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Standardization and characterization of *Mohanthal* using response surface methodology

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Mohanthal, a traditional Indian sweet made from chickpea flour, *ghee*, khoa, and sugar, holds significant cultural and culinary importance. However, its preparation lacks standardization, resulting in inconsistencies in quality that hinder large-scale production and commercialization. This study addresses these challenges by employing Response Surface Methodology with a Central Composite Design to optimize the ingredient formulation of *Mohanthal*, ensuring consistent quality while preserving its traditional essence. Experiments were conducted to evaluate the effects of varying levels of *ghee*, khoa, and sugar on sensory, textural, and color attributes, with chickpea flour kept constant. The optimized formulation, comprising 103.13 g of *ghee*, 27.70 g of khoa, 98.24 g of sugar, and 100 g of chickpea flour, exhibited superior sensory and textural characteristics, including enhanced flavor, color, and consistency. Quadratic models developed for key attributes, such as sensory scores, textural parameters, and browning index, demonstrated excellent predictive capabilities with R^2 values exceeding 0.90, confirming the robustness of the optimization approach. This study significantly contributes to the scientific understanding of *Mohanthal* production by providing a validated and standardized formulation. The findings bridge the gap between traditional preparation methods and modern food technology, enabling consistent quality control and scalability for commercial production. By addressing the challenges of variability and preserving the cultural essence of this traditional sweet, this work lays a foundation for its large-scale manufacturing and market potential.

Keywords Central composite design, *Ghee*, Khoa, *Mohanthal*

Mohanthal is a traditional Indian sweet prepared from chickpea flour, *ghee*, sugar, and khoa. It is known for its medium brown color, rectangular shape, cohesive and firm texture, and a granular consistency that carries a delightful roasted ghee flavor. This unique delicacy, prepared using a blend of pulse flour and milk solids, offers a rich source of essential macronutrients and micronutrients[1,2]. Beyond its nutritional benefits, *Mohanthal* holds deep traditional and cultural significance in Indian cuisine, especially in Gujarat and Rajasthan[2]. It is commonly prepared for festivals, weddings, and other auspicious occasions. This sweet is closely linked to religious practices and is often offered as prasad (sacred food) to deities during celebrations such as Janmashtami et al.[2,3]. The name *Mohanthal* is derived from "*Mohan*," a name for Lord Krishna, highlighting its spiritual connection. Additionally, its presence at weddings and social gatherings symbolizes hospitality, goodwill, and togetherness[1–4].

The preparation of *Mohanthal* involves combining fresh chickpea flour (*besan*) with milk and *ghee* to form a crumbly mixture called *dhrabo*, which is left undisturbed for 30 min. This mixture is then roasted in melted *ghee* until it attains a light brown color and roasted flavor. A sugar syrup with one-third consistency is added to the mixture, which is continuously blended to achieve a semisolid state. The final mixture is spread on a greased dish, garnished with nuts and cardamom, and left to cool and set before being cut into pieces[2,3].

Despite cultural significance and artisanal craftsmanship, the manufacturing process of *Mohanthal* encounters considerable challenges such as the absence of standardized formulations and comprehensive scientific data[2,3]. Traditional recipes generally lead to inconsistencies in quality across different batches, posing barriers to scalability, commercialization, and industrial production. Furthermore, there is a limited understanding of

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essential parameters, including ingredient composition, process optimization, shelf-life stability, and packaging requirements[2–4].

Response Surface Methodology (RSM) provides a systematic approach to identify and quantify the effects of key ingredients (*ghee*, khoa, and sugar) and their interactions on sensory and textural attributes. The application of a Central Composite Design (CCD) within RSM allowed for a comprehensive exploration of the design space while minimizing the number of experiments, leading to a predictive quadratic model for optimizing ingredient levels[5–7].

The optimization of the *Mohanthal* formulation through RSM offers several advantages for manufacturers as well as consumers. For manufacturers, precise ingredient ratios ensure consistent product quality, which minimizes variability across batches and facilitates scalability for commercial production[5–8]. Moreover, the optimized formulation, characterized by low moisture content and a balanced composition, enhances shelf-life stability by reducing microbial spoilage and extending the distribution range, crucial for market expansion[7,8]. For consumers, this standardized product delivers superior, reproducible sensory attributes, such as flavor and texture, closely resembling traditional handmade *Mohanthal*. The improved shelf-life provides added convenience, allowing for prolonged storage without compromising quality, thus addressing contemporary demands for consistent quality and extended stability[3,4].

The potential for *Mohanthal* in global markets is significant, driven by the Indian diaspora of approximately 35.4 million individuals worldwide as of November 2024[9]. Major populations in countries such as the United States, United Arab Emirates, Malaysia, and Canada represent a substantial consumer base for authentic Indian sweets[9]. To capitalize on this opportunity, it is essential to produce *Mohanthal* that complies with international quality standards. This requires further research into quality parameters, preservation techniques, and innovative packaging solutions to enhance export potential[10–13]. The standardization achieved in this study will position *Mohanthal* as a premium ethnic product, enabling it to meet the growing global demand while preserving its authentic traditional essence[2].

Beyond its immediate applications, this study establishes a scientific framework for advancing food science and technology by systematically optimizing ingredient ratios through RSM[13–15]. The reproducibility of this optimization process facilitates the standardization of production parameters, which is essential for integrating automated manufacturing systems[5,7]. By minimizing formulation variability, this approach guarantees consistent product quality and enhances production efficiency. Moreover, the methodology is adaptable to ingredient substitutions, providing a robust tool for developing alternative formulations that align with changing consumer preferences and regulatory requirements[5,7]. This innovative framework for modernizing traditional food production techniques effectively bridges the gap between artisanal craftsmanship and industrial efficiency[13–15].

Considering these, the primary objective of this investigation was to determine the optimal quantities of *ghee*, khoa, sugar, and chickpea flour to produce a product with superior textural, sensory, and color characteristics. This study successfully optimized the ingredient levels for *Mohanthal*, resulting in a standardized product with consistent quality. The optimized recipe achieved high sensory and textural scores, closely replicating traditional handmade *Mohanthal*, and has significant potential for scalability and commercialization[2,7].

Materials and methods

Materials

Fresh cow milk (~3.5% fat), standardized to 4.0% fat and 8.5% solids-not-fat (SNF), was obtained from the Experimental Dairy of the ICAR-National Dairy Research Institute, Southern Regional Station, Bengaluru, India. The milk was stored under refrigeration at 4 °C until processing to ensure freshness and prevent microbial growth. Cream was separated using a cream separator (Alfa Laval, Sweden) for the preparation of *ghee* and standardization purposes. Bengal gram dal (chickpea) was sourced from a local market in Bengaluru, India and selected based on its freshness and physical quality. The dal was sun-dried, milled into flour, and stored in airtight containers in a cool and dry environment to prevent moisture absorption and maintain its quality. Refined cane sugar, fully ripened cardamom, and almonds were also procured from local markets, chosen based on visual inspection and suitability for traditional sweet preparation. Refined cane sugar, and fully ripened cardamom were stored in sealed containers to avoid contamination and moisture exposure, ensuring consistency in flavor and texture. Almonds were stored in a dry, cool place to maintain their freshness. Refined cane sugar, fully ripened cardamom, and almonds were also procured from local markets, chosen based on visual inspection and suitability for traditional sweet preparation.

