RESEARCH PAPER

Development of Dairy-Free Ice-cream Using Microencapsulated Natural Sweeteners

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ABSTRACT

The present study focuses on the development of dairy-free ice cream using microencapsulated natural sweeteners as a healthier alternative to conventional frozen desserts. Increasing consumer awareness regarding lactose intolerance, diabetes, and the demand for plant-based foods has driven the need for innovative formulations that are both nutritious and sensory acceptable. Coconut milk was used as the primary base due to its high fat content and ability to mimic the creamy texture of dairy ice cream. Stevia, a natural high-intensity sweetener, was selected to replace refined sugar; however, its inherent bitterness posed a major challenge. To overcome this limitation, microencapsulation technology was employed using maltodextrin and gum Arabic as wall materials. The encapsulated sweetener was incorporated into four different formulations (T1–T4) along with inulin as a functional ingredient to improve texture and dietary fiber content. The developed ice cream samples were evaluated for physicochemical properties, nutritional composition, sensory characteristics, and shelf-life stability. The results indicated that microencapsulation significantly improved the sensory profile by masking bitterness and enhancing sweetness perception. Among the formulations, T3 exhibited the highest overall acceptability with improved viscosity, overrun, and melting resistance. Nutritional analysis revealed reduced sugar content and increased dietary fiber, making the product suitable for health-conscious consumers. Shelf-life studies confirmed stability up to 21 days under frozen storage conditions. Overall, the study demonstrates that microencapsulation is an effective strategy for enhancing the quality of dairy-free ice cream, providing a promising approach for the development of functional, clean-label frozen desserts with potential for commercialization.

Keywords: Dairy-free ice cream, Microencapsulation, Natural sweeteners, Sensory evaluation, Shelf-life stability, Functional food.

How to cite this article: Angel Dharshini A, Kishore T, Ragul K, Rubadharshan GR, Mahesh S, Murugesan A, Rameshwari M, Kalpana VP, Sowntharya M, Sundarraj AA, Jamunasri N. Development of Dairy-Free Ice-cream Using Microencapsulated Natural Sweeteners. Int J Drug Deliv Technol. 2026;16(54s):1695-1706. DOI: 10.25258/ijddt.16.54s.161

Source of support: Nil.

Conflict of interest: None.

1 INTRODUCTION

The global food sector is undergoing a transformative shift driven by increasing consumer awareness of health, sustainability, and ethical considerations. Over the past decade, there has been a rapid increase in the demand for plant-based and functional foods, particularly in the dairy alternatives segment. This shift is largely attributed to the rising prevalence of lactose intolerance, milk allergies, veganism, and lifestyle-related diseases such as obesity and diabetes. Ice cream is one of the most popular frozen desserts worldwide, traditionally made using milk, cream, sugar, and stabilizers. While it is highly appreciated for its creamy texture, rich flavor, and smooth mouthfeel, conventional ice cream is also associated with high levels of saturated fat and added sugars. These factors have raised concerns among health-conscious consumers, leading to the exploration of healthier alternatives. Dairy-free ice cream has emerged as a promising substitute, utilizing plant-based ingredients such as coconut milk, almond milk, soy milk, and oat milk. Among these, coconut milk is widely preferred due to its high fat content, which closely mimics the creaminess of dairy-based ice cream. However, despite its advantages, dairy-free ice cream often fails to match the sensory and structural properties of conventional ice cream. Simultaneously, the reduction of refined sugar in food products has become a major focus area in food research and development. Natural sweeteners, particularly stevia (Stevia rebaudiana), have gained significant attention due to their high sweetness intensity and negligible caloric contribution. However, the direct use of stevia in food systems often results in undesirable sensory effects such as bitterness and lingering aftertaste, which negatively impact consumer acceptance.

To address these challenges, innovative technologies such as microencapsulation are being explored. Microencapsulation involves the coating of active ingredients with protective materials to enhance stability, mask undesirable flavors, and enable controlled release. This study integrates microencapsulation technology with dairy-free ice cream formulation to improve the sensory and functional properties of the product.

