International Journal of Agriculture and Food Science 2025; 7(11): 425-432

ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(11): 425-432
www.agriculturaljournals.com
Received: 04-10-2025
Accepted: 06-11-2025

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Optimization and quality assessment of protein-rich, sugar-free, medium-fat ice cream with milk protein concentrate and stevia

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DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i11f.986

Abstract
This study addresses the growing demand for health-conscious food products by developing a protein-rich, sugar-free, medium-fat ice cream enriched with Milk Protein Concentrate (MPC-80) and stevia. Using a three-phase research approach, the optimal levels of MPC-80 and stevia were determined through RSM Design Expert software, resulting in a formulation with 5.95% MPC-80 and 40.96 ppm stevia. The optimized product (T_1) was characterized for its proximate composition, calorific value, physico-chemical properties, sensory attributes, and microbiological quality and compared with two control samples: Medium-Fat-Control (MFC) and Full-Fat-Control (FFC). T_1 demonstrated superior overrun (95%), improved melting resistance (1.73 ml/min), and intermediate hardness (160), validating its structural and sensory quality. Sensory scores positioned T_1 as a nutritionally optimized alternative with good consumer acceptability. A 180-day storage study confirmed the stability of T_1 in sensory, microbial, and physico-chemical parameters. The production cost of T_1 was ₹177/kg, reflecting its premium positioning for health-conscious and diabetic consumers. The study concludes that the developed ice cream is a viable, health-focused dessert option with consistent quality and extended shelf life.

Key words: Protein-rich, sugar-free, medium-fat ice cream, MPC-80, stevia, response surface methodology

Introduction
Ice cream is a globally cherished dairy-based dessert known for its complex physicochemical structure (Akbari *et al.*, 2019; Goff & Hartel, 2013; Marshall *et al.*, 2012) [11, 15]. Traditionally, it is prepared with ingredients such as milk, cream, sugar, stabilizers, and emulsifiers, offering approximately 200 kcal per 100 grams (Arslaner & Salık, 2017) [5]. While valued for its taste and energy content, consumer preferences have increasingly shifted towards healthier options (Bisla *et al.*, 2020; Muse & Hartel, 2004). The demand for low-calorie, high-protein, and functional foods has driven significant innovations in ice cream formulations (Akbari *et al.*, 2019) [4, 6, 16].

In response to these trends, ice cream manufacturers are integrating natural sweeteners, dietary fibers, and protein sources to enhance the nutritional profile of their products (Ahmed *et al.*, 2015; Abo-Srea *et al.*, 2017) [1, 2]. Ingredients like maltitol, fructooligosaccharides (FOS), and stevia are gaining popularity as sugar replacements due to their health benefits (Akalin *et al.*, 2018; Elango *et al.*, 2017; Khuenpet *et al.*, 2015) [3, 9, 14]. Additionally, high-protein ice creams enriched with ingredients such as milk protein concentrate (MPC) and whey protein isolate have demonstrated potential in improving the nutritional value without compromising sensory attributes (Daw & Hartel, 2015) [8]. Such innovations align with the broader market trend emphasizing clean labels and health-conscious food items.

The Indian ice cream market, valued at INR 228.6 billion in 2023, is projected to grow at a compound annual growth rate (CAGR) of 17.4% to reach INR 956 billion by 2032 (IMARC, 2024) [13]. Maharashtra leads with the highest market share, followed by Uttar Pradesh, Andhra Pradesh, Tamil Nadu, and Gujarat. Globally, New Zealand and the USA are the largest per capita consumers, highlighting ice cream's universal appeal (USDA, 2022) [21].

This strong demand reflects an opportunity for manufacturers to innovate with functional and value-added products (Sharma *et al.*, 2023; Swarup & Poonia, 2022) [20].

Research into ice cream and other food products fortified with functional ingredients has shown promising results (Vasundhara & Amrita, 2022) [22]. Studies demonstrate that protein-enriched ice creams with added plant extracts, dietary fibers, and natural antioxidants can enhance both nutritional content and sensory appeal (Gremski *et al.*, 2019) [12]. For instance, MPC effectively boosts protein levels, while FOS contributes prebiotic benefits, and stevia offers a natural, calorie-free sweetening alternative. These ingredients collectively improve viscosity and texture, making them ideal for reduced-fat formulations (El-Sayed *et al.*, 2021; Rashidi & Khosrowshahi, 2021) [10, 18].