Preparation of raw materials and sugar syrup

Preparation of khoa and ghee

Standardized cow milk with 4.0% fat and 8.5% solids-not-fat (SNF) from the Experimental Dairy, ICAR-NDRI, Karnal, Haryana, India, was processed to prepare khoa. This milk was turned into khoa using the heat desiccation method in an open steam-jacketed kettle at a steam pressure of 2 kg/cm^2. *Ghee* was produced using the direct creamery method, with mixed cream obtained from the experimental dairy plant of the institute. The cream was clarified until it reached approximately 111 °C[2].

Preparation of sugar syrup

The required amount of sugar was placed in a container, followed by the addition of a small quantity of water. The mixture was then heated to boiling and stirred until the syrup attained the golden color. To refine the sugar mixture, a small amount of milk (10 ml) was added, and the foam was removed using a spoon. The °Brix level was determined using a refractometer. The final °Brix level (i.e., 70–80) was adjusted by adding water or boiling to evaporate excess water. The syrup was then strained through a muslin cloth and kept at a temperature of 75 ± 2 °C by placing it in a water bath[2].

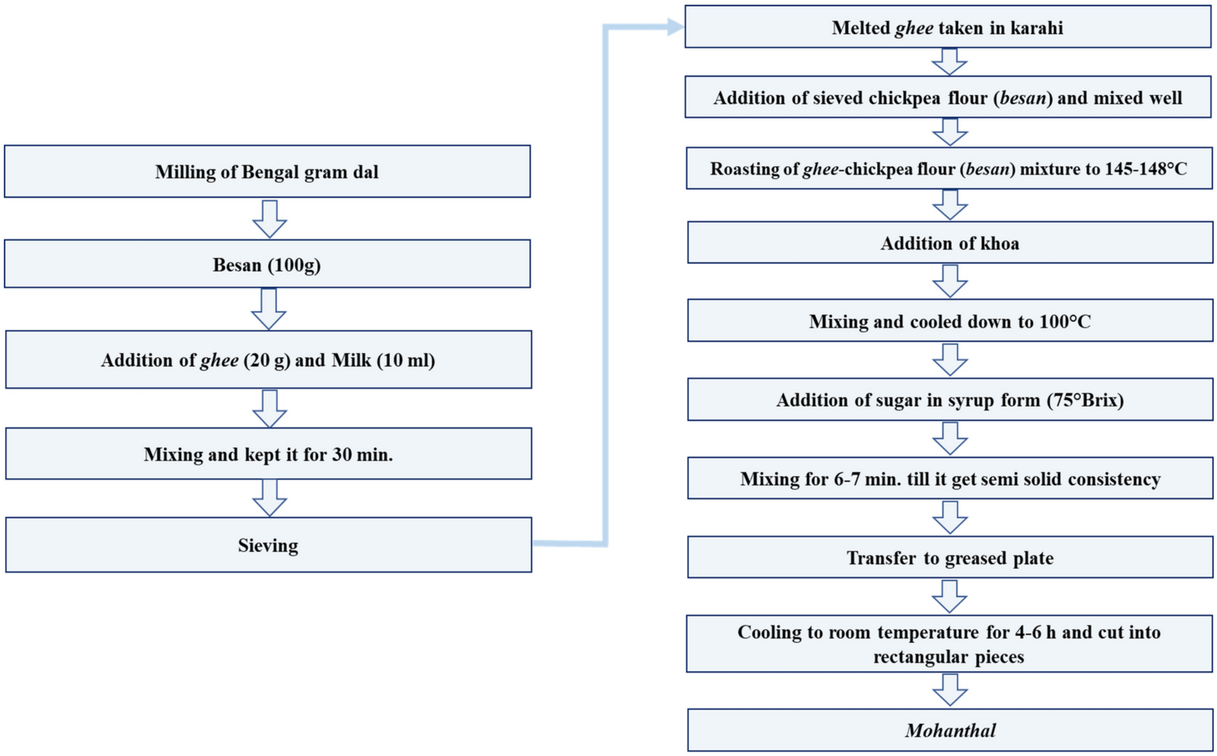

Fig. 1. Process flow diagram of *Mohanthal* production.

	Coded level				
	Axial point (Min)	Factorial point	Centre coordinate	Factorial point	Axial point (Max)
Factor	− 1.67	− 1	0	+ 1	+ 1.67
Ghee	66.36	80	100	120	133.64
Khoa	13.18	20	30	40	46.32
Sugar	66.32	80	100	120	133.64

Table 1. Coded and actual levels of the *ghee* (g), hoa (g) and sugar (g) formulations.

Preparation of *Mohanthal*

Mohanthal was prepared using different levels of ingredients, such as *ghee*, khoa, and sugar, while the quantity of *dhrabo* was kept constant in all formulations. During all trials, *dhrabo* was made using 100 g chickpea flour (*besan*), 20 g *ghee*, and 10 ml milk. This mixture was then left undisturbed for approximately 30 min. and finally sieved. After the sieving step, *Mohanthal production* was carried out according to the process described in Fig. 1.

Design of the experiment

Different levels of *ghee*, khoa, and sugar were used to determine their optimal levels using the Central Composite Rotatable Design (CCRD)[2,7,13]. The central values of the three independent variables were denoted as A, B, and C, representing the *ghee* (g), khoa (g), and sugar (g) levels, respectively. The range and levels for these variables are provided in Table 1. A total of 20 experiments were conducted in a randomized order, consisting of 8 factorial points, 6 axial points, and 6 central points (Table 2).

The response (y) was assumed to be a function of experimental variables (A, B, C), represented as y = f (A, B, C). Second-order polynomial models were developed for each response via multiple regression techniques in Design Expert (version 7.0.0) software[2,7,13]. The model is expressed as:

$$y = \beta 0 + \beta 1 \times A + \beta 2 \times B + \beta 3 \times C + \beta 12 \times A \times B + \beta 13 \times A \times C + \beta 23 \times B \times C + \beta 11 \times A^2 + \beta 22 \times B^2 + \beta 33 \times C^2$$

here β0 represents the intercept, while β1, β2, and β3 are the first-order coefficients of the linear terms; β12, β13, and β23 are the interaction coefficients; and β11, β22, and β33 are the coefficients of quadratic terms. The adequacy of the model was assessed using the F ratio, whereas the effects of the variables at linear, quadratic, and interaction levels on individual responses were described using 95 and 99% levels of confidence.

Standard order	Variable A	Variable B	Variable C	Coefficient assessed by
1	80	20	80	Factorial
2	120	20	80	Factorial
3	80	40	80	Factorial
4	120	40	80	Factorial
5	80	20	120	Factorial
6	120	20	120	Factorial
7	80	40	120	Factorial
8	120	40	120	Factorial
9	66.36	30	100	Axial
10	133.64	30	100	Axial
11	100	13.18	100	Axial
12	100	46.82	100	Axial
13	100	30	66.36	Axial
14	100	30	133.64	Axial
15	100	30	100	Center
16	100	30	100	Center
17	100	30	100	Center
18	100	30	100	Center
19	100	30	100	Center
20	100	30	100	Center

Table 2. Details of the response surface experiments with three independent variables: A—*Ghee* level (g); B—Khoa level (g); and C—Sugar level (g).

