumetric flask. Rinse the filter paper with several portions of hot water, and collect all washings in the same volumetric flask. Cool the contents and flask to room temperature, then dilute to the desired volume with water. Transfer a 5 mL aliquot into a 100 mL volumetric flask and dilute to 70 mL with distilled water. Add about 20 mL of 1.5 mol/L potassium thioeyanate to the flask, then make up to volume with water. Read the absorbance immediately at 480 nm. Phytate phosphorus was calculated using the formula below.

$$Phytate\ phosphorus\left(mg\ /\ 100\ g\right) = \frac{\mu g\ Fe \times 15}{Weight\ of\ sample\ (g)} \quad (4)$$

Functional properties

We determined water absorption capacity (WAC) and oil absorption capacity (OAC) using the methodology described by Beuchat [41]. The swelling power and solubility index were estimated as described by Shimelis et al. [42]. We used the following formulas to calculate water absorption and OAC, respectively.

$$WAC\,(\%) = \frac{Sample\ weight\ after\ centrifugation - Dry\ sample\ weight}{Dry\ sample\ weight} \times 100 \quad (5)$$

$$OAC\,(\%) = \frac{Sample\ weight\ after\ centrifugation - Dry\ sample\ weight}{Dry\ sample\ weight} \times 100 \quad (6)$$

Proximate analysis

The samples were analyzed for moisture, total ash, crude protein, crude fat, and crude fibre using standard AOAC [43] methods. Carbohydrate content was calculated by difference, and the physiological energy value (kcal/100 g) was calculated using the given formulas.

$$Carbohydrate\,(\%) = 100 - [Ash\,(\%) + Crude\ fat\,(\%) + Crude\ protein\,(\%) + Crude\ fibre\,(\%)] \quad (7)$$

$$Physiological\ energy\ value\,(kcal/100\,g) = 4 \times Protein\,(\%) + 9 \times Fat\,(\%) + 4 \times Carbohydrate\,(\%) \quad (8)$$

Color difference (ΔE)

The color parameters of the samples, including L (lightness), a* (red–green coordinate), and b* (yellow–blue coordinate), were analysed using a Color Flex EZ colorimeter (HunterLab, Virginia, USA). The calculation of total color difference (TCD; ΔE) was done using the formula used by Sharma et al. [44].

$$TCD\,(\Delta E) = \sqrt{(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})} \quad (9)$$

Texture profile analysis (TPA)

The setup for TPA is designed to measure the cohesiveness, springiness, gumminess, hardness, chewiness, adhesive force, fracture force, springiness index, and adhesiveness of a food sample. Texture Analyzer (TAXT2i), Stable Micro System (UK), was used to measure the textural properties of fresh samples.

Sensory evaluation

Sensory evaluation of the developed cake was conducted based on attributes including appearance, texture, taste, aroma, aftertaste, and overall acceptability, using a 9-point hedonic scale where 9 indicates “like extremely” and 1 indicates “dislike extremely”. A panel of ten members was selected, including staff and students of the Department of Post-Harvest Process and Food Engineering, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. The samples were served panelists were asked to rate the product’s acceptability using a 9-point hedonic scale [45]. Ethical approval for this study was waived in accordance with the regulations of the relevant ethics committee/local institutional guidelines. Informed consent was obtained from participants without mentioning the verbal form.

Microbial analysis of RHG-incorporated instant cake mix

The total plate count (TPC) method was determined using nutrient agar for an optimized RHG-incorporated instant cake mix. TPC analysis was carried out by aseptically adding 0.1 mL of serially diluted samples to standard plate count medium, following the procedure described by Ranganna [46]. After serial dilution, an aliquot of the sample was aseptically inoculated from (10^{-4}, 10^{-5}, 10^{-6}, and 10^{-7}) into pre-sterilised Petri plates, followed by pouring 10–15 mL of medium into each Petri plate under the sterilized environment of laminar air flow (LAF). After the medium solidified in the LAF, the plates were inverted and incubated at 35–37°C for 48 h for microbial (bacteria, yeast, and mould) colony counting. The results of TPC were expressed as colony-forming unit/g (CFU/g).

$$CFU/g = \frac{Number\ of\ colonies \times Dilution\ factor}{Weight\ of\ sample\ taken\,(g)} \quad (10)$$

Statistical analysis of the model

The data were analysed using ANOVA, along with calculations of the coefficient of determination (R^2) and its adjusted value (R^2adj), to evaluate model significance. Differences were considered statistically significant at ($p < 0.05$). Design-Expert software (version 13.0.1) was used for all statistical computations. The optimisation of process parameters was carried out using Design-Expert software. Model validation was performed by comparing predicted and experimental values. For the comparison study, each

experiment was conducted in triplicate, and the results are reported as the mean value ± standard deviation (SD).

Results

Physical properties of raw and RHG

The physical properties of raw and RHG seeds are shown in Table 1. It was observed that hydration index (1.2 vs. 0.9), hydration capacity (0.03 g/seed), and swelling capacity (0.04 vs. 0.03 mL/seed) were higher in raw horse gram seeds compared to RHG seeds; on the other hand, seed density was higher in RHG seeds. The swelling index decreased significantly from 1.4 to 1.1 upon roasting ($p < 0.05$).

Table 1. Experimental results of raw and roasted horse gram.

Parameters	Raw	Roasted	*F*-value	*p*-value
Seed density (kg/m^3)	1.15 ± 0.03	1.17 ± 0.07	0.25	0.63
Hydration capacity (g/seed)	0.03 ± 0.01	0.03 ± 0.01	9.90	0.03*
Hydration index	1.2 ± 0.1	0.9 ± 0.1	12.20	0.02*
Swelling capacity (mL/seed)	0.04 ± 0.01	0.03 ± 0.01	6.18	0.07
Swelling index	1.4 ± 0.04	1.1 ± 0.2	24.99	0.005*
Moisture (%)	9.9 ± 0.4	3.6 ± 0.2	456.37	< 0.0001*
Total ash (%)	3.2 ± 0.1	3.4 ± 0.1	4.65	0.09
Crude fat (%)	1.3 ± 0.2	1.4 ± 0.5	0.13	0.75
Crude protein (%)	25.1 ± 0.2	24.6 ± 0.3	6.66	0.06
Crude fibre (%)	5.3 ± 0.1	5.0 ± 0.1	5.57	0.08
Carbohydrate (%)	65.1 ± 0.4	65.6 ± 0.8	0.88	0.40
Energy (kcal)	373 ± 1	373 ± 2	0.22	0.65
Tannins (mg/g)	10.8 ± 0.4	7.5 ± 0.5	132.70	< 0.0001*
Phytate (mg/g)	9.9 ± 0.5	7.1 ± 0.7	196.70	< 0.0001*
WAC (%)	124.7 ± 0.8	138 ± 1	13.40	0.02*
OAC (%)	194.9 ± 0.6	219.4 ± 0.3	4248.20	< 0.0001*
Swelling power (g/g)	13.5 ± 0.8	16.8 ± 0.2	49.39	0.003*

Values are presented as mean ± SD. *F*- and *p*-values were obtained by ANOVA. * denotes significant values at the 5% level of significance. ANOVA: analysis of variance; OAC: oil absorption capacity; SD: standard deviation; WAC: water absorption capacity.

Nutritional composition of raw and RHG flour on dry weight basis

The nutritional composition of raw and RHG flour is shown in Table 1. The results revealed a highly significant decrease in moisture content (from 9.9% to 3.6%, $p < 0.0001$) and a slight decrease in crude protein and crude fibre (25.1 to 24.6, $p = 0.06$ and 5.3 to 5.0, $p = 0.08$, respectively) after roasting. Fat content showed a slight, non-significant increase (1.3% to 1.4%, $p = 0.75$) after roasting, while total ash content showed no significant change ($p = 0.09$).

Anti-nutrients in raw and RHG flour

The effect of roasting on anti-nutritional factors, namely tannins and phytates, is shown in Table 1. The results indicated a decrease in tannins and phytate content after roasting; the tannin and phytate content of raw horse gram flour was 10.8 mg/g and 9.9 mg/g, respectively, and decreased to 7.5 mg/g and 7.1 mg/g after roasting.

Functional properties of raw and RHG flour

The functional properties for raw and RHG flour are shown in Table 1. Roasting significantly increased the OAC from 194.9% to 219.4% ($p < 0.0001$) and the WAC from 124.7% to 138% ($p = 0.02$). The swelling power of horse gram flour also significantly increased from 13.5 g/g to 16.8 g/g ($p = 0.003$) on roasting.

Numerical optimization and effect of quality parameters for the development of RHG-incorporated cake

The present study aimed to develop RHG-incorporated cake (Figure 2). Table 2 shows the experimental results of quality parameters, i.e., moisture, ash, fat, protein content, color difference, cohesiveness, hardness, springiness, and overall acceptability of RHG-incorporated cake. These response variables were fitted to a second-order quadratic model to develop efficient correlations between the process variables, i.e., RWF:RHG, milk powder, and baking time. The signs (+ and –) and the magnitudes of the coefficients in eq. 11 to eq. 19 indicate the positive and negative effects of the significant independent parameters on responses, respectively [47].



Figure 2. Images of developed roasted horse gram incorporated cake (a) to (b) and instant cake mix (c).

ANOVA was performed to assess the significance of the results. Table 3 shows that the model for all responses was significant, with R^2 and R^2adj ranging from 0.97 to 0.98 and 0.93 to 0.96, respectively, and that the lack of fit (LOF) was non-significant for all responses. The linear, square, and interaction terms were used to explain the variability of the designed model. To observe the interactive effect of process parameters on different responses, 3D response surface curves at centre points were plotted.

Effect of process parameters on the moisture content of the developed cake

Table 2 shows the experimental moisture content of the developed cake; it varied from 29.0 to 36.0%. These results align with Agrahar-Murugkar et al. [5], who developed a cake using an egg replacer and gluten-free composite flour prepared from sprouted and malted ingredients. The results demonstrated that the moisture content increased with the addition of RWF and milk powder to the cake. The analysis of

Table 2. Experimental results of quality parameters for the development of RHG-incorporated cake.

