Indian J Dairy Sci 78(3): 208-215
https://doi.org/10.33785/IJDS.2025.v78i03.002

RESEARCH ARTICLE

Optimization of frozen yoghurt based on fat content and freezing temperature for superior sensorial attributes

Arijit Ray(✉), **PS Minz, Chitranayak, Hima John and HK Rohit**

Received: 18 July 2024 / Accepted: 21 November 2024 / Published online: 23 June 2025

Abstract: A beloved dairy desert with a long history, frozen yoghurt has garnered praise for its creamy and tangy flavour profile and is marketed as a refreshing substitute for traditional ice cream. The interaction of fat content and freezing temperature is acknowledged as a key factor influencing the sensory characteristics of frozen yoghurt. Even though these characteristics are very important, there is a major research gap since not much has been done to explicitly examine the best fat content and freezing temperature combination for frozen yoghurt. This study intends to close this gap by optimizing frozen yoghurt depending on fat content and ultimate temperature utilizing factorial design capabilities. For every sensory property, the model demonstrated great significance and accuracy (R^2e"88.96% and $p<0.05$). The model's forecast and the optimized frozen yoghurt were closely matched ($p>0.05$), also had the greater sensory qualities (more than 8.2). The optimized product was cohesive and chewy, with good springiness and mild firmness. It also confirmed microbiological safety criteria with a adequate total plate count (2.1×10^8 cfu/g) and non-detectable levels of mold, yeast, and coliform. The research offers a comprehensive grasp of the aspects impacting product quality, such as consistent sensory qualities, textural features, and microbiological safety, which is essential information for the industry. The results open the door to improved frozen yoghurt quality, satisfying customer demands, and promoting industrial improvements.

Dairy Engineering Division, ICAR-National Dairy Research Institute, Karnal-132001, India
Arijit Ray(✉)
Dairy Engineering Division, ICAR-National Dairy Research Institute, Karnal-132 001, India
E-mail: rayarijit300@gmail.com

Keywords: Factorial, Frozen yoghurt, Freezing, Optimization, Sensory, Texture profile analysis

Introduction

Within the category of frozen desserts, frozen yoghurt has become a popular dairy delicacy with a long history and a growing following as a preferred pleasure. Frozen yoghurt was first introduced as a healthier substitute for regular ice cream. Its creamy and tangy flavour profile has captured the attention of customers, and its living cultures are often commended for their apparent health advantages. With its delicious flavour and healthy benefits, this adaptable frozen treat has grown to be a popular option, reflecting changing consumer tastes for decadent but healthful sweets.

Owing to the bioactive peptides produced during fermentation, yoghurt intake has a variety of health advantages. These peptides have many benefits, such as immunomodulatory, antioxidant, and antihypertensive properties. Interestingly, yoghurt has been associated with increased resistance to respiratory infections and has shown effectiveness in treating gastrointestinal disorders including acute gastroenteritis and diarrhoea, as well as in avoiding common diseases like the cold and influenza (Gouda et al. 2021).

The texture and stability of frozen yoghurt are largely shaped by the freezing process. Low temperatures are given to the yoghurt product during the freezing process, which causes a phase shift from a liquid, gel network, or colloidal suspension to a mixed phase with ice crystals and a supersaturated solution (Alinovi et al. 2021). At lower freezing temperatures, there is less water activity and molecular mobility, which slows down the kinetics of deteriorative events such proteolysis and oxidation (Verdini and Rubiolo 2002). For frozen yoghurt to remain stable overall and to minimize quality losses, temperature and freezing rate must be carefully balanced. The sensory qualities of frozen yoghurt are also significantly impacted by freezing temperature, which is necessary for managing the size and formation of ice crystals. Frozen yoghurt's smoothness and general attractiveness by consumers are significantly impacted by the production of ice crystals (Giroux et al. 2023).

Frozen yoghurt has gained popularity as a healthier substitute for traditional ice cream in recent years due to growing consumer awareness of balanced diets. Its market presence has been facilitated by its nutritional advantages and sensory qualities, such as its low-fat content and live bacteria (Skryplonek et al. 2019).

Particularly in India, the dairy industry is essential to the country's economy. For rural areas, the dairy business provides a vital source of revenue due to its significant contributions to GDP and agricultural output. With a predicted rise from USD 1.69 to 2.14 billion at a CAGR of 3.5% from 2021 to 2025, the global frozen yoghurt industry is expected to flourish in this context. Similarly, from 2021 to 2026, the Indian market for frozen and flavoured yoghurt is expected to rise at a notable pace of 21.3% (Sajeev 2022).