Optimization and validation of formulation for *Mohanthal* preparation

The optimization function within Design Expert 7.0.0 was utilized to determine the optimal combination of ingredients for *Mohanthal*[2,7,14]. The parameters considered encompassed sensory aspects such as flavor, texture, color, sweetness, and overall acceptability, as well as textural attributes such as hardness, gumminess, chewiness, and color attributes, including the browning index. Table 5 outlines the upper and lower limits of the constraints. After analysis, three optimal solutions were proposed, and the solution with the highest desirability value of 0.906 (Formulation No. 1) was selected for further examination.

The validation of this formulation was carried out by preparing *Mohanthal* using the specified ingredient levels. Predicted values of sensory and textural attributes obtained through the Design Expert 7.0.0 software (Stat-Ease Inc., Minneapolis, USA) were compared with experimentally observed results. Statistical analysis was performed using a t-test to evaluate the significance of differences between predicted and observed values[2,7,13,14]. The t-test was conducted using SPSS software (IBM Corp., Armonk, NY, USA) to ensure validation of the optimization process.

Texture profile analysis

Texture profile analysis of the *Mohanthal* samples was carried out using a texture analyzer (TA-XT plus Stable Micro System, England). The instrumental test protocols were as follows: option: return to start; test mode: compression; pretest speed: 1 mm/s; test speed: 5 mm/s; post-test speed: 5 mm/s; target mode: distance; distance: 10 mm; time: 5 s; trigger type: auto (force); trigger force: 5 g; break mode: off; advanced option: ON; and probe: P/75 plunger probe. The *Mohanthal* samples were gently patted into cubes of 20 × 20 × 20 mm and tempered at 30 °C for approximately 1 h. The cubes were positioned centrally over the platform of the texture analyzer, and the computer was allowed to execute the program to run the test. The sample was compressed (50% compression) by the plunger twice (resembling two bites), and the force exerted back by the sample onto the plunger was sensed by the machine, generating a two-peak force–time curve. Different textural parameters, such as hardness, gumminess, and chewiness, were computed from the force–time graph as described by Patel and Rao[16].

Color

Color measurements were carried out using a Hewlett-Packard ScanJet 5370C scanner, supported by a Dell computer equipped with a Core i5 processor and 8 GB RAM, ensuring accurate and efficient data processing. The ground sample of *Mohanthal* was placed in a scratch-less petri plate (diameter: 3 cm), and the bottom surface was scanned under standardized lighting conditions to ensure consistency in color analysis. The scanner was configured with the following settings: 24-bit true color mode to capture over 16 million colors for detailed color information, 300 dpi resolution to balance image clarity and file size, and color dropout disabled to retain all color data during scanning. The scanned image was opened in Adobe Photoshop [Photoshop 2017 (Version 18.1.6)], and color parameters were measured as described by Gokmen and Sugut[17]. The browning index was computed as described by Yam and Papadakis[18].

Sensory evaluation

Sensory evaluation was carried out by a panel comprising ten individuals, including seven males and three females, aged between 25 and 46 years. The panelists were selected from the Dairy Technology Division, Southern Regional Station, ICAR-National Dairy Research Institute, Bengaluru, India, based on their expertise and prior training in sensory evaluation, particularly in the assessment of traditional Indian dairy products. This selection ensured a balanced and experienced panel capable of providing reliable and nuanced feedback[13,14]. The evaluations were conducted in a well-ventilated sensory evaluation room maintained at a controlled temperature of 22 °C with a relative humidity of 60–70%. To standardize conditions, twenty samples were presented at room temperature on uniform white ceramic plates. Each sample was randomly assigned a unique three-digit code to eliminate potential biases, and the sequence of presentation was varied among panelists to prevent order effects. Panelists were provided with adequate time between samples to cleanse their palates using water, minimizing sensory fatigue.

Proximate composition analysis of *Mohanthal*

The chemical composition was determined using different methods: moisture content employing the gravimetric method[19], fat by Mojonnier method[19], protein content using the Micro Kjeldahl method BIS[19], lactose and sugars[19] and ash[20] and other carbohydrates (by difference).

Results and discussion

This investigation involves the optimization of the levels of each of three variables, viz., *ghee*, khoa and sugar, as shown in Table 1.

Effects of different levels of Ghee, Khoa and Sugar on the sensory characteristics of *Mohanthal*

Sensory attributes play a crucial role in determining the acceptability of a product in the product development process[21]. The sensory parameters for assessing the quality of *Mohanthal* were color and appearance, body and texture, flavor, sweetness and overall acceptability[2]. The quadratic models for various sensory parameters were obtained through successive regression analysis. The sensory scores along with formulations per their standard run order of *Mohanthal* and partial coefficients of regression of these responses with respect to the levels of three factors in the form of correlations are presented in Tables 3 and 4, respectively.

Color and appearance

The color and appearance scores of the samples from *Mohanthal* ranged from 7.39 to 8.03 (Table 3). Notably, the *Mohanthal* sample with 100 g *ghee*, 30 g khoa, and 100 g of sugar received the highest score, whereas the lowest score was associated with 100 g *ghee*, 30 g khoa, and 66.36 g sugar. The regression analysis (Table 4) demonstrated an R^2 of 0.8657 for the quadratic model, with a lack of fit test indicating that the model's accuracy was within the tested range. Moreover, the precision was 7.287, surpassing the desirable minimum of 4, and the model F value of 7.16 was found to be statistically significant ($p \leq 0.01$ and $p \leq 0.05$). Additionally, interaction effects are graphically represented in 3-dimensional graphs (Fig. 2a–c). The model coefficients (Table 2) revealed that *ghee* had a significant positive linear effect ($p \leq 0.05$) on color and appearance, whereas khoa and sugar did not have significant effects. Furthermore, the quadratic terms for *ghee* and sugar were negatively significant ($p \leq 0.01$), indicating lower scores at higher levels of these ingredients.

The color and appearance score of *Mohanthal* can be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Color and appearance score} = & -0.61453 + 0.07027 \times \textit{ghee} + 0.04047 \times \text{Khoa} + 0.084929 \\ & \times \text{Sugar} - 2.06250\text{E}^{-004} \times \textit{ghee} \times \text{Khoa} - 9.84375\text{E}^{-005} \times \textit{ghee} \\ & - \times \text{Sugar} + 7.81250\text{E}^{-005} \times \text{Khoa} \times \text{Sugar} - 2.54649\text{E}^{-004} \times \textit{ghee}^2 \\ & - 5.01522\text{E}^{-004} \times \text{Khoa}^2 - 3.79497\text{E}^{-004} \times \text{Sugar}^2\end{aligned}$$

Body and texture

The body and texture scores of *Mohanthal* ranged from 6.86 to 8.06 (Table 3), with the lowest score for the formulation containing 120 g *ghee*, 40 g khoa, and 120 g sugar, and the highest score for 100 g *ghee*, 30 g khoa, and 100 g sugar. The model's F-value of 10.82 indicates significance. The regression analysis (Table 4) revealed an R^2 of 0.91, and the non-significant lack of fit test confirmed the accuracy of the model. The adequate precision was 9.538, well above the desirable minimum of 4. Interaction effects can be seen in (Fig. 2d–f). The interaction between *ghee* and khoa had a negatively significant ($p \leq 0.05$) effect on the body and texture scores, whereas a nonsignificant effect was observed for the other two interactions. The coefficients indicated that increasing khoa levels significantly ($p \leq 0.05$) decreased body and texture scores. The quadratic terms for *ghee*, khoa, and sugar were negatively significant ($p \leq 0.01$), indicating lower scores at higher ingredient levels.