Independent parameters									Responses			
S.No.	RWF:RHG w/w	M.P. (g/100 g flour)	B.T. (min)	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Color difference (∆E)	Cohesiveness	Hardness (N)	Springiness	Overall acceptability
1	3:1	20	11	32.8 ± 0.3	**1.30 ± 0.05***	12.8 ± 0.3	8.8 ± 0.1	9.98 ± 0.03	**0.6 ± 0.1****	15.7 ± 0.9	0.8 ± 0.1	7.5 ± 0.5
2	2:1	20	12	31.0 ± 1.0	1.37 ± 0.02	11.8 ± 0.1	**8.6 ± 0.2***	10.4 ± 0.1	**0.6 ± 0.1****	21.8 ± 0.4	0.6 ± 0.4	7.8 ± 0.2
3	3:1	30	11	**36.0 ± 0.6****	1.39 ± 0.01	**14.2 ± 0.04****	9.8 ± 0.1	10.39 ± 0.03	**0.6 ± 0.3****	**11.5 ± 0.6***	**1.0 ± 0.3****	8.6 ± 0.4
4	2:1	25	11	32.0 ± 0.4	1.40 ± 0.04	12.6 ± 0.2	9.8 ± 0.2	10.4 ± 0.1	0.52 ± 0.04	16.7 ± 0.1	0.8 ± 0.5	8.6 ± 0.1
5	2:1	25	11	31.7 ± 0.1	1.42 ± 0.03	12.5 ± 0.3	9.6 ± 0.1	10.5 ± 0.2	0.5 ± 0.1	17.7 ± 0.2	0.8 ± 0.2	**8.8 ± 0.2****
6	1:1	30	11	32.6 ± 0.6	1.45 ± 0.02	11.8 ± 0.3	11.5 ± 0.3	**12.4 ± 0.1****	0.5 ± 0.2	20.7 ± 0.7	0.7 ± 0.2	7.3 ± 0.2
7	2:1	25	11	32.1 ± 0.4	1.40 ± 0.07	12.6 ± 0.2	9.6 ± 0.2	10.53 ± 0.04	**0.6 ± 0.1****	17.7 ± 0.9	0.8 ± 0.6	**8.8 ± 0.4****
8	3:1	25	12	32.8 ± 0.3	1.38 ± 0.02	13.5 ± 0.5	8.8 ± 0.1	10.2 ± 0.1	**0.6 ± 0.2****	13.5 ± 0.7	0.9 ± 0.2	7.8 ± 0.4
9	2:1	25	11	32.1 ± 0.9	1.39 ± 0.01	12.8 ± 0.3	9.6 ± 0.1	10.7 ± 0.1	0.5 ± 0.2	17 ± 1	0.8 ± 0.8	**8.8 ± 0.3****
10	1:1	25	12	29.4 ± 0.4	1.45 ± 0.01	11.5 ± 0.2	10.1 ± 0.4	12.2 ± 0.1	0.5 ± 0.4	**27.4 ± 1****	**0.5 ± 1.1***	**7.1 ± 0.5***
11	2:1	20	10	31.7 ± 0.4	1.38 ± 0.01	11.5 ± 0.5	9.6 ± 0.3	10.2 ± 0.1	0.51 ± 0.05	22 ± 1	0.6 ± 0.9	7.6 ± 0.4
12	2:1	30	12	32.1 ± 0.6	1.44 ± 0.02	13.0 ± 0.8	10.2 ± 0.4	12.0 ± 0.1	**0.6 ± 0.2****	18.1 ± 0.6	0.8 ± 0.7	8.4 ± 0.6
13	3:1	25	10	**36.0 ± 1.0****	1.36 ± 0.01	13.2 ± 0.6	9.4 ± 0.3	**9.7 ± 0.1***	0.5 ± 0.1	12.7 ± 0.8	0.9 ± 0.3	7.9 ± 0.6
14	1:1	25	10	31.5 ± 0.1	1.45 ± 0.01	11.2 ± 0.2	**11.6 ± 0.3****	11.4 ± 0.1	**0.4 ± 0.1***	20.6 ± 0.2	0.7 ± 0.4	7.2 ± 0.2
15	1:1	20	11	**29.0 ± 2***	1.40 ± 0.02	**11.1 ± 0.3***	10.6 ± 0.4	11.1 ± 0.3	0.5 ± 0.1	26 ± 1	**0.5 ± 0.2***	7.4 ± 0.4
16	2:1	30	10	35.7 ± 0.7	**1.46 ± 0.02****	13.1 ± 0.2	10.8 ± 0.4	11.1 ± 0.1	0.5 ± 0.2	14 ± 1	0.9 ± 0.1	8.3 ± 0.4
17	2:1	25	11	31.5 ± 0.4	1.42 ± 0.01	12.8 ± 0.9	9.9 ± 0.3	10.8 ± 0.1	**0.6 ± 0.2****	17 ± 1	0.8 ± 0.5	8.6 ± 0.2

Values are presented as mean ± SD. B.T.: baking time. M.P.: milk powder. RHG: roasted horse gram. RWF: refined wheat flour. SD: standard deviation. ** and * indicate maximum and minimum values, respectively.

Table 3. Numerical analysis of quality parameters for the development of RHG-incorporated cake.

Source	Moisture content		Total ash		Crude fat		Crude protein		TCD		Cohesiveness		Hardness		Springiness		Overall acceptability	
	F-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
Model	54.85	< 0.0001**	28.31	< 0.0001**	57.13	< 0.0001**	40.84	< 0.0001**	35.81	< 0.0001**	34.04	< 0.0001**	55.60	< 0.0001**	55.38	< 0.0001**	51.21	< 0.0001**
X_1	229.91	< 0.0001**	130.22	< 0.0001**	362.67	< 0.0001**	210.16	< 0.0001**	200.93	< 0.0001**	198.57	< 0.0001**	345.12	< 0.0001**	343.63	< 0.0001**	74.02	< 0.0001**

Table 3. Numerical analysis of quality parameters for the development of RHG-incorporated cake. (*continued*)

Source	Moisture content		Total ash		Crude fat		Crude protein		TCD		Cohesiveness		Hardness		Springiness		Overall acceptability	
	F-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value
X_2	147.14	< 0.0001**	100.97	< 0.0001**	127.09	< 0.0001**	80.53	< 0.0001**	72.76	< 0.0001**	0.30	0.59	94.60	< 0.0001**	94.33	< 0.0001**	49.99	0.0002**
X_3	84.97	< 0.0001**	0.23	0.64	3.25	0.11	51.15	0.0002**	23.53	0.0019**	93.49	< 0.0001**	22.69	0.002051**	22.52	0.0021**	0.16	0.69
X_1X_2	1.29	0.29	5.67	0.04*	6.59	0.03*	0.01	0.91	5.74	0.04*	0.02	0.89	0.98	0.35	1.00	0.35	25.44	0.001**
X_1X_3	1.10	0.32	0.46	0.51	0.11	0.74	7.52	0.02*	0.84	0.38	0.50	0.49	14.11	0.007**	14.05	0.0072**	0.01	0.89
X_2X_3	17.67	0.004**	0.65	0.44	1.51	0.25	0.06	0.80	4.41	0.07	0.06	0.80	8.30	0.02*	8.32	0.02*	0.38	0.55
X_1^2	1.21	0.30	6.19	0.04*	1.74	0.22	12.64	0.009**	4.27	0.07	12.21	0.01*	1.00	0.34	1.03	0.34	198.41	< 0.0001**
X_2^2	6.68	0.03*	3.12	0.12	1.09	0.33	4.58	0.06	6.51	0.03*	1.61	0.24	6.54	0.03*	6.49	0.03*	17.18	0.0043**
X_3^2	2.63	0.14	7.99	0.02*	9.10	0.01*	0.002	0.95	1.96	0.20	0.12	0.73	5.69	0.04*	5.69	0.04*	69.99	< 0.0001**
Lack of fit	2.61	0.18	1.28	0.39	1.52	0.33	2.11	0.24	2.43	0.20	1.42	0.36	4.00	0.10	4.01	0.10	0.90	0.51
R^2	0.98		0.97		0.98		0.98		0.97		0.97		0.98		0.98		0.98	
R^2adj	0.96		0.93		0.96		0.95		0.95		0.94		0.96		0.96		0.96	

**,* represents 1% and 5% levels of significance, respectively. X_1: refined wheat flour (RWF):roasted horse gram (RHG); X_2: milk powder (g/100 g flour); X_3: baking time (min); X_1X_2, X_1X_3, X_2X_3: interaction terms; X_1^2, X_2^2, X_3^2: square terms. TCD: total color difference.

experimental data examined the effect of independent parameters on moisture content. The moisture-content model was significant at the 5% level. Table 3 shows that all three independent variables had a significant effect ($p < 0.0001$) on moisture content for linear terms, whereas the interaction effect was observed for milk powder-baking time at the 1% level of significance, and the quadratic effect was observed for milk powder at the 5% level of significance.

Statistical analysis indicated that the proposed model was adequate and significantly fit. Higher R^2 (0.98) and R^2adj (0.96) showed the closeness between the experimental and predicted values, confirming the model's accuracy and stability. A second-order polynomial equation (eq. 11) with significant terms was developed to show the empirical relationship between moisture content and the input test variables.

$$Moisture = 4.43917 + 1.88750\,X_1 + 0.991111\,X_2 + 2.55250\,X_3 - 0.148000\,X_2X_3 + 0.018778\,X_2^2 \quad (11)$$

Figure 3a–3d depicts the effect of process parameters on moisture content. Moisture increased sharply as the RWF:RHG ratio increased from 1:1 to 3:1 and as milk powder increased from 20 to 30 g/100 g flour. Conversely, moisture decreased by 6% at higher baking times. The interactive effect of milk powder and baking time was significant ($p < 0.01$).