Data collection and processing are crucial for developing new products and enhancing existing ones. Response Surface Methodology (RSM) plays a pivotal role in this process. RSM is valuable for optimizing factors to achieve optimal results. It is a robust and essential tool for data analysis, providing an adequate approximation of the relationship between input and output variables and identifying the optimal operating conditions for a system (Patel *et al.*, 2024; Chaudhari *et al.*, 2023) [7, 17].

Despite the advancements, limited research has explored the combined use of MPC, FOS, stevia, and maltitol in medium-fat, sugar-free ice cream. This study aims to bridge this gap by developing a protein-rich ice cream that meets consumer demands for healthier desserts. By optimizing ingredient proportions, the study intends to create a formulation with improved nutritional and sensory characteristics.

The objectives of this research include evaluating the feasibility of incorporating MPC and stevia into medium-fat ice cream, characterizing the optimized product for proximate composition, physico-chemical properties, and sensory attributes, and assessing its storage stability. This work not only contributes to the existing literature but also supports the growing market demand for innovative, health-focused frozen desserts.

Materials and methods

The study utilized a combination of carefully selected dairy and non-dairy ingredients to develop a protein-rich, sugar-free, medium-fat ice cream. Dairy ingredients included Full Cream Milk (FCM), Skimmed Milk Powder (SMP), and Milk Protein Concentrate (MPC-80), sourced from Vidya Dairy, Anand, and Dindigul Farm Product Pvt. Ltd., Tamil Nadu. Non-dairy ingredients included stevia (Pure Circle NSF-12), fructooligosaccharides (FOSSENCE L95), maltitol (SweetPearl® P200), and a stabilizer-emulsifier blend (KreAmaze MAJIK LFHP 2500-2), all procured from reputable suppliers. Vanilla flavouring and crystalline sugar were used for control samples. Analytical-grade reagents were employed for compositional and microbiological analysis. The final product was packaged in 55 mL High Impact Polystyrene (HIPS) cups with lids, designed for storage at -18±1°C.

The first phase of development of protein-rich, sugar-free, medium-fat ice cream involved optimization of MPC-80 (3-9%) and stevia (20-60 ppm) using RSM across 13 trials. The mix was preheated, homogenized (2000 psi, 500 psi), pasteurized (80°C, 5 minutes), aged (below 5°C, 6 hours), flavoured with vanilla, frozen, and packaged in HIPS cups. The optimized product was analyzed for its composition, calorific value, physico-chemical properties, sensory attributes, and microbiological quality.

Fat, protein, ash, and total solids were analyzed using standard methods, with carbohydrates calculated by difference. Viscosity, overrun, melting resistance, and hardness were measured, and microbiological analysis (APC, coliforms, YMC) adhered to BIS standards. Sensory evaluation used a modified ADSA scorecard under controlled conditions. Statistical methods ensured reliable results, with RSM optimizing MPC-80 and stevia, CRD analyzing physico-chemical, sensory, and microbial data, and Factorial CRD evaluating storage stability.

Results and discussion

The optimization of MPC-80 and stevia was based on sensory attributes and key parameters like fat, total solids, and melting resistance. Quadratic models with R^2 values ranging from 0.82 to 0.99 showed a strong fit, supported by significant F-values and non-significant lack of fit. Adequate precision values (7.51 - 45.25) exceeded the threshold of 4, confirming the model's reliability for optimizing the formulation of protein-rich, sugar-free, medium-fat ice cream.

Effect on colour & appearance score: The colour and appearance of ice cream significantly influence consumer perception and quality expectations. The colour and appearance scores ranged from 4.18 to 4.56 (out of 5), with the highest score given to the formulation containing 9% MPC-80, 20 ppm stevia, and 4.99% water, while the lowest score was for the formulation with 3% MPC-80, 20 ppm stevia, and 10.99% water (Table 1). A strong model fit was confirmed with an R^2 value of 0.89 (Table 2), an APV of 12.08, and a model F-value of 12.19. Linear coefficients of MPC-80 and stevia positively influenced the scores, while their interaction and quadratic effects negatively impacted the response.

Effect on flavour score: Flavour, a critical sensory attribute influencing product acceptability, had scores ranging from 40 to 41.67 (out of 45) for medium-fat ice cream (Table 1). The highest score was achieved by the formulation with 3% MPC-80, 60 ppm stevia, and 10.99% water, while the lowest scores were shared by formulations with 9% MPC-80, 20 ppm stevia, and 4.99% water, and 6% MPC-80, 40 ppm stevia, and 7.99% water. A moderate R^2 value of 0.82 (Table 2) indicates a reasonable model fit, supported by an APV of 8.93 and a significant model F-value of 6.48. MPC-80 negatively impacted flavour (-0.54), likely due to its proteinaceous taste, while stevia positively contributed (+0.35) to the flavour profile ($p<0.05$). Interaction and quadratic terms had negligible effects ($p \geq 0.1$). The variable interactions affecting flavour scores are depicted in 3D response surface plots in Figure 1.