The body and texture scores of *Mohanthal* could be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Body and texturescore} = & -8.77200 + 0.12527 \times \textit{ghee} + 0.21075 \times \text{Khoa} + 0.14994 \times \text{Sugar} - 7.14531\text{E}^{-004} \\ & \times \textit{ghee} \times \text{Khoa} - 8.02344\text{E}^{-005} \times \textit{ghee} \times \text{Sugar} - 2.48906\text{E}^{-004} \times \text{Khoa} \\ & \times \text{Sugar} - 4.97752\text{E}^{-004} \times \textit{ghee}^2 - 2.11254\text{E}^{-003} \times \text{Khoa}^2 - 6.60718\text{E}^{-004} \times \text{Sugar}^2\end{aligned}$$

Standard order	A: *Ghee* (g)	B: Khoa (g)	C: Sugar (g)	Color and appearance	Body and texture	Sweetness	Flavor	Overall acceptability	Hardness (N)	Gumminess (N)	Chewiness (N)	Browning index
1	80	20	80	7.63	7.00	7.59	7.63	7.49	10.26	0.79	0.14	192.77
2	120	20	80	7.84	7.18	7.65	7.82	7.68	6.44	0.69	0.12	194.05
3	80	40	80	7.55	7.16	7.65	7.72	7.53	9.56	0.80	0.14	196.96
4	120	40	80	7.72	6.94	7.52	7.8	7.45	6.09	0.75	0.13	192.19
5	80	20	120	7.66	7.25	7.25	7.38	7.41	6.02	0.83	0.14	216.68
6	120	20	120	7.84	7.47	7.76	7.73	7.73	5.25	0.75	0.12	206.08
7	80	40	120	7.77	7.38	7.65	7.53	7.62	7.66	0.84	0.14	208.34
8	120	40	120	7.66	6.86	7.62	7.57	7.37	5.03	0.78	0.13	196.26
9	66.36	30	100	7.46	7.62	7.62	7.23	7.55	9.19	0.81	0.14	210.33
10	133.64	30	100	7.73	7.22	7.57	7.84	7.53	5.85	0.67	0.12	192.58
11	100	13.18	100	7.76	7.72	7.71	7.66	7.75	8.14	0.75	0.13	206.12
12	100	46.82	100	7.72	7.05	7.75	7.87	7.65	6.76	0.82	0.14	194.59
13	100	30	66.36	7.39	7.25	7.26	7.78	7.55	6.96	0.74	0.14	192.77
14	100	30	133.64	7.52	7.22	7.35	7.38	7.35	6.01	0.82	0.14	212.41
15	100	30	100	7.86	7.79	7.88	8.00	7.84	7.85	0.77	0.14	198.43
16	100	30	100	8.03	7.89	8.00	7.91	7.96	7.86	0.76	0.14	198.04
17	100	30	100	7.92	7.88	7.88	8.00	7.90	7.92	0.77	0.14	202.57
18	100	30	100	7.97	7.82	8.01	8.00	7.92	7.94	0.78	0.14	196.73
19	100	30	100	8.00	8.06	7.88	8.06	7.98	7.86	0.76	0.14	202.56
20	100	30	100	8.00	7.88	7.84	8.06	7.91	7.81	0.77	0.14	198.99

Table 3. Effects of ingredient (*ghee*, khoa and sugar) levels on the sensory, textural and instrumental color attributes of *Mohanthal*.

Factor	Color and appearance	Body and texture	Flavor	Sweetness	Overall acceptability	Hardness	Gumminess	Chewiness	Browning index
Intercept	7.96	7.89	8.00	7.91	7.92	7.88	0.77	0.14	199.59
A	0.07*	−0.08^{NS}	0.12**	0.02^{NS}	0.01^{NS}	−1.19**	−0.04**	−7.16e^{-3}**	−4.10**
B	−0.02^{NS}	−0.12*	0.03^{NS}	0.02^{NS}	−0.04^{NS}	−0.14^{NS}	0.02**	3.06e^{-3}**	−2.58**
C	0.03^{NS}	0.05^{NS}	−0.11**	1.44e^{-3NS}	−0.03^{NS}	−0.73**	0.02**	9.74e^{-4NS}	6.18**
AB	−0.04^{NS}	−0.14*	−0.05^{NS}	−0.09*	−0.10**	−0.19^{NS}	0.01**	1.15e^{-3NS}	−0.94^{NS}
AC	−0.04^{NS}	−0.03^{NS}	0.02^{NS}	0.07*	−6.10e^{-3NS}	0.49*	2.99e^{-3NS}	−8.03e^{-4NS}	−2.40*
BC	0.02^{NS}	0.05^{NS}	−9.38e^{-3NS}	0.04^{NS}	5.16e^{-3NS}	0.31^{NS}	−3.81e^{-3}**	−1.57e^{-3NS}	−2.56*
A^2	−0.10**	−0.20**	−0.16**	−0.10**	−0.14**	−0.14^{NS}	−7.60e^{-3}**	−2.47e^{-3}**	0.43^{NS}
B^2	−0.05^{NS}	−0.21**	−0.08**	−0.05*	−0.08**	−0.16^{NS}	7.80e^{-3}**	−1.54e^{-3NS}	0.04^{NS}
C^2	−0.15**	−0.26**	−0.14**	−0.20**	−0.17**	−0.50*	6.01e^{-3NS}	4.79e^{-4NS}	0.83^{NS}
R^2	0.87	0.91	0.94	0.92	0.95	0.90	0.97**	0.93	0.94
Adjusted R^2	0.75	0.82	0.88	0.84	0.91	0.84	0.94	0.86	0.89
Adq. Pre	7.29	9.54	11.69	9.73	12.61	10.54	19.77	12.31	15.36
Model F-value	7.16**	10.82**	16.09**	12.11**	23.14**	10.23**	31.41**	13.70**	18.28**
Lack of fit	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4. Regression coefficients and ANOVA of the quadratic model for the sensory, textural and instrumental color characteristics of *Mohanthal* influenced by different levels of *ghee* (A), khoa (B) and sugar (C) (coded values). **Significant at 1% level, *Significant at 5% level, *NS* non-significant.

Flavor

The flavor scores of *Mohanthal* ranged from 7.23 to 8.06 (Table 3), with the lowest score for the formulation with 66.36 g *ghee*, 30 g khoa, and 100 g sugar, and the highest score for 100 g *ghee*, 30 g khoa, and 100 g sugar. Regression analysis (Table 4) revealed an R^2 of 0.9354, indicating high accuracy in predicting flavor scores. The model's F value of 16.09 was significant ($p \le 0.01$), and adequate precision was well above the desirable minimum of 4. The interaction effects are shown in Fig. 2g–i.