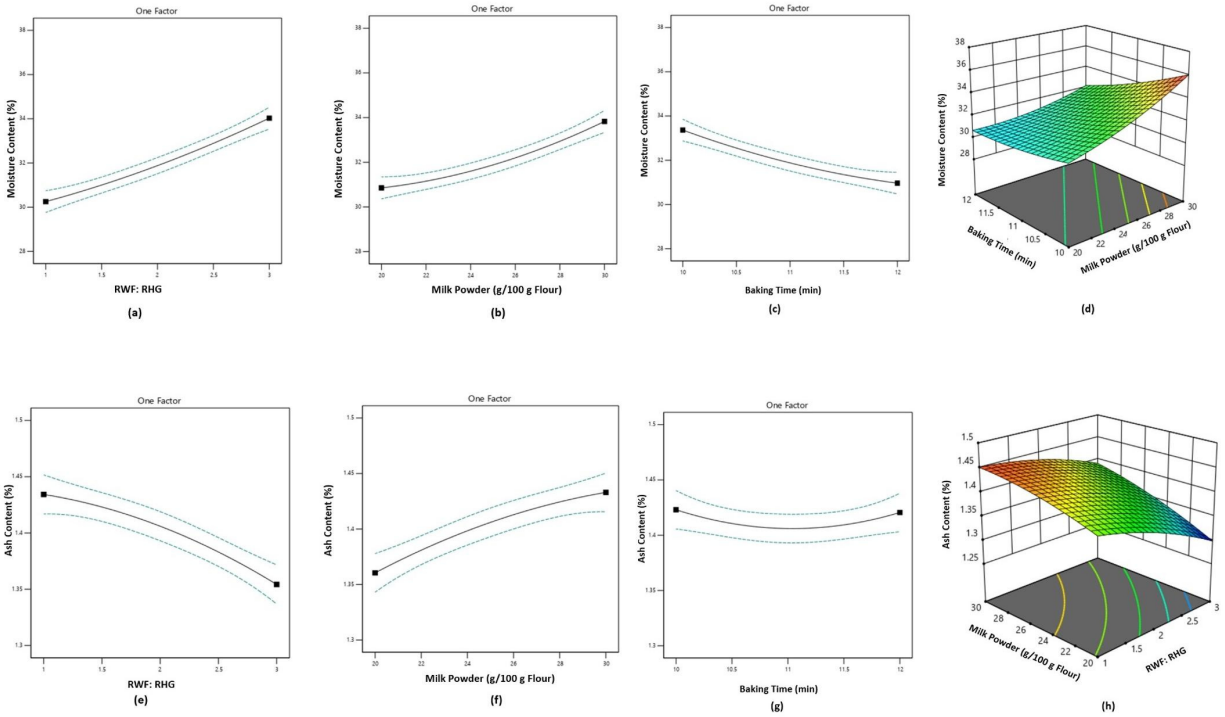

Figure 3. Effect of process parameters on moisture content (a–d) and on ash content (e–h).

Effect of process parameters on total ash of the developed cake

Table 2 shows the total ash in the developed cake; total ash varied from 1.30 to 1.46%. These findings align with Salve and Mehrajfatema [48] on moth bean-fortified cake, which observed total ash content ranging from 1 to 1.5%, with the highest value at 20% incorporation of moth bean flour. The model for total ash content was significant ($p < 0.01$). Table 3 shows that the RWF:RHG ratio and milk powder had significant effects at the linear ($p < 0.0001$), interaction ($p < 0.05$), and quadratic levels ($p < 0.05$). RWF:RHG ratio and baking time had a significant effect ($p < 0.05$) on total ash. The statistical analysis showed that the proposed model was adequate and provided a significantly fit.

Higher R^2 (0.97) and R^2adj (0.93) indicate close agreement between the experimental and predicted values, verifying the model's accuracy and stability. A second-order polynomial equation (eq. 12) with significant terms was developed to show the empirical relationship between total ash and the input test variables.

$$Total\ ash = 3.03202 - 0.050263\,X_1 + 0.002378\,X_2 + 0.002415\,X_1X_2 - 0.012759\,X_1^2 + 0.013516\,X_3^2 \quad (12)$$

Figure 3e–3h shows the effect of process parameters on ash content. Total ash decreased as the RWF:RHG ratio increased from 1:1 to 3:1, but increased as milk powder content increased. Baking time had no significant standalone effect on the total inorganic component. The RWF:RHG ratio and milk powder showed a significant interaction ($p < 0.05$).

Effect of process parameters on crude fat of the developed cake

The experimental data in Table 2 show that crude fat content in the developed samples ranged from 11.1% to 14.2%. These findings align with the study by Zambrano et al. [49] on using guar gum and xanthan in low-fat cake production, which reported fat content ranging from 8.4 to 14.5 g. The model for crude fat was significant ($p < 0.0001$), and Table 3 reveals that the RWF:RHG ratio and milk powder had a significant effect ($p < 0.05$) at linear and interactive levels, and baking time had a significant effect ($p < 0.05$) on crude fat at the quadratic level.

Higher R^2 (0.98) and R^2adj (0.96) indicate close agreement between experimental and predicted values, verifying the model's accuracy and stability. A second-order polynomial equation (eq. 13) with significant

terms was developed to show the empirical relationship between crude fat and the input test variables in actual form.

$$Crude\ fat\ =\ -19.34386\ +\ 0.047262\,X_1\ +\ 0.042482\,X_2\ +\ 0.038430\,X_1X_2\ -\ 0.229708\,X_3^{\,2} \quad (13)$$

Figure 4a–4d shows the effect of process parameters on crude fat. Fat content increased continuously with increases in both the RWF:RHG ratio and milk powder. With increasing baking time, fat content increased slightly before subsequently decreasing. The interactive effect of RWF:RHG and milk powder was significant ($p < 0.05$).

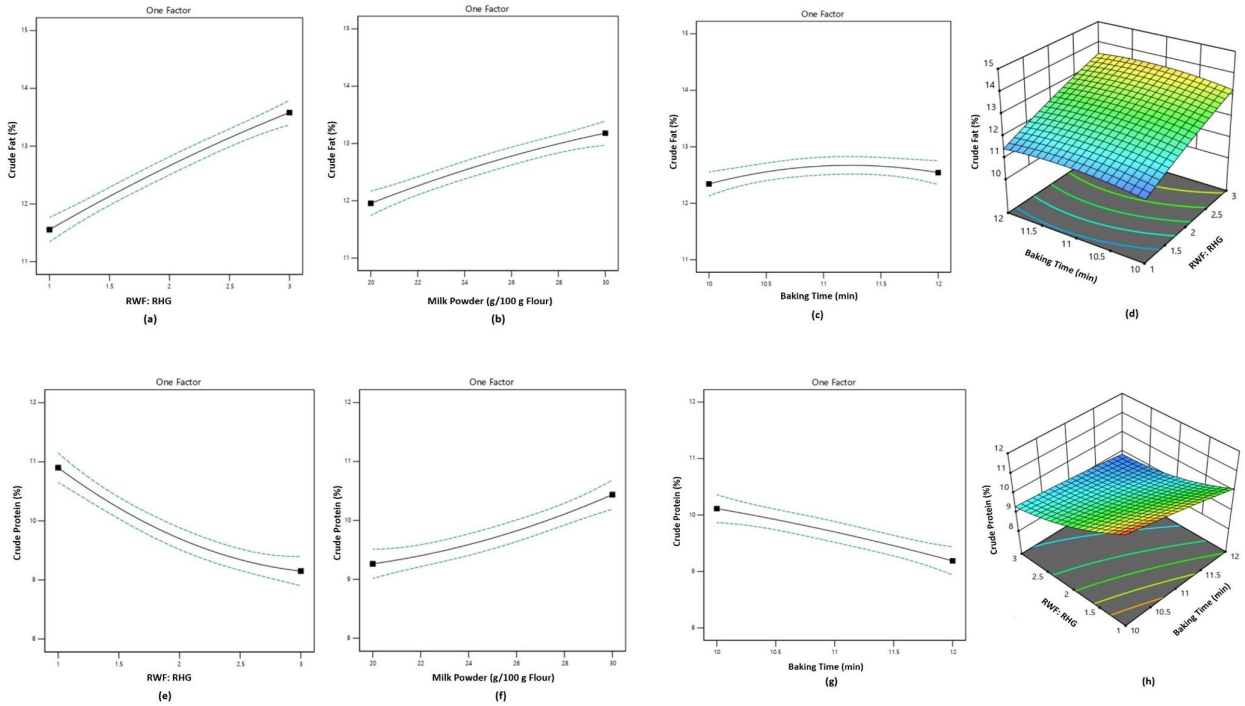

Figure 4. Effect of process parameters on crude fat (a) to (d) and on crude protein (e) to (h).

Effect of process parameters on crude protein of the developed cake

The experimental data in Table 2 show that crude protein content in the developed cake samples varied from 8.6% to 11.6%. These findings align with research by Abdallah et al. [50] on wheat flour enriched with seed sprout flours, which reported crude protein in prepared cakes ranging from 7.4 to 11%. The T6 sample (35% wheat, 35% barley and 30% faba bean) contained the highest crude protein values.

The model for crude protein was significant ($p < 0.0001$). Table 3 shows that all independent variables had a significant effect ($p < 0.001$) at the linear level, whereas only the RWF:RHG ratio and baking time were significant at the 5% level of significance for the interaction term. RWF:RHG ratio was significant at the 1% level of significance for the quadratic term.

Higher R^2 (0.98) and R^2adj (0.95) indicate close agreement between experimental and predicted values, verifying the model's accuracy and stability, as shown in Table 3. A second-order polynomial equation (eq. 14) with significant terms was developed to show the empirical relationship between crude protein and the input test variables.

$$Crude\ protein\ =\ 19.80425\ -\ 4.60958\,X_1\ +\ 0.106875\,X_2\ -\ 0.887875\,X_3\ +\ 0.231000\,X_1X_3\ +\ 0.301333\,X_1^{\,2} \quad (14)$$

Figure 4e–4h depicts the effect of process parameters on crude protein. Crude protein levels decreased as the RWF:RHG ratio increased. Increased baking time also reduced crude protein values. However, increasing milk powder raised the protein content. RWF:RHG and baking time had a significant interactive effect ($p < 0.05$).

Effect of process parameters on TCD of the developed cake

Table 2 presents the experimental data for the different experimental runs. The color difference values for the developed cake varied from 9.7 to 12.4. The model for color difference was significant ($p < 0.0001$) and from Table 3 it is visible that all three independent variables had a significant effect ($p < 0.01$) at the linear level, RWF:RHG ratio and milk powder ratio were significant at 5% level of significance on interactive level also milk powder was significant at 5% level of significance on the quadratic level.

Higher R^2 (0.97) and R^2adj (0.95) indicate close agreement between experimental and predicted values, verifying the model's accuracy and stability, as shown in Table 3. A second-order polynomial equation (eq. 15) with significant terms that show an empirical relationship between the TCD and the input test variables in actual form was developed.

$$Color\ difference = 10.29167 + 0.165000\,X_1 - 0.269222\,X_2 + 0.290000\,X_3 - 0.040500\,X_1X_2 + 0.009044\,{X_2}^2 \quad (15)$$

Figure 5a–5d shows the effect of process parameters on TCD. It was found that TCD decreased with an increasing RWF:RHG ratio, but increased significantly with higher milk powder content and extended baking times. RWF:RHG and milk powder had a significant interactive effect ($p < 0.05$) on product color.