Effect on body and texture: Body and texture, critical sensory attributes for product acceptability, had scores ranging from 25.25 to 27.67 (out of 30) for medium-fat ice cream (Table 1). The highest score was achieved by the formulation with 6% MPC-80, 40 ppm stevia, and 7.99% water, while the lowest score was for the formulation with 9% MPC-80, 20 ppm stevia, and 4.99% water. A high R^2 value of 0.9 (Table 2) confirms strong model reliability, supported by an APV of 11.43 and a significant model F-value of 12.76. Stevia significantly improved body and texture (+0.60, $p<0.05$), enhancing creaminess and structural integrity, while MPC-80 had a minor positive effect (+0.054). The interaction term (+0.54) amplified these effects ($p<0.05$). However, quadratic terms of MPC-80 (-0.29) and stevia (-0.66) indicated that excessive levels negatively impacted texture. The variable interactions are visualized through 3D response surface plots in Figure 1.

Effect on melting quality scores: Melting quality, a key evaluation criterion for frozen products, had scores ranging from 3.7 to 4.1 (out of 5) for medium-fat ice cream (Table 1). The highest score was achieved by the formulation with 6% MPC-80, 40 ppm stevia, and 7.99% water, while the lowest score was for the formulation with 3% MPC-80, 20 ppm stevia, and 7.99% water. A high R^2 value of 0.95 (Table 2) confirms strong model reliability, supported by an APV of 14.78 and a significant model F-value of 30.06. Melting quality showed minor positive contributions from MPC-80 (+0.06) and stevia (+0.05), with negligible interaction effects ($p<0.05$). Quadratic terms negatively impacted melting quality, underscoring the need for moderation in ingredient levels. Non-significant interactive effects between MPC-80 and stevia were also observed ($p \geq 0.1$). The variable interactions are visualized through 3D response surface plots in Figure 1.

Effect on total scores: The total score, reflecting the overall sensory quality of medium-fat ice cream, ranged from 88.61 to 91.99 (out of 100) (Table 1). The formulation with 6% MPC-80, 40 ppm stevia, and 7.99% water received the highest score, while the formulation with 9% MPC-80, 20 ppm stevia, and 4.99% water scored the lowest. A high R^2 value of 0.94 (Table 2) indicates strong model reliability, supported by an APV of 14.06 and a significant model F-value of 20.98. MPC-80 had a significant positive impact on the total score (+0.52, $p<0.05$), while stevia contributed minimally (+0.05). Negligible interactive and quadratic effects of both factors were observed ($p \geq 0.1$). The variable interactions are visualized through 3D response surface plots in Figure 1.

Effect on fat: Fat, a key component influencing both nutritional and sensory qualities of ice cream, ranged from 2.9% to 4.4% in medium-fat ice cream samples (Table 1). The highest fat content was observed in formulations with 9% MPC-80, 40 ppm stevia, and 4.99% water, and with 9% MPC-80, 60 ppm stevia, and 4.99% water. The lowest fat content was found in the formulation with 3% MPC-80, 20 ppm stevia, and 10.99% water. A moderate R^2 value of 0.81 (Table 2) and an APV of 7.51 indicate a reasonable model fit, supported by a significant model F-value of 6.16. MPC-80 had a strong positive impact on fat content (+3.73), while stevia contributed moderately (+0.50, $p<0.05$). Interaction and quadratic terms had minor effects. The variable interactions are visualized in 3D response surface plots in Figure 1.

Effect on total solids (TS): Total solids (TS), crucial for mouthfeel and structural integrity, ranged from 29.8% to 37.94% in medium-fat ice cream samples (Table 1). The highest TS content was observed in the formulation with 9% MPC-80, 40 ppm stevia, and 4.99% water, while the lowest was in the formulation with 3% MPC-80, 20 ppm stevia, and 10.99% water. An outstanding R^2 value of 0.99 (Table 2) and a high APV of 45.25 confirm the model's accuracy and robustness, supported by a significant model F-value of 213.98. MPC-80 significantly increased TS content (+0.26), while stevia had a minor negative effect (-0.11, $p \leq 0.05$). Minor negative effects were also observed at the interaction and quadratic levels for stevia and at the quadratic level for MPC-80 ($p \leq 0.1$). The variable interactions are visualized in 3D response surface plots in Figure 1.