The model coefficients indicated that *ghee* and sugar had significant linear effects on flavor ($p \le 0.01$), with *ghee* positively affecting flavor scores and sugar negatively affecting flavor scores. The quadratic terms for all the factors were negatively significant ($p \le 0.01$), indicating lower flavor scores at higher levels of each ingredient.

The flavor score of *Mohanthal* could be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Flavor score} = &-0.85491 + 0.088511 \times \textit{ghee} + 0.079801 \times \text{Khoa} + 0.062847 \times \text{Sugar} - 2.65625\text{E}^{-004} \times \text{ghee} \\ &\times \text{Khoa} + 3.90625\text{E}^{-005} \times \textit{ghee} \times \text{Sugar} - 4.68750\text{E}^{-005} \times \text{Khoa} \times \text{Sugar} - 3.91172\text{E}^{-004} \\ &\times \textit{ghee}^2 - 7.58143\text{E}^{-004} \times \text{Khoa}^2 - 3.53054\text{E}^{-004} \times \text{Sugar}^2\end{aligned}$$

Sweetness

The sweetness scores of *Mohanthal* ranged from 7.25 to 8.01 (Table 3). The lowest score was for the formulations with 80 g *ghee*, 20 g khoa, and 120 g sugar, whereas the highest score was for the formulations with 100 g *ghee*, 30 g khoa, and 100 g sugar. Regression analysis (Table 4) revealed an R^2 of 0.9160, with a non-significant lack of fit test, indicating an accurate prediction of sweetness scores. The adequate precision was 9.725, above the desirable minimum of 4, and the model's F value of 12.11 was highly significant ($p \le 0.01$). The interaction effects are shown in Fig. 2j–l. None of the factors had significant linear effects on sweetness ($p \le 0.05$). Significant interactions ($p \le 0.05$) indicated that sweetness increased with increasing *ghee* and sugar contents but decreased with increasing sugar contents. Additionally, sweetness increased with more *ghee* and less khoa but decreased with more *ghee* and khoa. The quadratic terms for *ghee*, khoa, and sugar were negatively significant ($p \le 0.01$), indicating lower sweetness scores at higher ingredient levels.

The sweetness score of *Mohanthal* can be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Sweetness score} = &+0.68788 + 0.047568 \times \textit{ghee} + 0.058266 \times \text{Khoa} + 0.077607 \times \text{Sugar} - 4.57812\text{E}^{-004} \times \textit{ghee} \\ &\times \text{Khoa} + 1.71094\text{E}^{-004} \times \textit{ghee} \times \text{Sugar} + 2.04688\text{E}^{-004} \times \text{Khoa} \times \text{Sugar} - 2.48706\text{E}^{-004} \\ &\times \textit{ghee}^2 - 5.17525\text{E}^{-004} \times \text{Khoa}^2 - 5.03927\text{E}^{-004} \times \text{Sugar}^2\end{aligned}$$

Overall acceptability

The overall acceptability score of *Mohanthal* ranged from 7.35 to 7.98 (Table 3). The lowest score was for the formulations with 100 g *ghee*, 30 g khoa, and 133.64 g sugar, whereas the highest score was for the formulations with 100 g *ghee*, 30 g khoa, and 100 g sugar. Regression analysis (Table 4) revealed an R^2 of 0.9542, with a non-significant lack of fit test, indicating an accurate prediction of overall acceptability. The precision was 12.612, which was well above the desirable minimum of 4. The interaction effects are shown in Fig. 2m–o. None of the factors had significant linear effects on overall acceptability ($p \le 0.05$). A negative interaction between *ghee* and khoa suggested that overall acceptability increased with more *ghee* at lower khoa levels but decreased with more

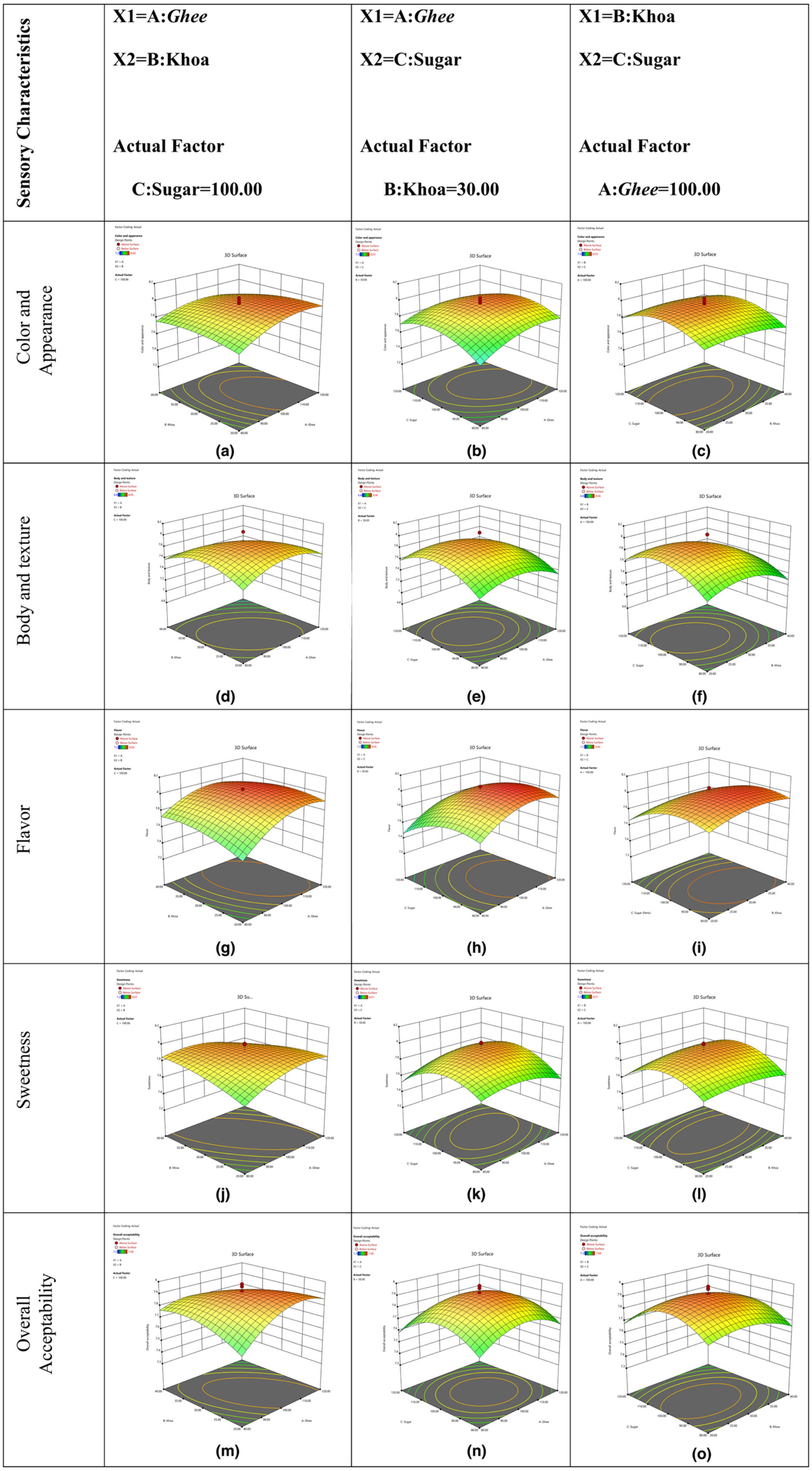

Fig. 2. Response surface plot relating to sensory characteristics as influenced by *ghee* (g), khoa (g) and sugar (g) levels/100 g chickpea flour (besan).

ghee at higher khoa levels. The quadratic terms for *ghee*, khoa, and sugar were negatively significant ($p \leq 0.01$), indicating lower overall acceptability scores at higher ingredient levels.