Effect of process parameters on cohesiveness of the developed cake

Table 2 presents the experimental data for the different experimental runs. The cohesiveness values for the developed cake varied from 0.4 to 0.6. These findings align with the study by Shao et al. [51], which examined how different flours and binding agents influence batter performance and the overall quality of eggless cakes. The model was significant ($p < 0.0001$) and showed that the RWF:RHG ratio and baking time had a significant effect ($p < 0.0001$) at the linear level. At the quadratic level, only the RWF:RHG ratio ($p < 0.05$) affected cohesiveness.

The statistical analysis showed that the proposed model was adequate and fit well. Higher R^2 (0.97) and R^2adj (0.94) indicate close agreement between experimental and predicted values, verifying the model's accuracy and stability, as shown in Table 3. A second-order polynomial equation (eq. 16) with significant terms was developed to show the empirical relationship between cohesiveness and the input test variables in actual form.

$$Cohessiveness = -0.203767 + 0.159460\,X_1 + 0.046925\,X_3 - 0.022768\,{X_1}^2 \quad (16)$$

Figure 5e–5f depicts the effect of process parameters on cohesiveness. Cohesiveness increased linearly with increases in both the RWF:RHG ratio and baking time ($p < 0.0001$).

Effect of process parameters on hardness of the developed cake

Table 2 presents the experimental data for different experimental runs. The results showed that hardness values ranged from 11.5 to 27.4 N. These findings align with the study by Özhamamci et al. [52] on the effects of emulsifiers on various properties of sponge cakes, which reported hardness ranging from 1,244 to 2,933 g force.

The hardness model was highly significant ($p < 0.0001$). Table 3 reveals that all three independent variables had a significant ($p < 0.01$) effect at the linear level, whereas at the interactive level, RWF:RHG ratio and baking time significantly ($p < 0.01$) affected hardness; also, the effect of milk powder and baking time was found significant at the 5% level of significance. Baking time and milk powder also had a significant ($p < 0.05$) effect on hardness at the quadratic level.

Higher R^2 (0.98) and R^2adj (0.96) indicate close agreement between the experimental and predicted values, verifying the model's accuracy and stability, as shown in Table 3. A second-order polynomial equation (eq. 17) with significant terms was developed to show the empirical relationship between hardness and the input test variables.

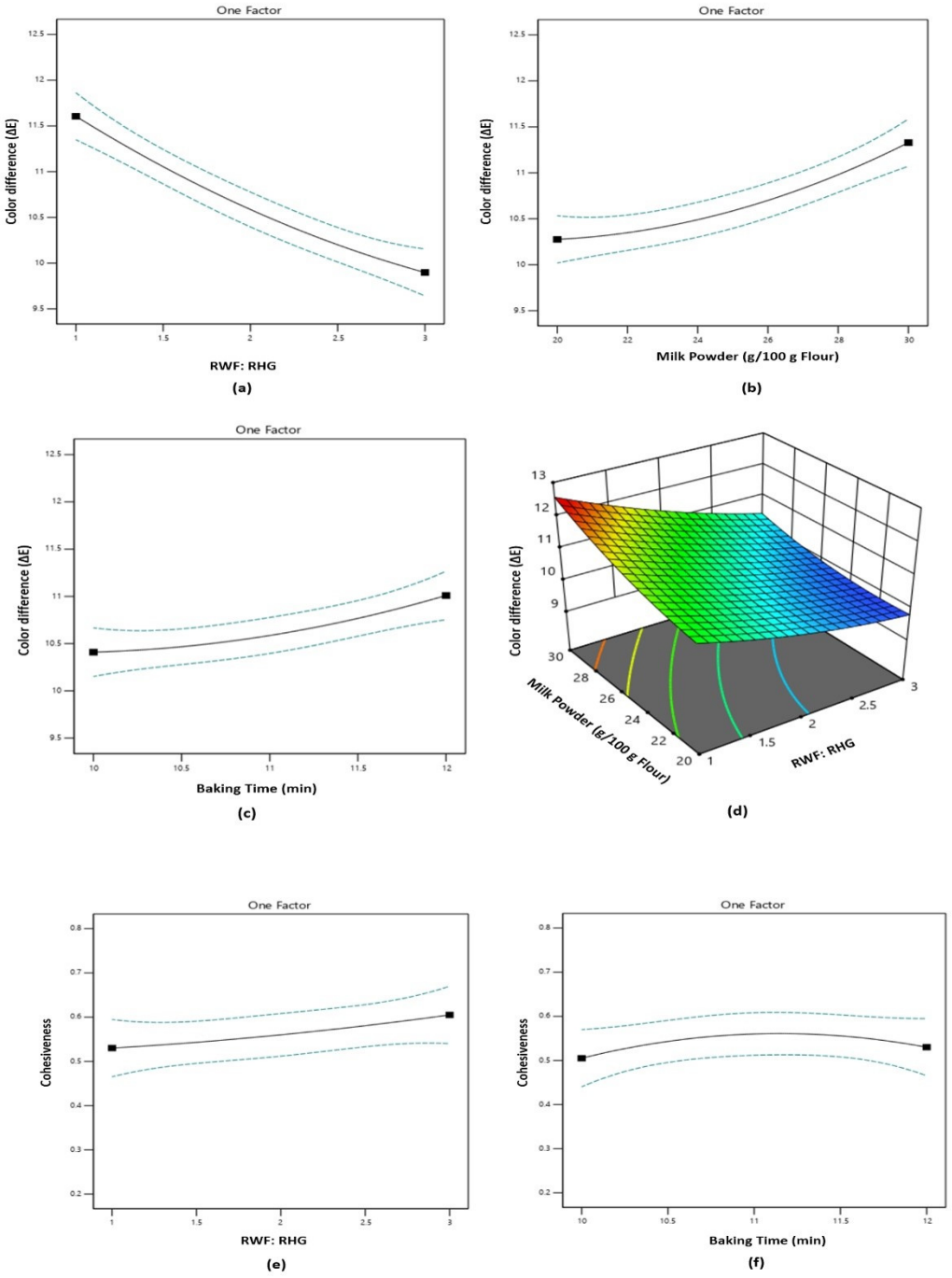

Figure 5. Effect of process parameters on color difference (a) to (d) and on cohesiveness (e) to (f).

$$Hardness = 196.39528 + 11.19239\,X_1 - 5.08356\,X_2 - 22.16696\,X_3 - 1.49152\,X_1X_3 + 0.228773\,X_2X_3 + 0.040421\,X_2^2 + 0.943988\,X_3^2 \quad (17)$$

The sign and magnitude of the coefficients in eq. 17 indicate the effect of the significant independent parameters on hardness. The positive coefficient on the RWF:RHG ratio (X_1) at the linear level indicates that hardness increased with an increase in these parameters, whereas the negative coefficient on milk powder (X_2) and baking time (X_3) at the linear level indicates that with the increase in these parameters, the hardness decreases. The negative coefficient of the combined effect (X_1X_3) of RWF:RHG ratio and baking time suggested that hardness decreases when high levels of both parameters are used; the positive coefficient of the combined effect (X_2X_3) of milk powder and baking time suggested that hardness increases

when high levels of both parameters are used. The positive coefficients of milk powder (X_2^2) and baking time (X_3^2) at the quadratic level indicate that hardness was lowest at the centre point of both parameters, and increased when milk powder and baking time were increased or decreased beyond the centre point.

Figure 6 shows the effect of process parameters on the hardness of the developed cake. Hardness decreased sharply as the RWF:RHG ratio increased from 1:1 to 3:1 and also decreased with higher milk powder content. Extended baking times increased hardness values. The interactive effects of RWF:RHG with baking time and milk powder with baking time were both significant.

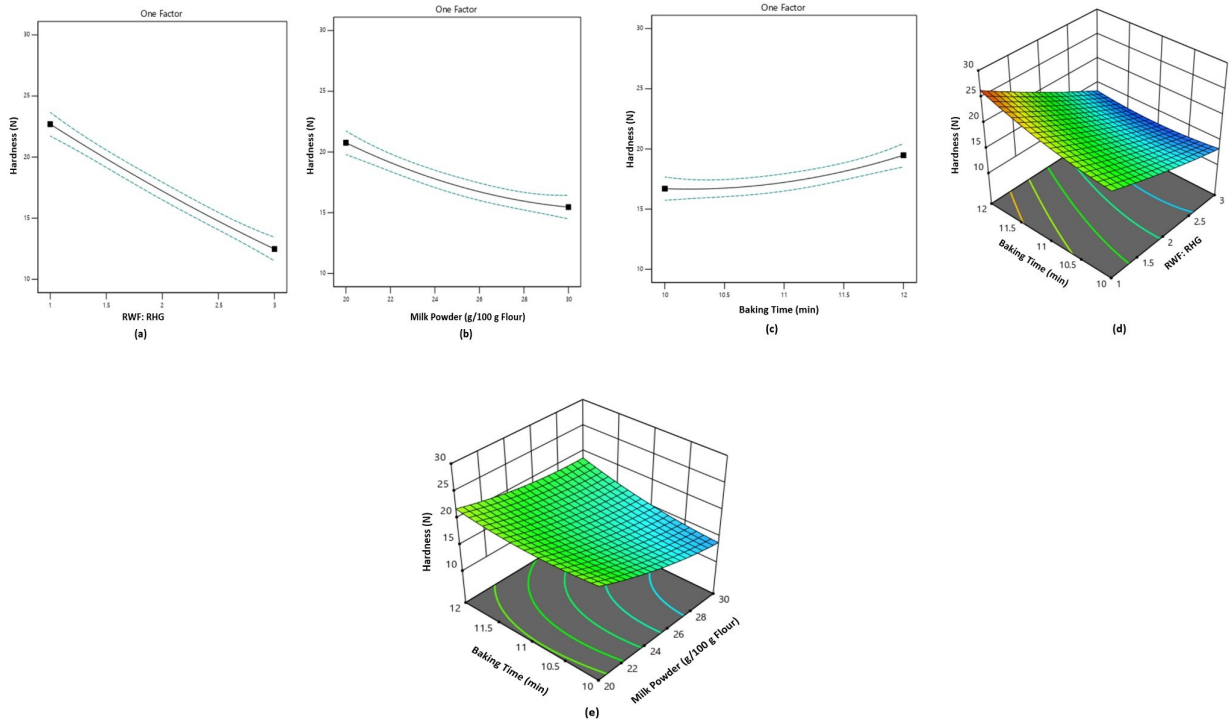

Figure 6. Effect of process parameters on hardness (a) to (e).