Effect on melting resistance (MR): Melting resistance (MR), reflecting the structural stability of medium-fat ice cream, ranged from 0.97 to 1.93 ml/min (Table 1). The highest melting rate was observed in the formulation with 9% MPC-80, 20 ppm stevia, and 4.99% water, while the lowest rate was in the formulation with 3% MPC-80, 20 ppm stevia, and 10.99% water. An R^2 value of 0.95 (Table 2) and an APV of 17.19 confirm the model's accuracy and robustness, supported by a significant model F-value of 27.16. MR strongly depended on stevia (+1.02), which enhanced acceptability, while MPC-80 slightly reduced the melting rate (-0.36). Quadratic effects of stevia (-0.89) indicated potential drawbacks at higher levels. Significant linear effects of MPC-80 (negative) and stevia (positive), along with interaction terms, influenced MR ($p \leq 0.05$).

Optimization of product formulation for protein-rich, sugar-free, medium-fat ice cream

The optimization process for manufacturing protein-rich, sugar-free, medium-fat ice cream identified 5.95% MPC-80 and 40.96 ppm stevia as the optimal combination for achieving high sensory acceptance and favourable physicochemical properties. The RSM analysis yielded a desirability of 1.00 for the proposed solution. The final product, manufactured using this formulation, was validated through experimental results (n=7), confirming alignment with predicted values. Statistical validation using a 't' test (Table 3) showed no significant differences ($p>0.05$) between predicted and actual values, affirming the robustness of the optimization process.

Analysis of protein-rich, sugar-free, medium-fat ice cream

The protein-rich, sugar-free, medium-fat ice cream (T_1) outperformed medium-fat control (C1) and full-fat control (C2) in physico-chemical properties, with the highest overrun (95±0.71%), intermediate hardness (160±5), and improved melting resistance (1.73±0.08 ml/min), attributed to MPC-80. T1 also had the highest acidity (0.20±0.005%) and viscosity (109.00±2.24 cP), enhancing stability and quality. While FFC led in sensory scores (96.10±1.52) due to its high-fat content, T_1 performed competitively with a total sensory score of 90.60±2.88 and superior melting quality (4.00±0.00). Microbial analysis confirmed T1's compliance with acceptable standards, with no coliform or yeast and mold presence. These results, validated through statistical analysis (Table 4, Figure 1), establish T_1 as a nutritionally optimized, low-calorie ice cream alternative.

Table 1: Design matrix with the experimental data on sensory score and physico-chemical attributes of medium fat ice cream for response analysis

Run	A: MPC80 (%)	B: Stevia (ppm)	Sensory scores					Fat (%)	TS (%)	Melting rate (ml/min)
			Colour & appearance (5)	Flavour (45)	Body & texture (30)	Melting quality (5)	Total Score (100)			
1	9	60	4.36	40.80	27.50	3.90	91.56	4.4	37.90	1.32
2	6	40	4.53	40.67	27.67	4.00	91.87	4.2	34.22	1.70
3	6	40	4.55	40.67	27.67	4.10	91.99	4.2	34.22	1.70
4	6	40	4.46	40.67	27.00	4.09	91.21	4.2	34.22	1.70
5	6	40	4.54	41.00	27.00	4.06	91.60	4.2	34.22	1.70
6	6	40	4.51	40.00	27.50	4.01	91.02	4.2	34.22	1.70
7	9	40	4.45	40.25	27.25	3.97	90.92	4.4	37.94	1.78
8	6	60	4.47	40.89	27.25	3.97	91.58	4.2	34.06	1.20
9	6	20	4.38	40.25	26.00	3.85	89.48	4.2	33.20	1.57
10	3	40	4.29	41.65	26.75	3.85	91.54	4.0	31.77	1.19
11	3	60	4.47	41.67	26.50	3.75	91.38	3.1	30.60	1.28
12	3	20	4.18	41.00	26.43	3.70	90.31	2.9	29.80	0.97
13	9	20	4.56	40.00	25.25	3.80	88.61	4.3	36.57	1.93

Table 2: Coefficient's table and ANOVA of quadratic model for sensory and physico-chemical responses to different levels of ingredients for medium fat ice cream samples