The overall acceptability score of *Mohanthal* can be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Overall acceptability score} = & -1.83668 + 0.085645 \times ghee + 0.094099 \times \text{Khoa} + 0.083150 \times \text{Sugar} - 5.28906\text{E}^{-004} \\ & \times ghee \times \text{Khoa} - 1.52344\text{E}^{-005} \times ghee \times \text{Sugar} + 2.57813\text{E}^{-005} \times \text{Khoa} \times \text{Sugar} \\ & - 3.38625\text{E}^{-004} \times ghee^2 - 7.91025\text{E}^{-004} \times \text{Khoa}^2 - 4.18727\text{E}^{-004} \times \text{Sugar}^2\end{aligned}$$

Influences of different levels of Ghee, Khoa and Sugar on the textural characteristics and instrumental color parameters of *Mohanthal*

The quadratic models for Textural Profile Analysis (TPA) attributes, such as hardness, gumminess, and chewiness, and color parameters, such as the browning index, were obtained through successive regression analysis. The TPA values of *Mohanthal* and partial regression coefficients concerning the levels of the three factors are presented in Tables 2 and 3, respectively.

Hardness

The hardness of *Mohanthal*, defined as the force required to break the product[22], ranged from 5.03 to 10.26 N (Table 3). The lowest hardness was for the formulations with 120 g *ghee*, 40 g khoa, and 120 g sugar, whereas the highest hardness was for the formulations with 80 g *ghee*, 20 g khoa, and 80 g sugar. Regression analysis (Table 4) revealed an R^2 of 0.9020 and an adequate precision of 10.541, indicating high prediction ability. The model's F value of 10.23 was significant ($p \leq 0.05$). The interaction effects, illustrated in Fig. 3a–c, showed that *ghee* and sugar significantly ($p \leq 0.01$) influenced the hardness of *Mohanthal*. A significant interaction ($p \leq 0.05$) between *ghee* and sugar content indicated that hardness decreased with increasing *ghee* content at relatively high sugar contents. The quadratic term for sugar was negatively significant ($p \leq 0.05$), indicating a lower hardness at higher sugar levels.

The hardness of *Mohanthal* can be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Hardness} = & +14.30138 - 0.083208 \times ghee + 0.023314 \times \text{Khoa} + 0.048220 \times \text{Sugar} - 9.35663\text{E}^{-004} \\ & \times ghee \times \text{Khoa} + 1.21346\text{E}^{-003} \times ghee \times \text{Sugar} + 1.54598\text{E}^{-003} \times \text{Khoa} \times \text{Sugar} - 3.48660\text{E}^{-004} \\ & \times ghee^2 - 1.64424\text{E}^{-003} \times \text{Khoa}^2 - 1.26250\text{E}^{-003} \times \text{Sugar}^2\end{aligned}$$

Gumminess

The gumminess of *Mohanthal*, representing the energy required to disintegrate the product for swallowing[22], ranged from 0.671 to 0.836 N (Table 3). The lowest gumminess was for the formulations with 133.64 g *ghee*, 30 g khoa, and 100 g sugar, whereas the highest gumminess was for the formulations with 80 g *ghee*, 40 g khoa, and 120 g sugar. Regression analysis (Table 4) revealed an R^2 of 0.9658, indicating high prediction accuracy. The precision was 19.773, which was well above the desirable minimum of 4, and the model's F value of 31.41 was significant ($p \leq 0.01$). The interaction effects, as shown in Fig. 3d–f, revealed that *ghee* negatively impacts the gumminess of *Mohanthal*, while khoa and sugar had highly significant positive effects ($p \leq 0.01$). Decreasing *ghee* and increasing khoa and sugar increased gumminess. Significant interactions ($p \leq 0.01$) included a positive effect between *ghee* and khoa and a negative effect between khoa and sugar. The quadratic terms revealed that higher *ghee* levels decreased gumminess ($p \leq 0.01$), whereas higher khoa levels increased it ($p \leq 0.01$).

The gumminess of *Mohanthal* can be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Gumminess} = & +1.01831 - 5.62115\text{E}^{-004} \times ghee - 6.65820\text{E}^{-003} \times \text{Khoa} - 2.08466\text{E}^{-003} \times \text{Sugar} + 5.53650\text{E}^{-005} \\ & \times ghee \times \text{Khoa} + 7.46937\text{E}^{-006} \times ghee \times \text{Sugar} - 1.90338\text{E}^{-005} \times \text{Khoa} \times \text{Sugar} - 1.89979\text{E}^{-005} \\ & \times ghee^2 + 7.79209\text{E}^{-005} \times \text{Khoa}^2 + 1.50147\text{E}^{-005} \times \text{Sugar}^2\end{aligned}$$

Chewiness

The chewiness of *Mohanthal* ranged from 0.118 to 0.144 N (Table 3). The lowest chewiness was for the formulations with 120 g *ghee*, 20 g khoa, and 80 g sugar, whereas the highest chewiness was for the formulations with 100 g *ghee*, 30 g khoa, and 133.64 g sugar. Regression analysis (Table 4) revealed an R^2 of 0.9250, with a non-significant lack of fit, indicating good model fit. The model's F value 13.70 was significant, and the adequate precision was 12.309, which was well above the desirable minimum of 4. The interaction effects shown in Fig. 3g–i revealed that *ghee* had a negative effect, whereas khoa had a highly significant positive impact ($p \leq 0.01$) on chewiness. Furthermore, the quadratic terms revealed that higher *ghee* levels significantly decreased chewiness ($p \leq 0.01$).