Despite the increasing popularity of the frozen yoghurt market, one important aspect i.e. the optimization of important variables that affect product quality has gotten little attention. In particular, the interaction between fat percentage and the ultimate freezing point continues to be crucial in determining the sensory characteristics of frozen yoghurt. This study intends to close this gap by examining the relationship between fat content and ultimate freezing temperature and how best to produce frozen yoghurt of superior quality.

This study aims to provide important insights since there are now no regulatory criteria for the fat content of frozen yoghurt and little research on the best freezing conditions. To close the knowledge gap on the variables affecting frozen yoghurt quality, a thorough understanding of these elements has to be provided. This study aims to optimise fat content and freezing temperature, which might eventually help to improve the overall quality and market appeal of frozen yoghurt.

Materials and Methods

Preparation of yoghurt

In order to create varying fat content frozen yoghurt, several types of milk from the (From ICAR-National Dairy Research Institute, Model Dairy Plant, Karnal, Haryana, India) were initially employed in the yoghurt-making process, including skim milk (fat 0.5%), double toned (fat 1.5%), toned (fat 3.0%), standardized (fat 4.5%), and full cream milk (fat 6.0%). After that, the temperature of the milk was raised to 80 to 90°C. The milk was gradually cooled to 37°C, creating the perfect environment for the microbial colonies. The milk was then inoculated with cultures of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* (Freeze-dried Direct Vat Set Culture) culture obtained from a local supplier), and vigorous stirring ensured uniform dispersion (Tripathi et al. 2022). The resultant mixture was poured in a 240 ml frozen yoghurt mould which had 4 individual compartment of 60 ml, then it was placed in an incubator and allowed to ferment at 37°C for six hours (Ray et al. 2024).

Experimental procedure

After the yoghurt mix was fermented, the yoghurt mould was put into a domestic refrigerator for freezing, and the freezer was set to -23°C. Pt100 sensors (Thermonic Stainless Steel Temperature Sensor, Model: TH-PT100-D) were placed in the frozen yoghurt samples. the sensors were connected to data logger to obtain the temperature of samples. The yoghurt was frozen to various temperature ranging from -4 to -20°C at 4°C interval, which took almost 96 to 190 minutes to freeze in a domestic refrigerator.

Sensory analysis

Each frozen yoghurt samples of different trials were evaluated by 10 semi trained assessors panel. 9-point hedonic scale was used to evaluate the samples based on the different sensory attributes like colour, appearance, body and texture, flavour, melting resistance and overall acceptability. The frozen yoghurt samples were removed from the moulds by briefly contacting the mould walls with running tap water at normal temperature. This method facilitated the easy removal of the samples from the moulds. After removal, the samples were presented to the judges for evaluation.

Optimization process of frozen yoghurt

Factorial design was used for the optimization of frozen yoghurt based on sensory attributes using statistical software Design Expert Version 13. Full factorial design was used to observe the effect of the two factors on the sensorial attributes. The two factor, fat and freezing temperature coded as A and B. Their range and level are presented in Table 1. 25 trials were suggested by the design and different sensory attributes were taken like colour, appearance, body and texture, flavour, melting resistance and overall acceptability to get optimized frozen yoghurt based on these properties. Factorial model (2FI) was fitted for each of the responses. To obtain the optimized solution, the desirability of the factors was set within the specified range, and the desirability of the responses was configured to the maximum weight of importance. This approach ensures that the optimization process prioritizes achieving the best possible product characteristics and sensory attributes. The optimization method is aimed at improving the end product's sensory appeal within a quantitative goal range, which was defined by the lower and upper bounds for these variables.

Texture profile analysis (TPA) and microbial analysis of the optimized frozen yoghurt

For Texture Profile Analysis (TPA), TA.HDplusC (Stable Micro Systems, UK) with a 60 kg load cell and a perplex cylindrical probe with a diameter of 25 mm was used. The pretest speed was set at 2.0 mm/sec, the test speed at 5.0 mm/sec, the post-test speed at 5.0 mm/sec, and the distance was set at 6 mm for the measurements (Hussain et al. 2016). The frozen yoghurt samples were taken out of the mould and placed in a rectangular plate for TPA. Using the technique described by researchers (Cappuccino and Sherman 2011), the frozen yoghurt sample that had been improved was also put through microbiological investigations for total plate count, yeast and mold count, and coliform count.

Results and Discussion

Diagnostic check of the fitted model

Sequential regression analysis was used to create the 2FI models for the many sensory metrics, including colour, appearance, body and texture, flavour, melting resistance, and overall acceptability. Table 2 displays the partial coefficients of regression for these responses, expressed as correlations between the values of two components. The fitted 2FI model explained more than 88.96 to 95.76% of the variance in the experimental data, as shown by the significant model F-value for the characteristics and coefficient of determination (R^2) for all the responses ranged between 0.8896 to 0.9576. The relevance of the model in precisely predicting the replies was shown by the model F-value for each response which ranges from 28.77 to 44.76. For every answer, the adequate precision value, which calculates the signal-to-noise ratio, is more than four, which is extremely desired. For each answer, the model's P-value was less than 0.05, indicating that it was a significant predictor of the responses.