Terms		Sensory properties					Physico-chemical properties		
		C & A	Flavour	B&T	MQ	Total Score	Fat%	TS%	MR (ml/min)
Intercept		4.50	40.61	27.34	4.05	4.27	34.29	1.67	91.50
Linear Level	MPC-80 (A)	0.07*	-0.54*	0.05	0.06*	0.52*	3.73*	0.26*	-0.36*
	Stevia (B)	0.03	0.35*	0.59*	0.05*	0.05	0.49*	-0.11*	1.02*
Interactive Effect	A x B	-0.12*	0.03	0.54*	0.01	-0.025	0.13	-0.23*	0.47*
Quadratic Level	A^2	-0.09*	0.32	-0.29	-0.13*	-0.25	0.37*	-0.12	-0.19
	B^2	-0.04	-0.06	-0.66*	-0.13*	-0.25	-0.85*	-0.22*	-0.89*
R^2		0.89	0.82	0.90	0.95	0.94	0.81	0.99	0.95
Model F-value		12.19	6.48	12.76	30.06	20.98	6.16	213.98	27.16
APV		12.08	8.93	11.43	14.78	14.06	7.51	45.25	17.19
Suggested Model		Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic
*: $p \leq 0.05$; APV= Adequate Precision Value; R^2= Coefficient of determination									
C & A: Colour and Appearance; B & T: Body & Texture; MQ: Melting quality; TS: Total Solids; MR: Melting rate									

Table 3: Comparison of predicted v/s actual values of responses used for process optimization of medium fat ice cream

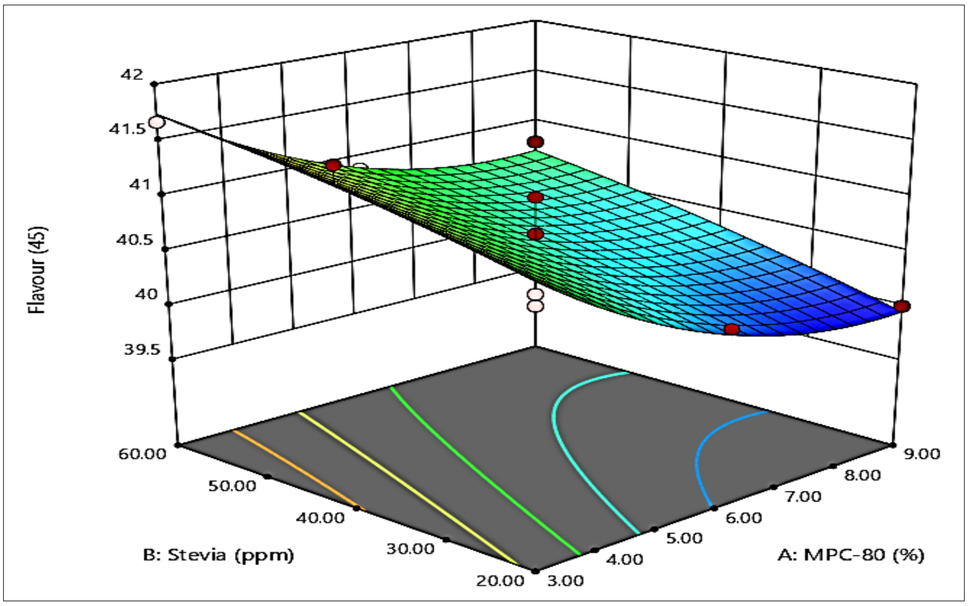
Sr. No.	Responses	Predicted value*	Actual value@	Cal. t-Value#	P Value	Level of Significance
1	Colour & appearance	4.50	4.36	0.96	0.38	NS
2	Flavour	40.63	39.86	1.08	0.29	NS
3	Body & Texture	27.37	26.86	0.84	0.41	NS
4	Melting quality	4.05	3.73	1.85	0.09	NS
5	Total score**	91.56	90.46	1.58	0.14	NS
6	Fat (%)	4.27	4.23	0.99	0.34	NS
7	Total Solids (%)	34.26	34.40	1.35	0.20	NS
8	Melting Rate (ml/ min)	1.66	1.57	1.48	0.17	NS
* Predicted values of Design Expert 13.0.5.0 package @ Actual values are average of seven trials for optimized product # t-values found non-significant at 5 per cent level of significance ** Maximum score for bacterial quality (15) has been added in total score NS = Non-significant; Tabulated t-value = 2.447 (cal. t-value less than tabulated value)						