Dairy-Free Ice Cream: Concept, Market Trends, and Importance:

Dairy-free ice cream refers to frozen desserts that do not contain any milk or milk-derived ingredients. These products are specifically designed for individuals who are lactose intolerant, allergic to dairy proteins, or following vegan diets. The increasing demand for such products has led to significant growth in the plant-based food market. From a nutritional perspective, dairy-free ice creams provide several notable advantages. They are naturally free from lactose, making them an ideal option for individuals with lactose intolerance. Additionally, these products typically contain lower levels of cholesterol compared to conventional dairy-based ice creams. Dairy-free formulations also allow for the incorporation of functional ingredients such as dietary fibers and antioxidants, enhancing their health benefits. Furthermore, they can be easily customized to meet specific dietary requirements, including low-calorie or diabetic-friendly variations, thereby catering to a wide range of consumer needs.

From an environmental standpoint, plant-based products are considered more sustainable, as they generally require fewer natural resources such as water and land, and produce lower greenhouse gas emissions compared to dairy farming. Despite these benefits, the formulation of dairy-free ice cream presents significant technological challenges. The absence of milk proteins, which play a crucial role in emulsification and structure formation, often results in products with inferior texture and stability.

Limitations and Challenges in Dairy-Free Ice Cream

Despite the growing popularity of dairy-free ice cream, several limitations continue to affect its overall quality and consumer acceptance. One of the primary challenges lies in achieving desirable texture. In conventional ice cream, milk proteins play a crucial role in forming stable emulsions and contributing to a smooth, creamy mouthfeel. In their absence, dairy-free alternatives often suffer from low viscosity, resulting in a thinner consistency. Additionally, these products may exhibit poor body and weak structural integrity, which negatively impacts their ability to incorporate and retain air during freezing. This reduced air incorporation, known as low overrun, leads to a denser product that lacks the light and creamy characteristics expected by consumers. Another significant limitation is related to melting behavior and sensory quality. Dairy-free ice creams generally have weaker structural networks due to the absence of casein and milk fat, which are essential for stabilizing the frozen matrix. As a result, these products tend to melt more rapidly, leading to a loss of shape and an unsatisfactory eating experience. Furthermore, the sensory attributes of plant-based ice creams often differ from those of traditional dairy products. The use of plant-based ingredients such as coconut, almond, or soy can introduce distinct flavors that may not align with consumer expectations of conventional ice cream. This difference in flavor profile, along with possible textural inconsistencies, can reduce overall acceptability, particularly among consumers accustomed to dairy-based products. In addition to these challenges, replacing sugar in dairy-free ice cream formulations presents a complex technological issue. Sugar is not only responsible for sweetness but also plays multiple functional roles, including lowering the freezing point, improving texture, and enhancing flavor perception. When sugar is substituted with high-intensity natural sweeteners, these functional properties are often compromised. This can lead to harder textures, improper freezing behavior, and diminished flavor quality. Consequently, developing dairy-free ice cream that successfully balances sweetness, texture, and stability remains a significant challenge, emphasizing the need for innovative formulation strategies and the use of suitable stabilizers and bulking agents to improve product quality.

Natural Sweeteners: Importance and Functional Role

Natural sweeteners have gained considerable attention in recent years as healthier alternatives to refined sugar, largely driven by increasing consumer awareness regarding lifestyle-related diseases such as obesity and diabetes. These sweeteners are typically derived from plant sources and are perceived as safer and more sustainable, aligning with the growing demand for clean-label food products. Unlike conventional sugars, many natural sweeteners offer reduced or zero caloric value, making them particularly attractive for formulating functional foods. Their use in dairy-free ice cream is especially relevant, as it complements the overall objective of developing healthier, plant-based dessert options without compromising on sweetness.

Among natural sweeteners, stevia stands out due to its high intensity and favorable health profile. Extracted from the leaves of *Stevia rebaudiana*, it contains bioactive compounds known as steviol glycosides, which are responsible for its sweetness. These compounds are approximately 200–300 times sweeter than sucrose, allowing for their use in very small quantities. Importantly, stevia does not contribute to blood glucose spikes, making it suitable for diabetic individuals. Additionally, studies have suggested that stevia may possess anti-hypertensive, antioxidant, and anti-inflammatory properties, further enhancing its functional appeal in food systems. Despite these advantages, the functional role of stevia in food products extends beyond simply providing sweetness. It can influence overall product formulation, stability, and nutritional value. However, its high potency and unique taste profile require careful handling during product development. In dairy-free ice cream, where sugar contributes to multiple physicochemical properties, replacing it with stevia necessitates a deeper understanding of its behavior in complex food matrices. Therefore, while stevia offers significant health benefits, its successful incorporation depends on overcoming formulation challenges through advanced food processing techniques.