Effect on colour

The frozen yoghurt's colour score (Fig 1. a) varied from 4.5 to 8.7. The standard deviation was 1.37 and the average colour score was 6.41. At a freezing temperature of -8ºC and 0.5% fat content, the minimal colour score was achieved. In contrast, frozen yoghurt that was made with 6% fat content and a freezing temperature of -20 ºC obtained the highest colour score. The model was very significant, as shown by the R^2 of 0.9487 obtained from the regression analysis of the data in Table 2. Richer and more vivid colour was a result of the higher fat content. The milk matrix's fat globules were essential for light scattering, which gave the product an appearance of greater depth and opacity (Cheng et

Table 1 Full factorial design and sensory acceptance scores for different attributes of frozen yoghurt

Run	A:Fat %	B:Freezing temperature Degree Celsius	Colour	Appearance	Body and texture	Flavour	Melting resistance	Overall acceptability
1	3	-12	6.5	6.6	6.3	6.7	6.6	6.2
2	4.5	-12	7.5	7.7	7.5	7.5	7.3	7.5
3	0.5	-20	4.7	4.6	4.7	4.5	4.7	4.7
4	3	-4	5.4	5.9	5.5	5.5	5.5	5.6
5	0.5	-12	4.5	4.5	4.3	4.5	4.4	4.2
6	6	-8	7.4	7.4	7.4	7.6	7.6	7.5
7	3	-8	6.6	6.7	6.4	6.3	6.6	6.5
8	6	-4	7.2	7.3	7.3	7.3	7.4	7.4
9	6	-20	8.7	8.8	8.5	8.6	8.5	8.3
10	3	-20	6.6	6.3	6.2	6.4	6.4	6.5
11	4.5	-4	6.4	6.2	6.4	6.3	6.3	6.4
12	0.5	-8	4.5	4.3	4.3	4.3	4.4	4.8
13	0.5	-4	4.5	4.4	4.2	4.2	4.3	4.7
14	4.5	-20	8.6	8.6	8.6	8.7	8.5	8.8
15	1.5	-20	5.7	5.4	5.6	5.5	5.7	5.7
16	1.5	-16	5.8	5.5	5.7	5.4	5.5	5.6
17	1.5	-8	5.6	5.3	5.5	5.4	5.5	5.6
18	6	-12	8.4	8.4	8.4	8.5	8.2	8.2
19	4.5	-16	7.7	7.5	7.6	7.8	7.4	7.8
20	1.5	-12	5.5	5.8	5.7	5.6	5.6	5.6
21	6	-16	8.4	8.8	8.5	8.4	8.3	8.7
22	1.5	-4	5.5	5.5	5.4	5.9	5.5	5.6
23	3	-16	6.5	6.5	6.5	6.3	6.7	6.3
24	4.5	-8	7.5	7.3	7.6	7.6	7.4	7.4
25	0.5	-16	4.6	4.5	4.5	4.7	4.3	4.6

al. 2019). Emulsified fat gave the frozen yoghurt a smooth and creamy texture that visually enhanced the overall colour profile.

$$Colour = 6.41-1.85A[1]-0.792A[2]-0.092A[3]+1.13A[4]-0.612B[1]-0.092B[2]+0.068B[3]+0.188B[4]$$

Where $A[1]$ to $A[4]$ and $B[1]$ to $B[4]$ are the specific levels of the fat content and product temperature which were used in the factorial design.

Moreover, the development of ice crystals within the frozen yoghurt structure was impacted by the usage of higher freezing temperatures. A rougher and less aesthetically pleasing texture may result from bigger ice crystals forming after freezing at a lower temperature. Higher freezing temperatures, on the other hand, may encourage the development of smaller ice crystals, giving the texture a creamier, smoother consistency (Mo et al. 2019). The frozen yoghurt had an appealing look due to its rich colour and smoother texture, which were both attributed to its increased fat content.