The chewiness score of *Mohanthal* could be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Chewiness} = & +0.068423 + 9.04211\text{E}^{-004} \times ghee + 1.44137\text{E}^{-003} \times \text{Khoa} + 2.45601\text{E}^{-004} \times \text{Sugar} + 5.72950\text{E}^{-006} \\ & \times ghee \times \text{Khoa} - 2.00775\text{E}^{-006} \times ghee \times \text{Sugar} - 7.84700\text{E}^{-006} - \times \text{Khoa} \times \text{Sugar} - 6.16719\text{E}^{-006} \\ & \times ghee^2 - 1.53973\text{E}^{-005} \times \text{Khoa}^2 + 1.19645\text{E}^{-006} \times \text{Sugar}^2\end{aligned}$$

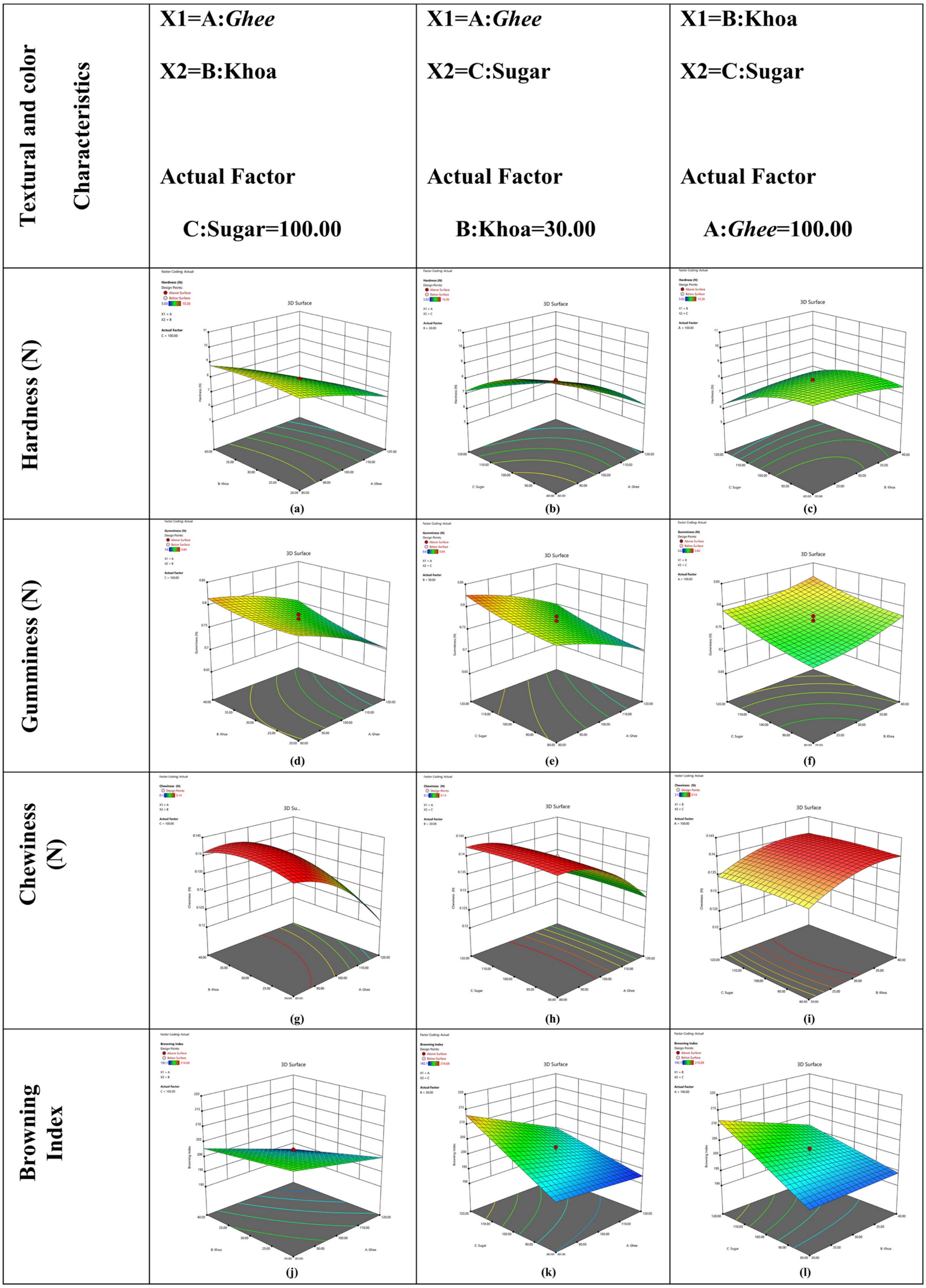

Fig. 3. Response surface plot relating to textural and instrumental color characteristics as influenced by *ghee* (g), khoa (g) and sugar (g) levels/100 g chickpea flour (besan).

Browning index

The browning index of *Mohanthal* was ranged from 192.19 to 216.68 (Table 3). The lowest indices were observed in formulations containing 120 g of *ghee*, 40 g of khoa, and 80 g of sugar, while the highest indices were found in formulations with 80 g of *ghee*, 20 g of khoa, and 120 g of sugar[2]. Table 4 provided the regression analysis, revealing a strong model fit with an R^2 value of 0.9427, a significant F-value of 18.28, and a precision score greater than the minimum threshold of 4, while the interaction effects are depicted in Fig. 3j–l. *Ghee* and khoa exhibited highly significant negative effects ($p \leq 0.01$) on the browning index, whereas sugar had a positive significant impact ($p \leq 0.01$). A linear decrease in *ghee* and khoa, coupled with an increase in sugar, correspondingly enhanced the browning index of *Mohanthal*.

The browning index of *Mohanthal* could be predicted by the equation (for actual values of the variables) given below:

$$\begin{aligned}\text{Browning Index} = &+116.08029 + 0.32254 \times ghee + 1.47049 \times \text{Khoa} + 0.87990 \times \text{Sugar} - 4.69994\text{E}^{-003} \\ &\times ghee \times \text{Khoa} - 6.00234\text{E}^{-003} \times ghee \times \text{Sugar} - 0.012808 \times \text{Khoa} \times \text{Sugar} + 1.06815\text{E}^{-003} \\ &\times ghee^2 + 3.73626\text{E}^{-004} \times \text{Khoa}^2 + 2.06809\text{E}^{-003} \times \text{Sugar}^2\end{aligned}$$

The variation in the browning index of *Mohanthal* formulations is primarily attributed to the Maillard reaction, a non-enzymatic browning process initiated by the interaction between reducing sugars (carbonyl group donors) and proteins or amino acids from khoa[23,24]. This reaction leads to the formation of Maillard reaction products (MRPs), which contribute to the characteristic darkening of *Mohanthal*, as observed in the browning index[25,26].

Regression analysis and interaction effects reveal that higher sugar content markedly accelerates the Maillard reaction, resulting in a pronounced increase in the browning index. This is attributed to the greater availability of carbonyl groups from sugar, which enhance the progression of the reaction[27,28]. In contrast, elevated levels of *ghee* and khoa dilute the sugar concentration in the mixture, thereby reducing the reaction rate and consequently lowering the browning index[2,28]. The linear increase in the browning index with increasing sugar content and decreasing *ghee* and khoa levels aligns with the well-established kinetics of the Maillard reaction, wherein sugar concentration is a critical determinant of reaction progression[25–28] (Table 5).

Furthermore, the Maillard reaction is highly sensitive to temperature and moisture content, which further modulate browning intensity. Elevated temperatures and controlled moisture levels favor the formation of MRPs, thereby enhancing the browning effect[23–25]. These findings are consistent with trends reported in similar food systems, underscoring the pivotal role of ingredient ratios in regulating the extent of Maillard browning[25–27]. By influencing the browning index, these ratios directly impact the sensory properties, particularly the color and flavor, of the final product[27,28].