Challenges Associated with Natural Sweeteners in Ice Cream

The incorporation of natural sweeteners such as stevia into ice cream formulations presents a range of challenges that affect both sensory quality and physicochemical properties. One of the most prominent issues is the presence of bitterness and a lingering aftertaste, which can significantly reduce consumer acceptability. This undesirable taste is often attributed to certain steviol glycosides that interact strongly with taste receptors. In frozen desserts, where flavor balance is critical, even a slight deviation from the expected taste profile can result in reduced preference among consumers. Another important challenge is the difference in sweetness perception between stevia and sucrose. Unlike sugar, which provides an immediate and well-rounded sweetness, stevia often exhibits a delayed onset and prolonged sweetness sensation. This temporal difference can disrupt the overall flavor experience, making the product feel less natural or less satisfying. Additionally, sugar contributes significantly to the bulk and body of ice cream, influencing its texture, mouthfeel, and freezing characteristics. Since stevia is used in very small quantities, it does not provide these essential structural contributions, leading to issues such as poor texture, reduced viscosity, and increased hardness. Furthermore, the interaction of stevia with other ingredients in ice cream formulations can complicate product development. It may affect the stability of emulsions, alter viscosity, and interfere with the functionality of stabilizers and emulsifiers. These interactions can lead to inconsistencies in product quality, particularly during storage. As a result, simply replacing sugar with stevia is not sufficient; it requires a comprehensive reformulation strategy. Addressing these challenges is essential for developing dairy-free ice cream that meets both nutritional and sensory expectations of consumers.

Microencapsulation Technology: Principles and Mechanism

Microencapsulation technology has emerged as a promising solution to enhance the performance of sensitive and functional ingredients in food systems. It involves the encapsulation of an active substance, known as the core material, within a protective layer called the wall material. This process results in the formation of microcapsules that can protect the core from adverse environmental conditions such as heat, oxygen, light, and moisture. In the context of food applications, commonly used wall materials include maltodextrin, gum Arabic, proteins, and various polysaccharides, which are selected based on their compatibility with the core material and desired release properties. The mechanism of microencapsulation is based on the formation of a physical barrier around the active ingredient, which not only protects it but also controls its release under specific conditions. For example, in the case of stevia, encapsulation can prevent its immediate interaction with taste receptors, thereby masking its bitterness. The release of the encapsulated compound can be triggered by factors such as temperature, pH, or mechanical action during consumption. This controlled release mechanism is particularly beneficial in food systems where the timing and intensity of flavor perception are critical to consumer acceptance.

Several techniques are employed for microencapsulation, each with its own advantages and limitations. Spray drying is one of the most widely used methods due to its simplicity, scalability, and cost-effectiveness. Freeze drying, although more expensive, offers better retention of sensitive compounds. Other techniques such as coacervation and extrusion are also used depending on the nature of the core and wall materials. In this study, drying-based microencapsulation is preferred as it provides a practical and efficient approach for encapsulating stevia, making it suitable for large-scale food production.

Role of Microencapsulation in Dairy-Free Ice Cream

Microencapsulation plays a critical role in improving the quality and acceptability of dairy-free ice cream, particularly when incorporating natural sweeteners like stevia. One of its primary benefits is taste masking, as the encapsulation process reduces the direct interaction of stevia with taste receptors. This helps in minimizing the bitterness and undesirable aftertaste commonly associated with stevia, resulting in a more pleasant flavor profile. By improving the sensory characteristics, microencapsulation enhances consumer acceptance of dairy-free ice cream products. In addition to taste masking, microencapsulation enables controlled release of sweetness, which is essential for achieving a balanced and natural flavor perception. Instead of an immediate burst of sweetness, the encapsulated stevia is gradually released during consumption, providing a more uniform and sustained sweetness experience. This helps in closely mimicking the sensory properties of sucrose, thereby improving the overall eating quality of the product. Moreover, the encapsulation process protects stevia from degradation during processing and storage, ensuring consistent sweetness and product stability over time. Another important advantage of microencapsulation is its contribution to the physical properties of dairy-free ice cream. The presence of encapsulated particles increases the total solids content, which can improve viscosity, texture, and mouthfeel. This is particularly beneficial in dairy-free formulations that lack milk proteins and fat, which are essential for structure development. Additionally, improved structural stability helps in reducing ice crystal growth during storage, thereby enhancing shelf life and maintaining product quality. Overall, microencapsulation serves as an effective strategy to address both sensory and functional challenges in dairy-free ice cream development.