Effect on appearance

Frozen yoghurt had an appearance score (Fig 1. b) ranging from 4.3 to 8.8. 6.39 was the average appearance score, with a 1.43 standard deviation. At a freezing temperature of -8ºC and 0.5% fat content, the minimal appearance score was achieved. Conversely, the frozen yoghurt that was produced at a freezing temperature of -20 ºC and 6% fat content received the highest appearance score. The model was very significant, as shown by the R^2 of 0.9359, which was found in the regression analysis of the data in Table 2. Additional statistical analysis revealed that the model provided a good fit to the data; the model's F-value of 28.92 suggests that it is significant ($p<0.05$). The increased fat level makes the creaminess more noticeable and gives the frozen yoghurt a luxurious and enticing look. Higher fat content also affected how light is reflected and absorbed, giving the hue a deeper, more brilliant appearance that improved the overall appearance (Huppertz et al. 2020). This creamy quality from the higher fat level together with its refined texture added a great deal to the frozen yoghurt's overall visual appeal. The final appearance equation, as determined by the coefficient table, is

$$Appearance = 6.39-1.93A[1]-0.892A[2]+0.008A[3]+1.07A[4]-0.532B[1]-0.192B[2]+0.208B[3]+0.168B[4]$$

Effect on body and texture

The frozen yoghurt's body and texture scores (Fig 1. c) varied from 4.2 to 8.6. 6.34 was the average body and texture score. At a freezing temperature of -4ºC and 0.5% fat content, the minimal body and texture score was achieved. On the other hand, frozen yoghurt made with 4.5% fat content and a freezing temperature of -20 ºC obtained the highest body and texture score. The model was very significant, as shown by the R^2 of 0.9572 obtained from the regression analysis of the data in Table 2. Additional statistical analysis revealed that the model provided a good fit to the data; the model's F-value of 44.76 suggests that it is significant ($p<0.05$). The creaminess and stability of the frozen yoghurt's body and texture were further enhanced by the increasing fat content. As an emulsifier, fat improved mouthfeel overall and keeps water from separating during freezing, which may cause unwanted ice crystallization (Mu et al. 2022). The combination of fat content and freezing temperature guaranteed a finished product with a cohesive and well-balanced texture. The body and texture final equation is based on the coefficient table is

$$\begin{aligned} Body\ and\ texture\ = {} & 6.34 - 1.94A[1] - 0.764A[2] - 0.164A[3] \\ & + 1.2A[4] - 0.584B[1] - 0.104B[2] \\ & + 0.096B[3] + 0.216B[4] \end{aligned}$$

Effect on flavour

The frozen yoghurt's flavour score (Fig 1. d) varied from 4.2 to 8.7. The flavour score had an average of 6.38 and a standard deviation of 1.43. At a freezing temperature of -4ºC and 0.5% fat content, the lowest flavour score was achieved. On the other hand, frozen yoghurt made with 4.5% fat content and a freezing temperature of -20 ºC earned the highest flavour score. The R^2 for the data in Table 2's regression analysis was 0.8896, indicating that the model was very significant. Additional statistical analysis revealed that the model provided a good fit to the data; the model's F-value of 40.29 suggests that it is significant ($p<0.05$). The likelihood of noise producing a model F-value this high was about 0.01%. Increased fat content in frozen yoghurt, which was typically attained by using higher fat content ingredients like full cream milk, enhanced the product's mouthfeel and richness. Fat is recognized as a carrier of flavour compounds, acting as a medium for the dissolution and dispersion of aromatic substances thereby contributing to the overall taste qualifications. In addition to giving the yoghurt a creamy texture, the increased fat content enhanced and interacted with its natural tastes (Dias et al. 2020; Mohan et al. 2021). This is especially important for frozen yoghurt since the freezing process may often make tastes seem less intense. The fat enhanced the flavour of the frozen yoghurt by giving it a smoother, more prominent taste profile, which increased the indulgence and pleasure of the dessert as a whole. Based on the coefficient table the final equation for flavour is

$$Flavour\ = 6.38 - 1.94A[1] - 0.82A[2] - 0.14A[3] + 1.2A[4]$$

Effect on melting resistance

The melting resistance score (Fig 1. e) of frozen yoghurt varied from 4.3 to 8.5. The average melting resistance score was 6.34. The minimal melting resistance score was achieved at 0.5% fat content and ultimate temperature of -4ºC. Whereas, frozen yoghurt manufactured with process parameters 4.5% fat content and ultimate temperature of -20 ºC got greatest melting resistance score. The model was very significant, as shown by the R^2 of 0.9487 obtained from the regression analysis of the data in Table 2. Further the statistical analysis found that the model matched the data well, the model F-value 42.87 suggests that the model is significant (*p<0.05*). When exposed to greater temperatures, frozen yoghurt retained its structural integrity for a longer duration due to the synergy between increased fat content and higher freezing temperatures. Consumers can indulge in frozen yoghurt for longer without sacrificing its quality because of the product's improved resistance to melting, which was produced by the stabilized emulsion that fat provides and the regulated ice crystal formation at higher freezing temperatures (Sitnikova and Tvorogova 2019; Zhao et al. 2023). Based on the coefficient table the final equation for melting resistance is

$$\begin{aligned} Melting\ resistance \ = \ & 6.344 - 1.924A[1] - 0.784A[2] \\ & + 0.016A[3] + 1.036A[4] - 0.544B[1] \\ & - 0.044B[2] + 0.076B[3] + 0.096B[4] \end{aligned}$$