Table 4: Comparison of protein-rich dairy spread with control spread

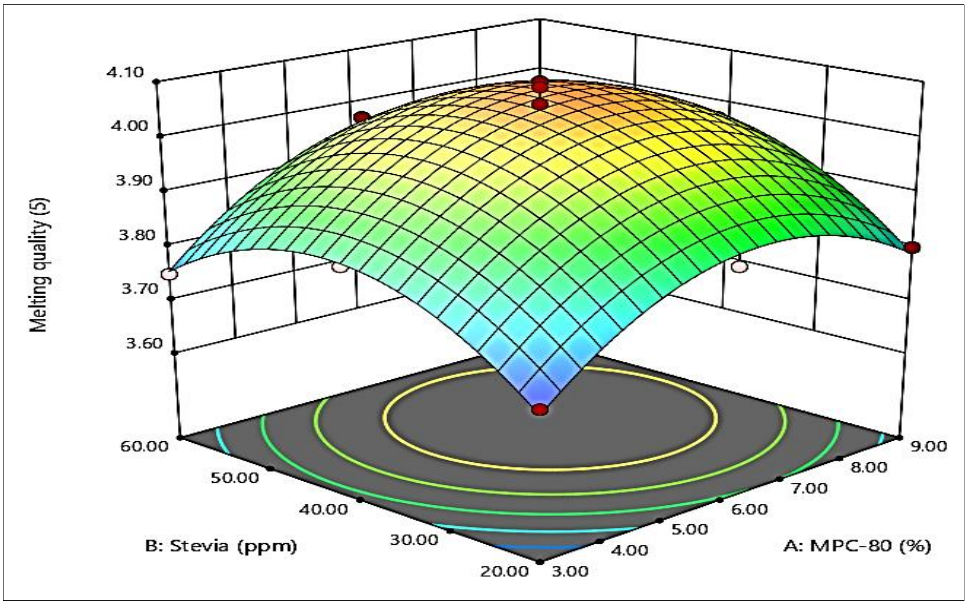
Particular	T_1	C_1	C_2	CD (0.05)
Proximate composition				
Fat (%)	4.28±0.01	6.05±0.03	13.03±0.02	0.03
TS (%)	34.29±0.02	34.13±0.02	39.07±0.04	0.04
Protein (%)	8.81±0.06	3.85±0.05	3.82±0.04	0.07
Ash (%)	0.91±0.01	0.74±0.05	0.75±0.01	0.04
Total Carbohydrate (%)*	20.28±0.06	23.49±0.10	21.46±0.07	0.11

Physico-chemical attributes				
Overrun (%)	95.00±0.71	87.80±1.92	93.80±0.84	1.76
Hardness (0.1 mm) **	160.00±5.00	148.40 ±6.35	180.20±3.27	6.94
Melting Resistance (ml/min)	1.73±0.08	1.92±0.08	1.49±0.09	0.12
Acidity of mix (%LA)	0.20±0.005	0.16±0.004	0.17±0.003	0.008
Viscosity of Mix (cP) at 20 °C	109.00±2.24	64.80±3.56	68.40±5.32	5.39
Sensory attributes				
Colour & appearance (Max. 05)	4.40±0.55	4.60±0.55	4.80±0.45	NS
Flavour (Max. 45)	41.00±1.41	41.60 ±1.14	43.30±0.55	1.51
Body & Texture (Max. 30)	26.20±1.64	26.40±1.52	28.60±0.89	1.92
Melting Quality (Max. 05)	4.00±0.01	3.80±0.84	4.30±0.67	NS
Total Score (Max. 100) #	90.60±2.88	91.40±3.78	96.10±1.52	3.97
Microbial analysis				
Aerobic Plate Count (log_{10}cfu/g)	3.64±0.02	3.59±0.03	3.57±0.03	0.035
Coliform Count	Absent/g			
Yeast & Mold Count	Absent/g			