Optimized and validated formulation for *Mohanthal* preparation

Formulation No. 1 refers to the optimal formulation determined through the Design Expert 7.0.0 software, achieving the highest desirability value of 0.906. This formulation comprised 103.13 g *ghee*, 27.70 g khoa, and 98.24 g sugar for 100 g of chickpea flour. The optimized product demonstrated high sensory scores, including color and appearance (8.00), body and texture (7.85), flavor (8.07), sweetness (7.86), and overall acceptability (7.96), closely resembling market sample of *Mohanthal*[3]. Instrumental analysis showed desirable textural properties with hardness, gumminess, and chewiness values of 7.60 N, 0.723 N, and 0.131 N, respectively. The browning index was 200.48, contributing to the characteristic appearance of product. Furthermore, the proximate composition analysis revealed a balanced nutritional profile, with 10.20% moisture, 31.05% fat, 7.88% protein, 1.70% lactose, 26.02% sucrose, 0.98% ash, and 22.17% other carbohydrates. These results confirm that the optimized formulation successfully replicates the sensory and nutritional qualities of traditional *Mohanthal* while ensuring consistency and potential scalability. A t-test revealed no significant differences ($p > 0.05$), confirming the reliability of the optimization process (Table 6).

Particular	Name	Goal	Lower limit	Upper limit	Final solution (0.906 desirability)
Factors	*Ghee*	Is in range	80	120	103.13
	Khoa	Is in range	20	40	27.70
	Sugar	Is in range	80	120	98.24
Responses	Color and appearance	Is in range	7.39	8.03	7.97
	Body and texture	Maximize	6.86	8.06	7.89
	Flavor	Maximize	7.23	8.06	8.02
	Sweetness	Is in range	7.25	8.01	7.91
	Overall acceptability	Maximize	7.35	7.98	7.93
	Hardness	Is in range	5.033	10.263	7.72
	Gumminess	Is in range	0.671	0.835	0.755
	Chewiness	Is in range	0.118	0.143	0.134
	Browning index	Is in range	192.19	216.68	199.03

Table 5. Goal set for constraints in the optimization of *Mohanthal*.

Attributes	Predicted value	Observed value	Calculated t (α = 0.05) value
Color and appearance	7.97	8.00 ± 0.14	0.659^{NS}
Body and texture	7.89	7.85 ± 0.14	0.383^{NS}
Flavor	8.02	8.07 ± 0.18	0.558^{NS}
Sweetness	7.91	7.86 ± 0.13	0.747^{NS}
Overall acceptability	7.93	7.96 ± 0.17	0.720^{NS}
Hardness (N)	7.72	7.60 ± 0.55	0.760^{NS}
Gumminess (N)	0.755	0.723 ± 0.089	0.683^{NS}
Chewiness (N)	0.134	0.131 ± 0.009	0.455^{NS}
Browning index	199.03	200.48 ± 1.28	0.633^{NS}

Table 6. Comparison of the predicted (Predicted values of the Design Expert 7.0.0 package) and observed values of the responses to validate the optimized results.

Constituents	% Percentage
Moisture	10.20 ± 0.23
Fat	31.05 ± 0.43
Protein	7.88 ± 0.41
Lactose	1.70 ± 0.15
Sucrose	26.02 ± 0.28
Ash	0.98 ± 0.12
Other carbohydrates	22.17 ± 1.12

Table 7. Proximate composition of the optimized *Mohanthal* product.

Proximate composition of the optimized product

The proximate composition of the optimized *Mohanthal* is presented in Table 7. The moisture content of *Mohanthal* was 10.20%, which indicates a low water activity, which is essential for enhancing shelf stability by minimizing microbial proliferation and enzymatic activity[28–30]. This characteristic renders the product more suitable for prolonged storage and distribution under ambient conditions, thereby facilitating its commercialization[28]. Furthermore, the low moisture content contributes to the characteristic crumbly, yet cohesive, texture of *Mohanthal*[1,2].

The fat content of the optimized product was notably high at 31.05%, primarily contributed from *ghee* and khoa, which was essential for the rich, creamy mouthfeel and smooth texture of *Mohanthal*[1,2]. The protein content was 7.88%, primarily contributed from khoa and chickpea flour (*besan*), reflecting the combined contributions of milk and plant proteins, which provide structural integrity, cohesiveness, and elasticity to the product. Such proteins also participate in the Maillard reaction during the roasting, enhancing the characteristic color and flavor of *Mohanthal*[28,31].

Carbohydrates constitute a substantial portion of the product, with sucrose making up 26.02% and other carbohydrates, primarily starches from chickpea flour, comprising 22.17%. Sucrose functions as the primary sweetener, imparting a pleasant sweetness that enhances consumer acceptability[1,2]. The starches from chickpea flour interact with proteins during heating, contributing to the granular texture and cohesive structure of the product, which also acts as a thickening agent, providing the desired consistency and stability[31,32].

The lactose content of *Mohanthal* was 1.70%, which contributes subtly to sweetness and promotes non-enzymatic browning during the Maillard reaction, imparting the characteristic golden-brown color to *Mohanthal*[24–28]. The ash content, recorded at 0.98%, represents the total mineral composition of the product, sourced from milk, chickpea flour, and other ingredients. In comparison to market samples, the optimized formulation achieves a composition that aligns with the traditional expectations of *Mohanthal* while ensuring batch-to-batch consistency. The carefully optimized proportions of *ghee*, khoa, sugar, and chickpea flour ensure that the product meets sensory and textural standards[3].

Conclusion

This study employed RSM to optimize the formulation of *Mohanthal*, a traditional Indian sweet, by analyzing the effects of key ingredients, *ghee*, khoa, sugar, and chickpea flour on its sensory and physicochemical properties. The optimization process determined the superior ingredient levels to be 103.13 g *ghee*, 27.70 g khoa, 98.24 g sugar, and 100 g chickpea flour, resulting in a product with maximized overall sensory acceptability. Key findings demonstrated significant improvements in flavor, texture, color, and overall acceptability compared to non-optimized formulations. The optimized *Mohanthal* also exhibited desirable textural properties and a desired proximate composition. The findings of this research highlight the significance of employing RSM for standardizing traditional dairy products, facilitating the transition from artisanal production methods to scalable industrial processes. This approach not only enhances product consistency and quality but also aids in meeting the sensory and nutritional expectations of diverse consumer demographics. Future research should prioritize scaling up the optimized formulation for industrial production, assessing the impact of various storage conditions on product stability, and developing innovative packaging solutions to extend shelf life. Furthermore, exploring alternative functional ingredient sources could enhance the nutritional profile and cater to emerging market trends, such as health-conscious and sustainable food products. The findings of this study provide a foundational framework for the scientific advancement and commercialization of traditional dairy products such as *Mohanthal*, ensuring their preservation and global outreach.

Data availability
Data will be available on request to corresponding author.

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Author contributions
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Ethical approval
The sensory evaluation in this study was conducted by trained panelists from the faculty of the Dairy Technology Division, Southern Regional Station (SRS), ICAR-National Dairy Research Institute (NDRI). Since no external human participants were involved, ethical approval for human participant research was not required.

Additional information
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