Effect on overall acceptability

Frozen yoghurt had an overall acceptance (Fig 1. f) score ranging from 4.2 to 8.8. 6.41 was the average overall acceptability score. With a freezing temperature of -12ºC and a fat content of 0.5%, the minimal overall acceptability score was achieved. The greatest colour and overall acceptability score were found in frozen yoghurt manufactured with process parameters of 4.5% fat content and a freezing temperature of -20 ºC. The R^2 for the data in Table 2's regression analysis was 0.935, indicating that the model was very significant. Additional statistical analysis revealed that the model provided a good fit to the data; the model's F-value of 28.77 suggests that it is significant (*p<0.05*). A harmonic balance between creaminess, smoothness, and taste intensity was ensured by the combination of greater freezing temperatures and increased fat content. Together, these elements affected how well-liked frozen yogurt is by customers, who generally choose products with a flavour profile that is balanced, a texture that is attractive, and a resistance to unfavourable

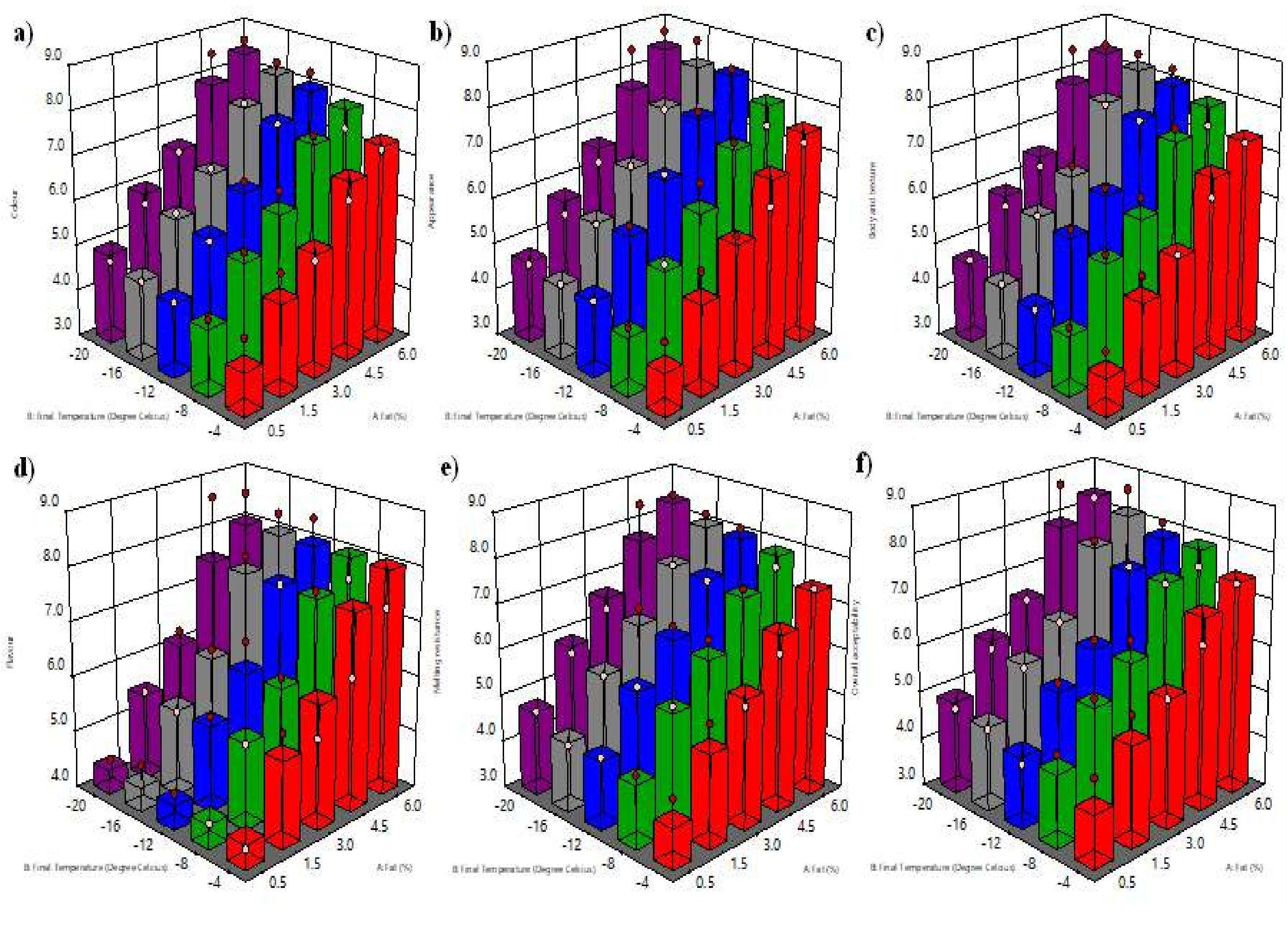

Fig 1. 3D surface plots for different sensory attributes as influenced by the two factors