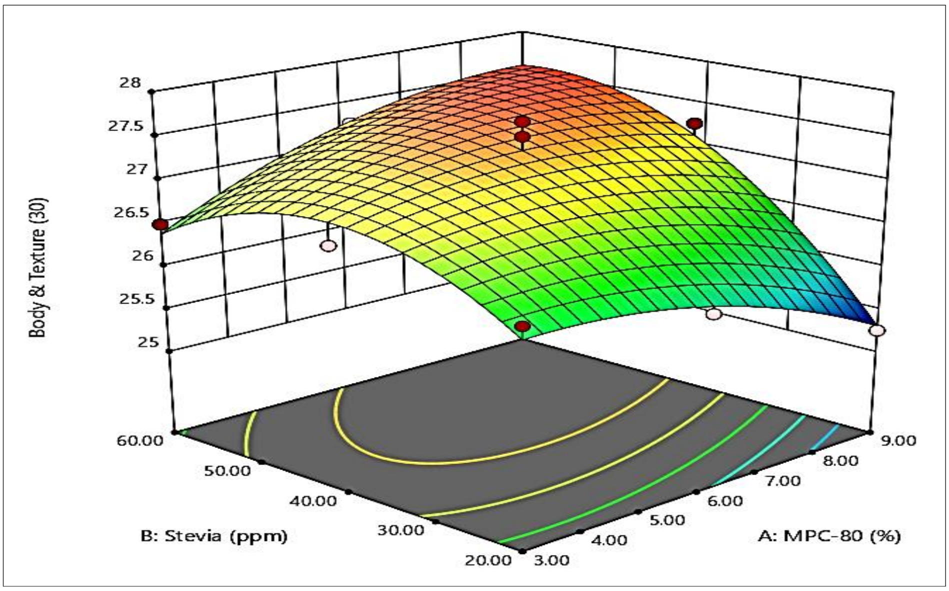
T_1- Optimized product; C_1- Medium fat control (MFC); C_2- Full fat control (FFC);
*- Calculated by difference; **- Hardness analyzed by cone penetrometer;
#- Total sensory score includes 15.0 for bacterial quality



a)

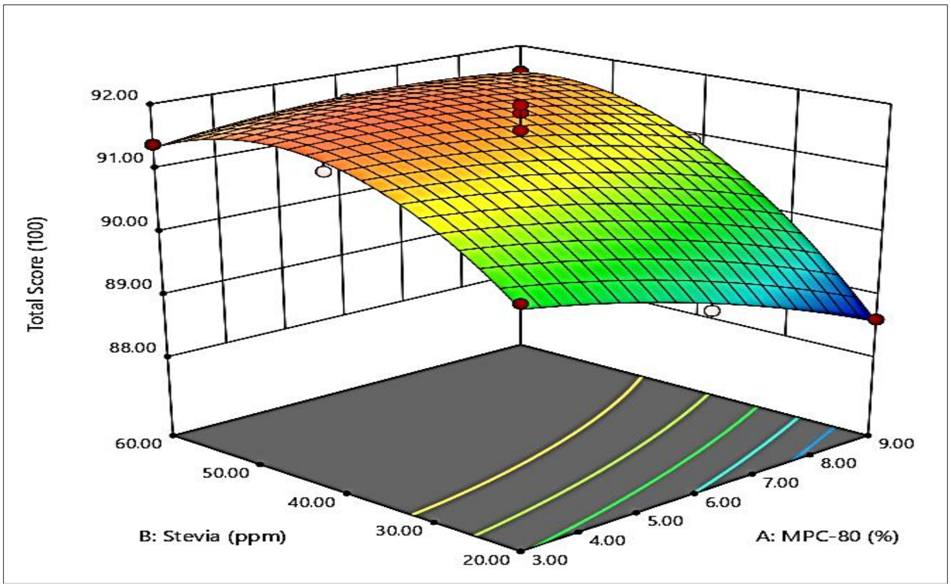


b)



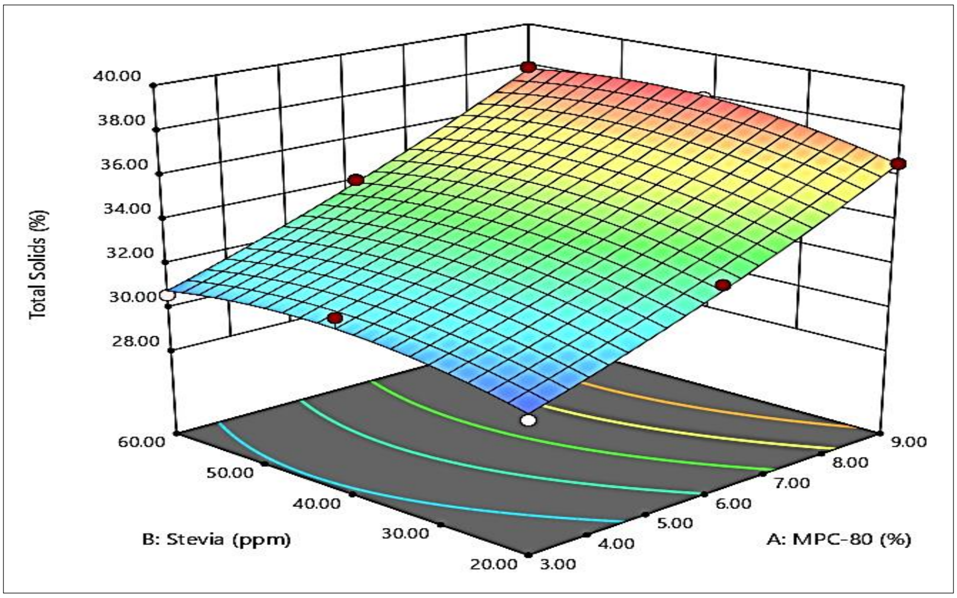
Body & Texture (30)
28
27.5
27
26.5
26
25.5
25
60.00
50.00
40.00
30.00
20.00
B: Stevia (ppm)
3.00
4.00
5.00
6.00
7.00
8.00
9.00
A: MPC-80 (%)

c)