Effect of process parameters on springiness of the developed cake

Springiness refers to a food product's ability to regain its original shape after compression and subsequent release, following a defined resting period between successive compression cycles. Table 2 presents the experimental data for different runs; springiness values ranged from 0.5 to 1.0. These findings align with the study by de la Hera et al. [53] on wheat-lentil composite flour cake; they evaluated the springiness of cakes prepared with different wheat-lentil flour ratios. The springiness model was significant ($p < 0.0001$). Table 3 reveals that all three independent variables are significant ($p < 0.01$) at the linear level, whereas at the interactive level, the RWF:RHG ratio and baking time significantly ($p < 0.01$) affected springiness; also, the effect of milk powder and baking time was significant ($p < 0.05$). Baking time and milk powder also had a significant ($p < 0.05$) quadratic effect on springiness. Higher R^2 (0.98) and R^2adj (0.96) indicate close agreement between the experimental and predicted values, verifying the model's accuracy and stability, as shown in Table 3. A second-order polynomial equation (eq. 18) with significant terms was developed to show the empirical relationship between springiness and the input test variables in actual form.

$$Springiness = -4.95358 - 0.358250\,X_1 + 0.162929\,X_2 + 0.711868\,X_3 + 0.047750\,X_1X_3 - 0.007350\,X_2X_3 - 0.001292\,{X_2}^2 - 0.030289\,{X_3}^2 \quad (18)$$

Figure 7 shows the effect of process parameters on the springiness of the developed cake. Springiness increased sharply as the RWF:RHG ratio increased to 3:1 and as milk powder increased. Extended baking times significantly decreased springiness.

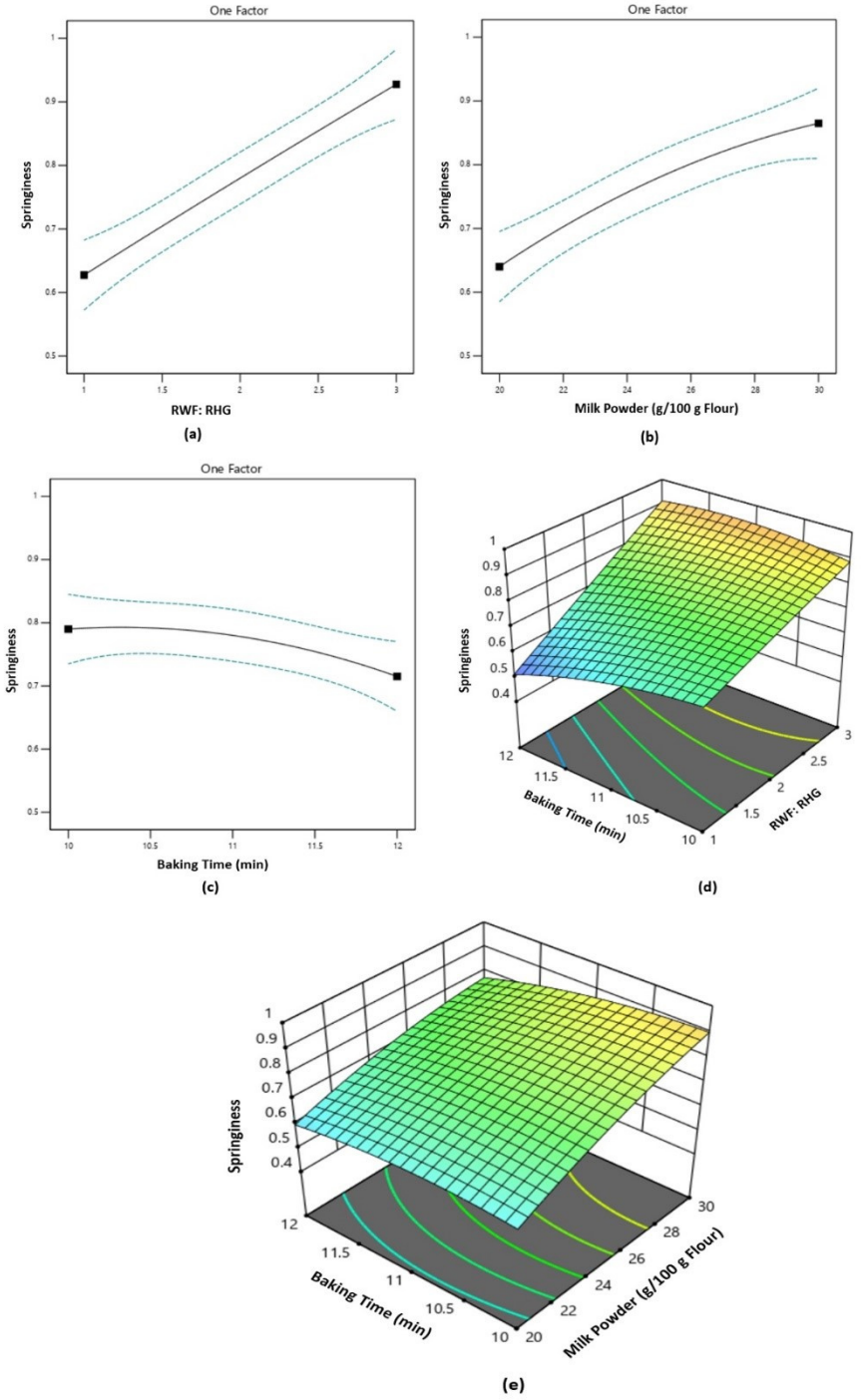

Figure 7. Effect of process parameters on springiness (a) to (e).

Effect of process parameters on overall acceptability of the developed cake

The experimental data represented in Table 2 show that the overall acceptability of the developed cake varied from 7.1 to 8.8. The model for overall acceptability was significant ($p < 0.0001$). Table 3 showed that the RWF:RHG ratio and milk powder were significant at the 1% level of significance at the linear and interaction levels, whereas all independent variables were significant at the 1% level of significance at the quadratic level.

Higher R^2 (0.98) and R^2 (0.96) values indicate close agreement between the experimental and predicted values, verifying the model's accuracy and stability, as shown in Table 3. A second-order polynomial equation (eq. 19) with significant terms was developed to show the empirical relationship between overall acceptability and the input test variables.

$$Overall\ acceptability = -55.28475 + 2.02175\,X_1 + 0.399000\,X_2 + 0.057000\,X_1X_2 - 0.775750\,X_1^{\,2} - 0.009130\,X_2^{\,2} - 0.46075\,X_3^{\,2} \quad (19)$$

Figure 8 shows the effect of process parameters on the overall acceptability of the developed cake. It was observed that overall acceptability increased as the RWF:RHG ratio shifted from 1:1 to 2:1, but decreased at 3:1. Similar quadratic trends were observed for milk powder and baking time, where acceptability increased up to a center point before declining.

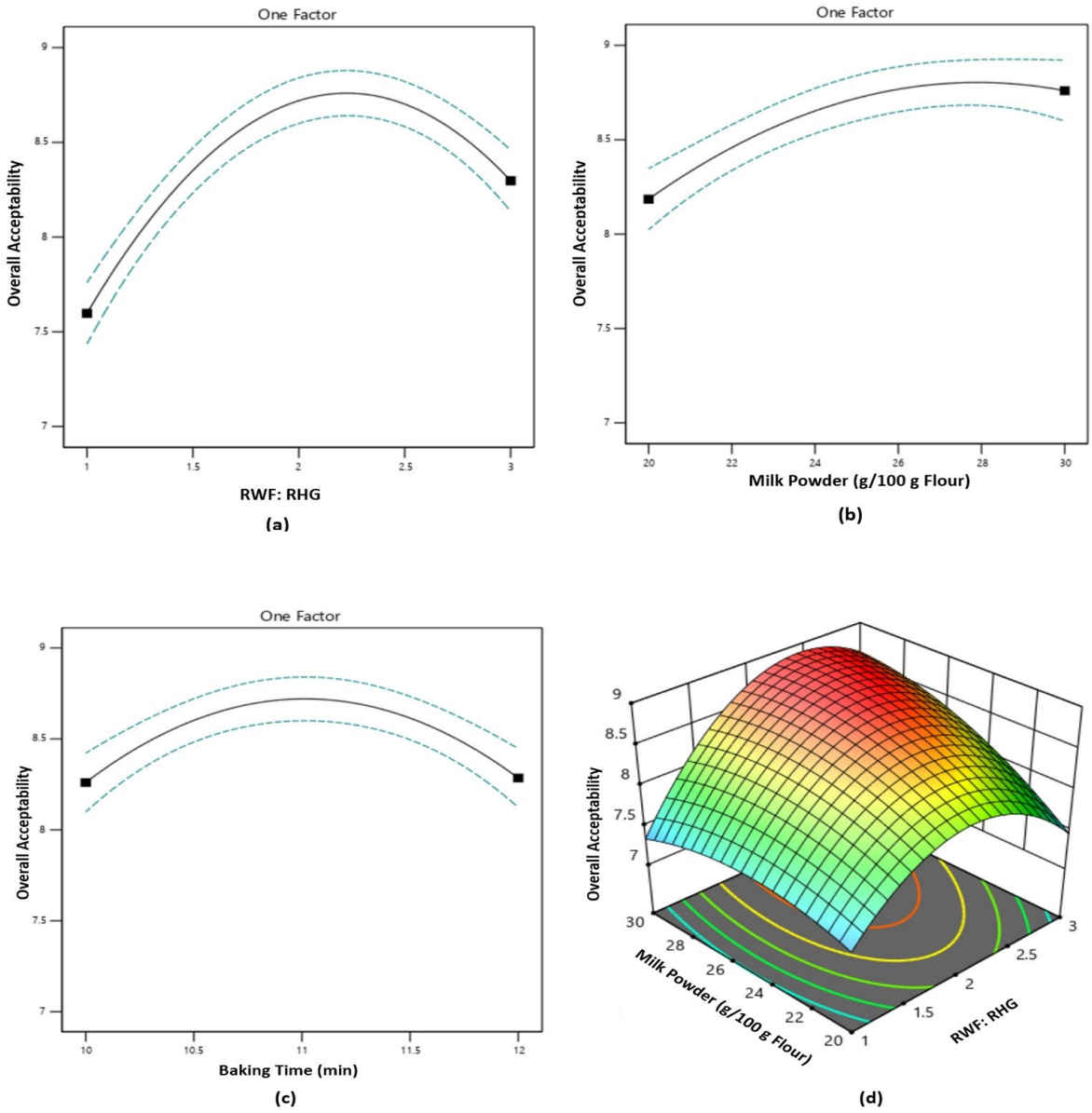

Figure 8. Effect of process parameters on overall acceptability (a) to (d).