qualities like iciness or melting quickly. Based on the coefficient table the final equation for overall acceptability is

$$Overall\ acceptability = 6.408 - 1.808A[1] - 0.788A[2] - 0.188A[3] + 1.172A[4] - 0.468B[1] - 0.048B[2] - 0.068B[3] + 0.192B[4]$$

Optimized solution for frozen yoghurt

The main objective (Table 3) was to make sure that the fat content and freezing temperature were within the designated limits (0.5 to 6% fat content and -4 to –20ºC freezing temperature, respectively), with each element having equal weight. In order to get the required frozen yoghurt qualities, this suggests a balanced consideration of these aspects.

With a weight of 5, these characteristics were given a greater relevance level, indicating their crucial involvement in influencing the frozen yoghurt's overall quality and acceptability by consumers.

Based on the requirements, an optimized solution with a freezing temperature of -20ºC and a fat content of 6% was provided for frozen yoghurt. With a desirability of 0.93 (Fig. 2), the optimized

Table 2 Regression coefficient and ANOVA of fitted model for sensorial attributes of frozen yoghurt

Partial coefficient	Colour	Appearance	Body and texture	Flavour	Melting resistance	Overall acceptability
Intercept	6.412	6.392	6.344	6.38	6.344	6.408
A[1]	-1.852**	-1.932**	-1.944**	-1.94**	-1.924**	-1.808**
A[2]	-0.792**	-0.892**	-0.764**	-0.82**	-0.784**	-0.788**
A[3]	-0.092**	0.008**	-0.164**	-0.14**	0.016**	-0.188**
A[4]	1.128**	1.068**	1.196**	1.2**	1.036**	1.172**
B[1]	-0.612**	-0.532**	-0.584**		-0.544**	-0.468*
B[2]	-0.092	-0.192**	-0.104**		-0.044**	-0.048*
B[3]	0.068**	0.208**	0.096**		0.076**	-0.068*
B[4]	0.188**	0.168**	0.216**		0.096**	0.192*
Model F-value	37.01	28.92	44.76	40.29	42.87	28.77
R^2	0.9487	0.9353	0.9572	0.8896	0.9554	0.935
APV	19.828	17.0111	21.3233	15.5892	21.3463	16.7855

** $p < 0.05$, * $0.05 \leq p > 0.1$ and A[1] to A[5] and B1[to B[5] represents the specific levels of the fat content and product temperature

Table 3 Goal set for constraints for optimized production of frozen yoghurt

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Fat	is in range	0.5	6	1	1	3
B: Freezing temperature	is in range	-4	-20	1	1	3
Colour	maximize	4.5	8.7	1	1	5
Appearance	maximize	4.3	8.8	1	1	5
Body and texture	maximize	4.2	8.6	1	1	5
Flavour	maximize	4.2	8.7	1	1	5
Melting resistance	maximize	4.3	8.5	1	1	5
Overall acceptability	maximize	4.2	8.8	1	1	5

Table 4 Comparison of predicted and observed sensorial attributes (scores) of frozen yoghurt

Parameters	Predicted	Actual	t-test value
Colour	8.5	8.7	0.423 (NS)
Appearance	8.5	8.7	0.423 (NS)
Body and texture	8.4	8.3	0.728 (NS)
Flavour	8.1	8.2	0.728 (NS)
Melting resistance	8.4	8.3	0.728 (NS)
Overall acceptability	8.4	8.3	0.728 (NS)

*NS means the predicted and actual scores are not significantly different

Table 5 Texture profile analysis (TPA) and microbial count of optimized frozen yoghurt

Analysis	Parameter	Value
TPA	Hardness (g)	51.63±0.15
	Cohesiveness	0.39±0.01
	Adhesiveness (g)	-1.34±0.04
	Springiness (mm)	1.03±0.02
	Gumminess (g)	25.77±0.1
Microbial	Total plate count (cfu/g) $\times 10^8$	2.1
	Yeast and mold (cfu/g) $\times 10^4$	ND
	Coliform count	ND

trial performed very well in terms of obtaining tightly matched data. The frozen yoghurt was prepared using the optimized approach, which demonstrated that the predicted values nearly matched the real values for every sensory metric (Table 4). This suggests that the expected and actual results for these sensory qualities are very consistent. According to the t-test results, there was no statistically significant difference between these groups (*p>0.05*). Overall concordance between expected and actual values suggests that the sensory qualities of the frozen yoghurt were well anticipated by the optimization experiment. Thus, it was determined that the ideal freezing temperature and fat content level for creating frozen yoghurt with the best sensory qualities was -20°C and 6% respectively.