Total Score (100)
92.00
91.00
90.00
89.00
88.00
60.00
50.00
40.00
30.00
20.00
B: Stevia (ppm)
3.00
4.00
5.00
6.00
7.00
8.00
9.00
A: MPC-80 (%)

d)



Total Solids (%)
40.00
38.00
36.00
34.00
32.00
30.00
28.00
60.00
50.00
40.00
30.00
20.00
B: Stevia (ppm)
3.00
4.00
5.00
6.00
7.00
8.00
9.00
A: MPC-80 (%)

e)

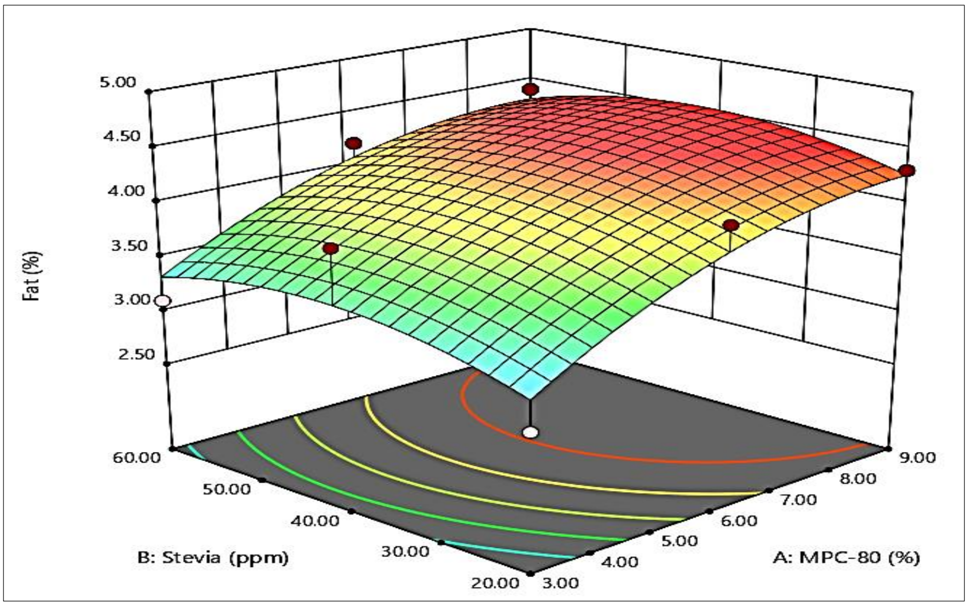


Fig 1: Influence of different variables on medium fat ice cream. a: Flavour, b: Melting quality, c: Body & texture, d: Total score, e: Total solids, f: Fat

Conclusion

A protein-rich, sugar-free, medium-fat ice cream (T_1) was developed using response surface methodology (RSM), optimizing MPC-80 and stevia levels to achieve a sensorially acceptable product. T_1 was compared to medium-fat-control (C1) and full-fat-control (C2) for proximate composition, sensory attributes, and quality parameters. T_1 demonstrated superior properties, including the highest overrun (95±0.71%), improved melting resistance (1.73±0.08 ml/min), and intermediate hardness (160±5), supported by enhanced acidity (0.20±0.005%) and viscosity (109.00±2.24 cP). These attributes, attributed to MPC-80 and functional ingredients, ensured structural and sensory quality. While FFC achieved the highest sensory scores due to its fat content, T_1 performed competitively, with strong scores in melting quality (4.00±0.00) and overall sensory acceptability (90.60±2.88). Slightly lower scores in colour and flavour for T_1 were attributed to its reduced fat content and the use of stevia. Microbiological analysis confirmed APC levels within acceptable limits, with no coliform or yeast and mold presence in any sample. Statistical validation revealed strong alignment between predicted and actual values for key parameters, confirming the reliability of the RSM optimization. These findings establish T_1 as a nutritionally optimized, low-calorie ice cream with excellent functional and sensory properties, as detailed in Table 4 and illustrated in Figure 1.

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