Optimization and validation of independent parameters for the development of RHG-incorporated instant cake mix

The present study aimed to optimise the independent parameters, i.e., RWF:RHG ratio, milk powder (g/100 g flour), and baking time (min), for the development of RHG-incorporated instant cake mix. Numerical Optimization of the parameters was performed using Design-Expert software (version 13.0.1). All responses, i.e., moisture (%), total ash (%), crude fat (%), crude protein (%), overall acceptability, TCD (ΔE),

cohesiveness, hardness (N), and springiness value, were considered for optimisation. The goal was set up for optimization considering the development of the RHG-incorporated instant cake mix, as given in Table S1. Based on these criteria, the best optimised solution for the independent variables was selected. During optimization 26 solutions were obtained, from which one of the most desirable solutions was selected. Table S2 presents the most desirable result. Regression analysis was performed to compare the model's actual and predicted values and validate its accuracy. The actual and predicted response values, together with the corresponding percentage and absolute errors, are presented in Table S2.

Comparative study between market cake and RHG-incorporated cake

Table 4 compares the optimized RHG cake with a commercial market cake. The RHG cake exhibited significantly higher moisture (35.4% vs. 19.3%), total ash (1.46% vs. 1.00%), crude protein (10.8% vs. 6.6%), carbohydrate (64.9% vs. 57.0%), and springiness (0.88 vs. 0.60). The market cake possessed significantly higher crude fibre (16.9% vs. 10.0%), crude fat (18.2% vs. 12.8%), and hardness (16.1 N vs. 13.9 N).

Table 4. Comparison between market cake and roasted horse gram (RHG) incorporated cake.

Parameter	Market cake	RHG-incorporated cake	*F*-value	*p*-value
Moisture content (%)	19.3 ± 0.5	35.4 ± 1	601	< 0.0001*
Total ash (%)	1.00 ± 0.01	1.46 ± 0.01	1,106	< 0.0001*
Crude fat (%)	18.2 ± 0.3	12.8 ± 0.2	558	< 0.0001*
Crude protein (%)	6.6 ± 0.3	10.8 ± 0.3	10,231	< 0.0001*
Crude fibre (%)	16.9 ± 0.7	10.0 ± 0.4	230.30	< 0.0001*
Carbohydrate (%)	57.0 ± 1	64.9 ± 0.2	137.50	< 0.0001*
Cohesiveness	0.45 ± 0.04	0.52 ± 0.02	5.25	0.06
Hardness (N)	16.1 ± 0.7	13.9 ± 0.4	21.30	0.0088*
Springiness	0.60 ± 0.1	0.88 ± 0.03	28.20	0.0058*
Energy (kcal)	419 ± 2	418 ± 2	0.83	0.40

Values are presented as mean ± SD. *F*- and *p*-values were obtained by ANOVA. * denotes significant values at the 5% level of significance. ANOVA: analysis of variance; SD: standard deviation.

Microbial load of RHG-incorporated instant cake mix

Microbial load was estimated using the TPC method over 80 days; the sample was packed in low-density polyethylene (LDPE) pouches. This was done to observe microbial growth in the sample over time. Over an 80-day storage period in LDPE pouches, the TPC remained < 1 CFU/g (0.0003 to 0.02 CFU/g). Moisture content experienced a slight increase from 6.0% to 7.6% (Table 5).

Table 5. Effect of storage period on moisture content and microbial load of instant cake mix during storage and sensory evaluation of prepared cake.

Parameters	0th day	10th day	20th day	30th day	40th day	50th day	60th day	70th day	80th day
Moisture content (%)	6.0 ± 0.4	6.4 ± 0.4	6.8 ± 0.1	6.9 ± 0.1	7.1 ± 0.1	7.1 ± 0.2	7.4 ± 0.2	7.4 ± 0.4	7.6 ± 0.1
CFU/g	0	0.0003	0.0004	0.0006	0.001	0.01	0.01	0.02	0.02
Appearance	8.5 ± 0.3	8.0 ± 0.2	8.0 ± 0.3	8.0 ± 0.3	8.0 ± 0.2	7.8 ± 0.5	7.8 ± 0.2	7.8 ± 0.4	7.8 ± 0.5
Taste/Flavor	8.0 ± 0.4	8.0 ± 0.3	8.0 ± 0.4	8.0 ± 0.3	8.0 ± 0.5	8.0 ± 0.4	7.8 ± 0.5	7.8 ± 0.3	7.8 ± 0.4
Texture/Consistency	8.5 ± 0.2	8.5 ± 0.3	8.5 ± 0.4	8.0 ± 0.3	8.0 ± 0.3	8.0 ± 0.3	8.0 ± 0.4	8.0 ± 0.2	8.0 ± 0.5
Aroma/Smell	8.0 ± 0.4	8.0 ± 0.5	8.0 ± 0.6	8.0 ± 0.4	8.0 ± 0.4	8.0 ± 0.4	8.0 ± 0.2	8.0 ± 0.3	8.0 ± 0.6
Aftertaste	8.5 ± 0.3	8.5 ± 0.3	8.5 ± 0.3	8.5 ± 0.3	8.0 ± 0.9	8.0 ± 0.4	8.0 ± 0.5	8.0 ± 0.3	8.0 ± 0.4
Overall acceptability	8.5 ± 0.4	8.5 ± 0.3	8.5 ± 0.2	8.2 ± 0.4	8.0 ± 0.4	8.0 ± 0.4	7.8 ± 0.5	7.8 ± 0.2	7.8 ± 0.6

Values are presented as mean ± SD. CFU: colony-forming unit; SD: standard deviation.

Sensory evaluation of RHG-incorporated cake during storage

The sensory evaluation of cake prepared from the instant mix was performed during storage for 80 days. The prepared cakes were marked from 1 to 9 on a hedonic scale, 9 being liked extremely and 1 being

disliked extremely. The results show no significant change in sensory characteristics during storage (Table 5). The appearance of the developed cake prepared from instant mix varied from 8.5 to 7.8; taste varied from 8.0 to 7.8; texture varied from 8.5 to 8.0; aroma scored 8.0 even after 80 days; aftertaste varied from 8.5 to 8.0; and overall acceptability varied from 8.5 to 7.8. After 80 days of storage, the prepared cake scored acceptable ratings. Therefore, the instant mix can be stored and consumed for longer periods.

Discussion

Physical and nutritional properties of raw and RHG

Roasting reduced hydration properties such as hydration capacity, hydration index, and swelling index, likely due to structural changes in starch and proteins and moisture loss during heat treatment. Similar results were observed for hydration capacity (0.03–0.04 g/seed), hydration index (1.017–1.408), swelling capacity (0.03–0.07 mL/seed), and swelling index (0.938–2.028) by Jain et al. [10] in raw horse gram seeds. Makkar et al. [54] reported similar findings, noting that thermal processing reduces water absorption due to protein denaturation and reduced seed weight.

From a nutritional perspective, roasting significantly decreased moisture content and slightly reduced crude protein and fiber, likely due to thermal degradation and denaturation effects [55]. Conversely, fat content slightly increased, possibly due to heat-induced release of bound lipids. These findings are consistent with Thirukkumar and Gurumeenakshi [56] and Bhokre et al. [57], confirming that while roasting effectively reduces surface moisture, it largely preserves the macronutrient profile.

Anti-nutritional factors and functional properties of raw and RHG flour

Horse gram contains certain anti-nutrients that reduce nutrient bioavailability; processing methods such as roasting can help reduce the effects of these unwanted factors. In the present study, roasting significantly reduced anti-nutritional factors such as tannins and phytates, confirming earlier findings by Ojha et al. [58] and Sarvani et al. [59], thereby improving mineral bioavailability and overall nutritional quality.

Functional properties including WAC, OAC, and swelling power increased significantly after roasting. The increase in WAC after roasting may be due to major protein dissociation into subunits, creating more water-binding sites. Gelatinisation of carbohydrates and swelling of crude fibre may also occur during roasting, increasing water absorption [60]. The increase in OAC might be due to protein solubilization and dissociation, along with exposure of non-polar constituents, resulting in greater oil absorption [61]. Ojha et al. [58] reported similar results for WAC and OAC. Nazni and Shobana Devi [62] reported similar results, noting that processing (such as boiling, roasting, and cooking) of barnyard millet and foxtail millet increased swelling power. The swelling power of raw horse gram was found to be similar to that reported by Handa et al. [63]. These improvements in functional properties indicate the suitability of RHG flour in bakery applications.

Numerical optimization and effect of quality parameters for the development of RHG-incorporated cake

The optimization study revealed that formulation variables (RWF:RHG ratio, milk powder, and baking time) significantly affected the quality attributes of the developed cake. The 3D response surface plots also showed the effect of process parameters on various responses.

Effect of process parameters on the moisture content of the developed cake

Moisture content is expressed as the measurement of total water present in a food product, either in free form or bound form [64]. The effect of RWF:RHG ratio on moisture content at centre values of milk powder and baking time is depicted in Figure 3a. It clearly describes the linear effect of the RWF:RHG ratio on moisture content and shows that the moisture content increased sharply as the RWF:RHG ratio increased from 1:1 to 3:1. A similar trend was observed by Köten [65] who studied the influence of roasted terebinth on the quality of cake and stated that with an increase in wheat flour ratio the moisture content of cake increased and decreased with an increase in roasted flour ratio.

A similar pattern was found with increasing milk powder, as shown in Figure 3b: moisture content increased as milk powder increased from 20 to 30 g/100 g flour. Ramya and Anitha [66] likewise evaluated the nutritional composition of sponge cake incorporating milk powder. However, moisture content decreased with increasing baking time, as shown in Figure 3c. This may be because the cake had longer contact time with heat, resulting in increased evaporation of water vapour [67]. Mior Zakuan Azmi et al. [68] observed a similar trend, reporting decreased moisture content with increasing baking time. Figure 3d shows the significant effect of milk powder and baking time on moisture content at the centre point of the RWF:RHG ratio (2:1). Moisture content decreased with an increase in baking time, regardless of the level of milk powder. This may be because longer baking time allows more surface moisture to evaporate [67]. However, a 2.71% greater drop in moisture was observed at the higher milk powder level than at the lower level. However, at lower baking times, moisture decreased by 6% compared with the higher level.