TPA and microbial count analysis of optimized frozen yoghurt

The combined TPA parameters (Table 5) provide a comprehensive description of the texture characteristics of the frozen yoghurt. The measured results pointed to a moderately hard frozen yoghurt with a balanced resistance to compression. A sample that rebounded from deformation to its original condition was indicated by a good springiness rating, which enhanced the eating experience. The cohesive and chewy texture of the frozen yoghurt was further highlighted by the stated gumminess value.

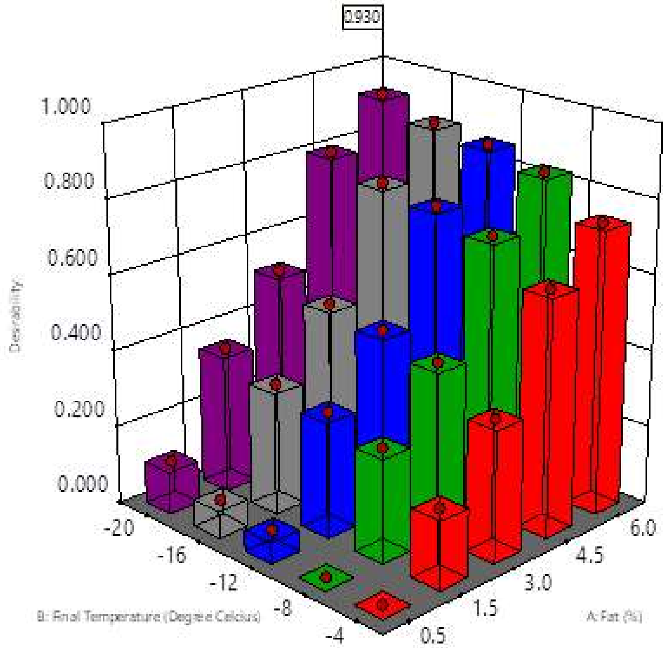

Fig 2. Desirability plot for optimized solution for frozen yoghurt

The overall plate count of 2.1×10^8 cfu/g (Table 5) indicated a reasonably adequate microbial load in the frozen yoghurt in terms of microbiological quality. Moreover, coliform counts, yeast, and mold were reported as non-detectable levels. The frozen yoghurt had been made under sanitary settings and satisfied microbial safety criteria, as evidenced by the collective microbiological parameters.

Conclusion

In summary, the goal of this study was to maximize the sensory qualities of frozen yoghurt by examining the relationship between fat content and freezing point. Significant prediction was shown by the 2FI models produced by stepwise regression analysis for a number of sensory measures, such as colour, appearance, body and texture, taste, melting resistance, and overall acceptability (R2≥88.96%, p<0.05). Dairy foods, especially frozen yoghurt, have a greater fat content, which is responsible for improving colour and appearance. Higher freezing temperatures simultaneously affected the creation of ice crystals, which changed the texture. Larger ice crystals with a rougher structure resulted from lower freezing temperatures. A larger fat level improved the creaminess and brilliance of the colour of the frozen yoghurt, adding to its visual appeal. The sense of natural tastes was enhanced by the higher fat content, resulting in a smoother and more distinct flavour profile. The frozen yoghurt exhibited improved resistance to melting due to its structural integrity being preserved by the combination of a higher fat content and freezing temperatures. The equilibrium of smoothness, flavour intensity, and creaminess all contributed to the frozen yoghurt's general appeal. The highly consistent ($p>0.05$) predicted and actual results of the improved frozen yoghurt validated the optimization trial's (Fat: 6%; Freezing temperature: -20ºC) efficacy in correctly improving the frozen yoghurt's sensory qualities. The product had a cohesive, chewy texture, good springiness, and a moderate level of hardness, according to the TPA values. microbiological examination demonstrated non-detectable amounts of mold, coliform, and yeast, along with a reasonable total plate count (2.1×10^8 cfu/g), demonstrating that frozen yoghurt is produced under hygienic circumstances and in compliance with microbiological safety regulations. Thus, by taking into account the relationship of fat content and ultimate freezing temperature, this study effectively improved frozen yoghurt, improving both product quality and consumer satisfaction.

Acknowledgement

The authors are thankful to the Indian Council of Agricultural Research (ICAR) and National Dairy Research Institute, Karnal for providing the necessary facilities to conduct this study.

Funding

The study was financially supported by Indian Council of Agricultural Research (ICAR) and National Dairy Research Institute, Karnal

Conflict of interest

The authors declare that they have no conflicts of interest.

References

Alinovi M, Mucchetti G, Wiking L, Corredig M (2021) Freezing as a solution to preserve the quality of dairy products: the case of milk, curds and cheese. Critical Rev Food Sci Nutr 61:3340–3360. https://doi.org/10.1080/10408398.2020.1798348

Cappuccino JG, Sherman N (2011) Microbiology: A Laboratory Manual. Benjamin Cummings. Pearson Higher Ed.

Cheng N, Barbano DM, Drake MA (2019) Effect of pasteurization and fat, protein, casein to serum protein ratio, and milk temperature on milk beverage color and viscosity. J Dairy Sci 102:2022–2043

Dias PGI, Sajiwani JWA, Rathnayaka R (2020) Consumer perception and sensory profile of probiotic yogurt with added sugar and reduced milk fat. Heliyon *6*(7)

Giroux HJ, Britten M, Gentès M-C (2023) Effects of milk fat substitution by canola oil on the properties of high-fat high-protein yoghurt. Int Dairy J 142:105653. https://doi.org/10.1016/j.idairyj.2023.105653

Gouda AS, Adbelruhman FG, Sabbah Alenezi H, Mégarbane B (2021) Theoretical benefits of yogurt-derived bioactive peptides and probiotics in COVID-19 patients – A narrative review and hypotheses. Saudi J Biol Sci 28:5897–5905. https://doi.org/10.1016/j.sjbs.2021.06.046

Huppertz T, Uniacke-Lowe T, Kelly AL (2020) Physical Chemistry of Milk Fat Globules. In: McSweeney PLH, Fox PF, O'Mahony JA (eds) Advanced Dairy Chemistry, Volume 2. Springer International Publishing, Cham, pp 133–167

Hussain SA, Patil GR, Yadav V, Bijoy Singh RR, Singh AK (2016) Ingredient formulation effects on physico-chemical, sensory, textural properties and probiotic count of *Aloe vera* probiotic *dahi*. LWT - Food Sci Technol 65:371–380. https://doi.org/10.1016/j.lwt.2015.08.035

Mo J, Groot RD, McCartney G, Guo E, Bent J, van Dalen G, Schuetz P, Rockett P, Lee PD (2019) Ice crystal coarsening in ice cream during cooling: A comparison of theory and experiment. Crystals 9:321

Mohan MS, O'Callaghan TF, Kelly P, Hogan SA (2021) Milk fat: opportunities, challenges and innovation. Critical Rev Food Sci Nutri 61:2411–2443. https://doi.org/10.1080/10408398.2020.1778631

Mu S, Ren F, Shen Q, Zhou H, Luo J (2022) Creamy mouthfeel of emulsion-filled gels with different fat contents: Correlating tribo–rheology with sensory measurements. Food Hydrocolloids 131:107754

Ray A, Minz PS, Sinha C (2024) Framework for accurate estimation of freezing time and convective heat transfer coefficient for freezing of a food product in domestic refrigerator: a numerical and simulation modeling approach. Multiscale and Multidiscip Model Exp and Des. https://doi.org/10.1007/s41939-024-00533-0

Sajeev MS (2022) Probiotic Rich Frozen Yogurt. Magazine article on Probiotic Rich Frozen Yogurt.

Sitnikova PB, Tvorogova AA (2019) Physical changes in the structure of ice cream and frozen fruit desserts during storage. Food systems 2:31–35

Skryplonek K, Henriques M, Gomes D, Viegas J, Fonseca C, Pereira C, Dmytrów I, Mituniewicz-Ma³ek A (2019) Characteristics of lactose-free frozen yogurt with ê-carrageenan and corn starch as stabilizers. J Dairy Sci 102:7838–7848. https://doi.org/10.3168/jds.2019-16556

Tripathi AD, Kumar P, Agarwal A (2022) Optimization of biofunctional jaggery yogurt: It's physicochemical and antioxidant properties. Indian J Dairy Sci 75

Verdini R a., Rubiolo A c. (2002) Effect of Frozen Storage Time on the Proteolysis of Soft Cheeses Studied by Principal Component Analysis of Proteolytic Profiles. J Food Sci 67:963–967. https://doi.org/10.1111/j.1365-2621.2002.tb09436.x

Zhao M, Chen L, Liu F, Zhong F, Chen M, Jin H, Kang J, Wu J, Xu J (2023) The impact of glycerol monostearate's similarity to fats and fatty acid composition of fats on fat crystallization, destabilization, and texture properties of ice cream. J Sci Food Agric 103:6837–6848. https://doi.org/10.1002/jsfa.12768