Effect of process parameters on total ash of the developed cake

The effect of the RWF:RHG ratio on total ash at the centre values of milk powder and baking time is depicted in Figure 3e. It shows that total ash decreased as the RWF:RHG ratio increased from 1:1 to 3:1. The decrease in total ash in the developed cake was due to the higher presence of RWF and the lower presence of RHG flour. RHG flour had a higher ash content; thus, decreasing its fraction also decreased total ash. A similar trend was observed by Yaqoob et al. [1], who observed the least total ash values for control cake as compared to the cake prepared by incorporation of sprouted and unsprouted barley flour. Figure 3f shows an increase in total ash values as the milk powder content (20 to 30 g/100 g flour) increases in the developed cake. The observable increase in total ash might be because total ash in milk powder is between 5–6% [69]. Figure 3g does not show much effect of baking time on total ash content, as with increasing or decreasing the baking time, the inorganic components do not change. Figure 3h shows the significant effect of RWF:RHG ratio and milk powder on total ash at the centre point of baking time (11 min). Total ash content increased with increasing milk powder regardless of the RWF:RHG ratio; this may be because milk powder has a higher total ash content [69]. However, 1.07% more increase in total ash was observed at higher levels of RWF:RHG ratio as compared to that at the lower level.

Effect of process parameters on crude fat of the developed cake

The effect of RWF:RHG ratio on crude fat at the centre point of milk powder and baking time is shown in Figure 4a. It was observed from the figure that the crude fat increases with an increase in RWF:RHG ratio from 1:1 to 3:1. The observable increase might be because of higher fat content in RWF, i.e., 2–2.5% [70]. The results were consistent with Abegunde et al. [71], who showed that crude fat increased in cakes containing higher levels of wheat flour. A similar trend was observed with the milk powder. Figure 4b shows the effect of milk powder on crude fat, at the centre level of RWF:RHG ratio and baking time. The figure shows that increasing milk powder also increased crude fat continuously. Figure 4c shows the effect of baking time at the centre point of RWF:RHG ratio and milk powder. It can be observed from the figure that with increasing baking time, the fat content slightly increases. This might be due to heat-induced bond breakage resulting in the efficient release of oil [55], whereas after a point, the crude fat decreases, which might be due to the burning of oil at high temperatures. The interactive effect of RWF:RHG ratio and milk powder at centre values of baking time (11 min) is shown in Figure 4d. The graph shows a continuous increase in crude fat with simultaneous increases in milk powder and the RWF:RHG ratio. This may be due to the higher fat content in milk powder [69] and RWF [72] compared with horse gram flour. However, minimum crude fat was observed at lower values of both.

Effect of process parameters on crude protein of the developed cake

The effect of RWF:RHG ratio on crude protein at the centre point of milk powder and baking time is shown in Figure 4e. The graph shows a decrease in crude protein as the RWF:RHG ratio increases. This decrease may be because RWF has lower protein content than RHG flour; crude protein in wheat flour is between 14 and 15% [70]. The results were consistent with Yaqoob et al. [1], who reported that the crude protein

content of cake varied with the composition of the wheat–barley flour blend. Figure 4f shows the effect of milk powder on crude protein by taking RWF:RHG ratio (2:1) and baking time (11 min) at the centre points.

The effect of baking time on crude protein at centre values of RWF:RHG ratio and milk powder is shown in Figure 4g. From the figure, it is clear that increasing baking time decreased crude protein; this may be because higher temperatures and longer heat exposure caused protein denaturation [55]. Figure 4h depicts the interactive influence of the RWF:RHG ratio and baking time at the centre level of milk powder (25 g/100 g flour) on the crude protein of the developed cake. Crude protein decreased with increasing baking time regardless of the RWF:RHG ratio; this decrease may be due to protein denaturation upon heating [55]. However, a 1.64% greater drop in crude protein was observed at a lower level of RWF:RHG ratio as compared with the value at a higher level. Conversely, increasing the RWF:RHG ratio decreased crude protein regardless of baking time; this may be due to the higher protein content in horse gram (Table 1) than in RWF (24.6% in RHG, Table 1, vs. 14–15% in wheat flour [70]). However, at lower baking times, crude protein decreased by 14.4% compared with higher baking times.

Effect of process parameters on TCD of the developed cake

The experimental data showed a significant increase in TCD of the developed cake. The increase in color difference could be due to the presence of RHG flour, an increase in baking time and milk powder. The sugar in milk powder caramelizes, resulting in darker cakes.

The effect of RWF:RHG ratio at centre values of milk powder and baking time on the color difference is shown in Figure 5a. The graph shows a decrease in the color difference with increasing RWF:RHG ratio. This might be because of the decrease in RWF ratio and increase in RHG ratio, resulting in the darker color of the cake. Similar results were observed by Kudake et al. [73], who observed the least color difference in maximum wheat flour-containing noodles compared to ragi flour-incorporated noodles. Contrastingly, Figure 5b shows the effect of milk powder on color difference by taking RWF:RHG ratio (2:1) and baking time (11 min) at centre points. The color difference increased with increasing milk powder. This might be because of the sugar (lactose) present in milk powder (approximately 37%), which caramelises upon heating [74]. Crust browning also results from the Maillard reaction induced by sugar [75].

The effect of baking time on color difference at centre values of RWF:RHG ratio and milk powder is shown in Figure 5c. From the figure, it is visible that as baking time increases, the color difference increases; this could be because of the high temperature and the cake's exposure time to heat [68]. A similar result was obtained by Mior Zakuan Azmi et al. [68] and stated that color difference increases by increasing baking time. Figure 5d shows the significant effect of the RWF:RHG ratio and milk powder at the centre point of baking time on color difference. Color difference increased with increasing milk powder regardless of the RWF:RHG ratio; this may be due to the Maillard reaction and caramelisation of sugar [76]. However, a 1.02% greater increase in color difference was observed at a lower level of milk powder as compared to that at a higher level. On the other hand, a decrease in the RWF:RHG ratio decreased the color difference irrespective of the values of milk powder; this might be due to the darker color of RHG flour [77]. However, at higher values of milk powder, the color difference decreased by 16.16% as compared to that at the lower level.

Effect of process parameters on cohesiveness of the developed cake

The effect of RWF:RHG ratio on cohesiveness at centre values of milk powder and baking time is depicted in Figure 5e. It clearly describes the linear effect of RWF:RHG ratio on cohesiveness and shows that it increased with an increase in RWF:RHG ratio, i.e., 1:1 to 3:1. The increase in the cohesiveness of developed cake might be due to an increase in RWF ratio, as wheat contains gluten protein, which is responsible for a more organized structure in cakes [2], whereas in gluten-free systems such as the legume-based muffins studied by Jeong and Chung [78], structure depends on other flour components. Similar results were observed by de la Hera et al. [53], who prepared a cake incorporating different lentil flours with wheat flour and found that lentil flour decreased cohesiveness, whereas increasing wheat flour increased cake cohesiveness. Gómez et al. [79] also reported an increase in the cohesiveness of wheat flour cake and

observed a decrease when substituting wheat flour with pea flour. Figure 5f depicts the effect of baking time on cohesiveness at centre levels of RWF:RHG ratio and milk powder. The figure shows that increasing baking time increased cake cohesiveness. This might be due to the strengthening of the cake structure with increasing baking time. Soleimanifard et al. [80] observed a similar effect of baking time on cake cohesiveness and reported increased values with increasing baking time.

Effect of process parameters on hardness of the developed cake

The effect of RWF:RHG ratio on hardness at centre levels of milk powder and baking time is shown in Figure 6a. The figure shows the effect of RWF:RHG ratio on hardness and reveals that the hardness decreases sharply as the RWF:RHG ratio increased from 1:1 to 3:1. The decrease in hardness could be since the 3:1 ratio sample contains the maximum amount of wheat flour, and the wheat flour used for cakes contains gluten, which helps in network formation, as well as the lower protein in wheat flour, which promotes maximum air enclosure, resulting in softer cakes [2]. Hosseini Ghaboos et al. [81] also reported that the hardness of sponge cake was affected by the level of pumpkin flour substituted for wheat flour. Figure 6b shows the effect of milk powder at the centre values of the RWF:RHG ratio and baking time on hardness. The figure shows hardness decreasing as milk powder increases. This may be because milk fat interacts with gluten proteins during baking, resulting in a moist, soft cake. The effect of baking time on hardness at centre values of RWF:RHG ratio and milk powder is shown in Figure 6c. Cake firming over time is primarily caused by moisture loss from the crumb and the recrystallization of starch components, a process commonly referred to as starch retrogradation [82]. The figure shows that hardness increases as baking time increases from 10 to 12 minutes. This may be because longer baking time increases surface moisture loss, resulting in harder cakes. The results were similar to the study by Alifakı and Şakıyan [67], who found that increasing baking time increased cake hardness; this increase could be related to baking loss with respect to baking time.

Figure 6d shows the interactive effect of RWF:RHG ratio and baking time at the centre level of milk powder (25 g/100 g flour) on hardness. Hardness increased by 25.2% with increased baking time at a lower RWF:RHG ratio; this may be due to the removal of surface moisture as baking time increases [67]. However, no significant change in hardness was observed at a higher level of RWF:RHG ratio. In contrast, decreasing the RWF:RHG ratio increased hardness regardless of baking time; this may be due to increased RHG flour, which changes the cake's internal structure. de la Hera et al. [53] also observed an increase in hardness after incorporation of legume flour in the cake. However, at higher baking times, hardness decreased by 48.40% compared with the lower level.

Figure 6e shows the significant effect of milk powder and baking time at the centre point of RWF:RHG ratio (2:1) on hardness. Hardness increased with increasing baking time at higher milk powder levels. However, hardness did not change significantly at the lower milk powder level. Conversely, decreasing milk powder increased hardness regardless of baking time. However, at lower baking times, hardness decreased by 35% compared with the higher level. This may be because shorter baking time leaves less surface moisture to evaporate, reducing hardness [83].

Effect of process parameters on springiness of the developed cake

Figure 7a shows the effect of the RWF:RHG ratio on springiness at the optimum milk powder concentration and baking time. The figure shows the effect of the RWF:RHG ratio on springiness and reveals that the springiness increased sharply as the RWF:RHG ratio increased from 1:1 to 3:1. This might be due to the presence of gluten protein in RWF, which strengthened the structure, forming an organised gluten network [84]. Springiness is commonly linked with products that are fresh, elastic, and well aerated [85]. Greater springiness values generally indicate a higher specific volume and a more open, aerated internal structure. Similar results were observed by de la Hera et al. [53], who prepared a cake incorporating different lentil flours with wheat flour and found that lentil flour decreased springiness; conversely, increasing wheat flour increased the cake's cohesiveness. Gómez et al. [79] also reported increased springiness in wheat flour cake and observed a decrease when substituting wheat flour with pea flour. Jeong and Chung [78] also reported

that flour composition influenced the springiness of legume-based gluten-free muffins. Figure 7b shows the effect of milk powder at the centre values of the RWF:RHG ratio and baking time on springiness. The figure shows that springiness increases with increasing milk powder. As milk powder content increased, moisture content also increased, making the cake springier. Li et al. [86] observed the effect of milk powder on cheese and reported increased springiness with higher milk powder content.

The effect of baking time on springiness at the centre values of RWF:RHG ratio and milk powder is shown in Figure 7c. The figure shows springiness decreasing as baking time increases from 10 to 12 min. This may be due to moisture loss during baking, which makes the cake less springy [87].

Figure 7d shows the interactive effect of RWF:RHG ratio and baking time at the centre level of milk powder (25g/100 g flour) on springiness. Springiness decreased as baking time increased at a lower RWF:RHG ratio; this may be due to the removal of surface moisture, resulting in less springy cakes, as Soleimanifard et al. [88] also reported a decrease in cake springiness with increasing baking time. However, no significant change in springiness was observed at a higher level of the RWF:RHG ratio. In contrast, increasing the RWF:RHG ratio increased springiness regardless of baking time; this may be due to the higher amount of RWF, which contains gluten that helps form an organised gluten network [84]. However, at higher baking times, springiness increased by 78.53% compared with the lower level.

Figure 7e shows the significant effect of milk powder and baking time at the centre point of RWF:RHG ratio (2:1) on springiness. Springiness decreased as baking time increased at higher milk powder levels. However, springiness did not change significantly at a lower milk powder level. In contrast, increasing milk powder increased springiness regardless of baking time, which may be due to the higher moisture content in milk powder [86]. However, at lower baking times, springiness increased by 34.97% compared with the higher level.

Effect of process parameters on overall acceptability of the developed cake

The results aligned with the findings of Abegunde et al. [71], who studied the quality of cake prepared from wheat breadfruit composite flour and reported that overall acceptability ranged from 6.90 to 8.60; the cake incorporating 20% wheat breadfruit flour scored highest.

Figure 8a shows the effect of the RWF:RHG ratio on the overall acceptability of the developed cake at the centre values of milk powder and baking time. The graph showed an increase in overall acceptability with an increase in RWF:RHG ratio from 1:1 to 2:1 and then a decrease after a further increase in RWF:RHG ratio from 2:1 to 3:1. This could be because after a further increase in RWF:RHG ratio, the developed cake became slightly bitter and hard, thus representing the 2:1 ratio as most acceptable. A similar effect was observed with milk powder on overall acceptability at the centre values of the RWF:RHG ratio and baking time. Figure 8b shows an increase in overall acceptability, and then after a point, it started decreasing. This may be because increasing milk powder increased the cake's overall sweetness, which panel members liked less. Similarly, Figure 8c shows the effect of baking time on overall acceptability at the centre values of the RWF:RHG ratio and milk powder. Figure 8c shows that overall acceptability increases with baking time, but after a point, it starts decreasing. This may be due to increased hardness with baking time; longer baking also produces a darker cake [68], which may not look appetising to panel members and thus reduces overall acceptability.

Figure 8d shows the interactive effect of the RWF:RHG ratio and milk powder at the centre level of baking time (11 min) on the overall acceptability of the developed cake. The graph shows that the overall acceptability decreased at higher and lower levels of both milk powder and RWF:RHG ratio. This might be due to increasing hardness and bitterness with increasing addition of RHG flour, also with increasing milk powder after a certain point, the overall sweetness increased, which might not be liked by panel members, thus resulting in decreased overall acceptability at higher levels of both, similarly, a creamier and roasty taste would not develop with minimum addition of milk powder and RHG flour, thus resulting in decreased overall acceptability at lower levels of both. Maximum overall acceptability was observed at the middle RWF:RHG ratio, with milk powder increasing from the middle to its extreme level.

Comparative study between market cake and RHG-incorporated cake

Cakes are generally high in calories and may not be suitable for elderly individuals or those with non-communicable diseases such as diabetes, obesity, and cardiovascular disorders [89]. Lenka et al. [89] focused on developing a nutritionally improved, low-calorie cake using whole wheat flour as the base ingredient. The researchers prepared four formulations: a control made solely with RWF (V0) and three variants (V1–V3) incorporating whole wheat flour with varying proportions of sugar, oil, milk, baking agents, and vanilla essence. Among these, V3 achieved the highest sensory scores, better nutritional composition, lower energy content, and reduced cost. The protein, fat, carbohydrate, crude fibre, phosphorus and iron per 100 g of the V3 cake and V0 were determined to be 5.69 g, 12.27 g, 31.75 g, 0.42g, 133.68 mg and 1.45 mg, for V3 and 4.84g, 18.13g, 43.16g, 0.1g, 70.50mg, 0.99 mg, for V0 respectively. Compared to commercial cakes, the developed formulation demonstrated clear nutritional and economic advantages. In comparison, commercially available cakes were higher in energy, lower in nutritional quality, and considerably more expensive, underscoring the nutritional and economic benefits of the developed cake formulations.

In this study, a comparative analysis was conducted between the developed RHG cake and market veg. fruit cake. The results showed increased moisture content, total ash, crude protein, carbohydrate, cohesiveness, and springiness in the RHG-incorporated cake. The increase in moisture might be because the RHG-incorporated cake needed more water to maintain proper consistency. On the other hand, an increase in crude protein and total ash might be because horse gram is rich in protein and minerals; i.e., horse gram contains approximately 24 to 30% crude protein [57] and 3.0 to 3.8% total ash [90] depending upon the variety. Crude fibre, hardness, and energy were highest in the market cake. The crude fibre and hardness might be maximum in market cake due to the presence of wheat fiber in the cake. Thus, the developed RHG cake demonstrated substantial nutritional superiority over the commercial control.

In another study by Ashritha et al. [91], cakes formulated with millet flour and jaggery were developed and evaluated against conventional cakes made with RWF through consumer acceptability analysis. Most respondents (69.3%) preferred jaggery over refined sugar, mainly because of increased health awareness, followed by perceived nutritional benefits. Additionally, millet-based cakes were favored over commercially available varieties commonly found in the market. Participants viewed the introduction of these value-added products as a positive, health-oriented approach, recognising them as nutrient-dense and suitable for consumption across different age groups. Overall, consumer response towards the newly formulated cakes was notably favorable. Azzizah and Handayani [92] formulated a coffee-flavoured cake by partially replacing conventional wheat flour with millet flour. Sensory evaluation showed that the formulation with 50% millet flour achieved the highest consumer acceptability.

Storage stability of RHG-incorporated instant cake mix

Microbial analysis confirmed the instant cake mix's stability over 80 days, with negligible microbial growth. This can be attributed to low moisture content and the preservative effect of sugar, as reported by Wadhawan and Bansal [93]. The results aligned well with the findings of Wijewardana et al. [94]. In their study, three different ready-to-bake vegetarian cake mixes were developed using combinations of wheat flour, rice flour, dehydrated bael (*Aegle marmelos*) powder, soursop (*Annona muricata*) powder, and pumpkin powder. All cake formulations maintained a safe water activity (a_W = 0.6) and showed a low microbial count of 1.8×10^3 CFU/g. Foods inevitably coexist with diverse microorganisms during production and distribution. Additionally, sensory scores remained within acceptable limits throughout storage, indicating good shelf stability and consumer acceptability over time. Overall, the study confirms that RHG can be effectively utilized in bakery formulations to enhance nutritional quality, reduce anti-nutritional factors, and maintain desirable sensory attributes. The optimized formulation presents a promising functional food product suitable for health-conscious consumers and potential industrial applications.

The present investigation demonstrated the successful development and storage stability of RHG-incorporated cake prepared from an optimized instant cake mix. Microbial analysis of the instant cake mix packed in LDPE pouches showed extremely low TPC values (< 1 CFU/g) throughout 80 days of storage, demonstrating excellent microbiological safety and shelf stability. The overall acceptability decreased marginally from 8.5 at day 0 to 7.8 at day 80, confirming that the product retained consumer-acceptable quality throughout the storage period. The relatively stable aroma and texture further indicated good structural and flavor preservation in the developed cake. The results confirm that incorporating RHG flour into instant cake mix not only enhances the nutritional quality but also provides good storage stability with safe microbial limits and sustained sensory acceptability for up to 80 days. The study highlights the strong potential of horse gram as an underutilised functional ingredient for developing value-added, shelf-stable bakery products suitable for commercial application.

Abbreviations

ANOVA: analysis of variance

BBD: Box-Behnken design

CFU: colony-forming unit

LAF: laminar air flow

LDPE: low-density polyethylene

LOF: lack of fit

OAC: oil absorption capacity

RHG: roasted horse gram

RSM: response surface methodology

RWF: refined wheat flour

TCD: total color difference

TPA: texture profile analysis

TPC: total plate count

WAC: water absorption capacity

Supplementary materials

The supplementary tables for this article are available at: https://www.explorationpub.com/uploads/Article/file/1010209_sup_1.pdf.

Declarations

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Author contributions

SG: Investigation, Methodology, Formal analysis, Writing—original draft. NCS: Conceptualization, Supervision. SS: Methodology, Supervision. UCL: Formal analysis, Validation, Writing—review & editing. AS: Writing—review & editing. SJ: Validation, Writing—review & editing. AC: Writing—review & editing. WA: Validation, Writing—review & editing. SK: Validation, Writing—review & editing. All authors read and approved the submitted version.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical approval

Ethical approval for this study was waived in accordance with local institutional guidelines, as the study involved only the sensory evaluation of food products by healthy adult volunteers and did not involve clinical interventions, invasive procedures, or the collection of biological samples. The study followed the ethical principles of the World Medical Association Declaration of Helsinki and the ICMR National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (2017).

Consent to participate

We obtained informed consent from all participants before they participated in the sensory evaluation. Participants were informed about the study objectives and procedures, their voluntary participation, and their right to withdraw at any time without consequences.

Consent to publication

Informed consent to publication was obtained from all participants.

Availability of data and materials

The data will be made available upon reasonable request.

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