Research Gap

Despite advancements in dairy-free ice cream formulation, several gaps remain:

- Limited research on microencapsulation of sweeteners specifically for frozen desserts
- Lack of studies focusing on bitterness masking in stevia-based ice cream
- Insufficient data on combined effects of encapsulation and prebiotics (inulin)
- Limited work on sensory optimization of dairy-free ice cream using advanced techniques

This study aims to bridge these gaps by integrating microencapsulation technology with dairy-free ice cream formulation.

Novelty of the Study

The novelty of this research lies in:

- Use of microencapsulation for natural sweeteners in ice cream systems
- Development of a dairy-free, sugar-reduced frozen dessert
- Improvement of sweetness perception through controlled release mechanisms
- Incorporation of inulin as a functional ingredient for texture and nutrition
- Comprehensive evaluation of physicochemical, sensory, and shelf-life properties

MATERIALS AND METHODS

Materials

All raw materials and chemicals used in this study were of food-grade quality. Coconut milk was selected as the primary base for the dairy-free ice cream due to its high fat content and ability to provide a creamy texture similar to conventional dairy products. Stevia was used as the natural high-intensity sweetener. Maltodextrin and gum Arabic were employed as wall materials for the microencapsulation process due to their excellent film-forming and encapsulation properties. Inulin was incorporated as a functional ingredient to enhance texture and increase dietary fiber content. Coconut oil was used to improve fat content and mouthfeel, while guar gum served as a stabilizer to enhance viscosity and prevent phase separation. Vanilla extract was added as a flavoring agent to improve sensory acceptability. Distilled water was used as the solvent for preparation of encapsulated sweetener solutions. All materials were stored under appropriate conditions prior to use.

Preparation of Microencapsulated Sweetener

Microencapsulation of stevia was carried out using a drying-based encapsulation technique. Initially, the wall materials, maltodextrin and gum Arabic, were accurately weighed in a ratio of 3:1 (wall material to core material basis) and dissolved in distilled water under continuous stirring to form a homogeneous solution. Stevia was then gradually added to the solution while maintaining constant agitation to ensure uniform dispersion.

Figure 3.1 Flowchart of microencapsulation process

The resulting mixture was subjected to homogenization using a hand blender for approximately 5–10 minutes to obtain a stable emulsion.

The prepared feed solution was then uniformly spread onto trays and dried in a hot air oven at a controlled temperature of 50–55°C until a constant weight was achieved, indicating complete removal of moisture. The dried material was collected as thin sheets and subsequently ground into a fine powder using a grinder. The powder was sieved to obtain uniform particle size and stored in airtight containers at 4°C until further use. This encapsulation process helped in masking the bitterness of stevia and improving its stability during ice cream formulation.

Ice Cream Formulation (T1–T4)

Four different formulations of dairy-free ice cream, designated as T1, T2, T3, and T4, were prepared by varying the levels of microencapsulated sweetener and inulin. Coconut milk, coconut oil, guar gum, maltodextrin, and vanilla extract were kept constant across all formulations to maintain consistency in base composition. The variation in formulations was primarily focused on optimizing the concentration of encapsulated stevia and inulin to achieve improved sweetness perception, texture, and overall acceptability. Each formulation was prepared in separate batches under identical processing conditions to ensure reproducibility. The formulations were designed to evaluate the effect of microencapsulation on sensory characteristics, physicochemical properties, and storage stability of the dairy-free ice cream.

Table 3.1 Ice Cream Formulations (T1–T4)

Trial	Encapsulated Stevia (%)	Inulin (%)	Guar Gum (%)
T1	0.2	2	0.3
T2	0.3	3	0.3
T3	0.4	4	0.3
T4	0.5	5	0.3

Preparation of Ice Cream Mix

The preparation of the ice cream mix involved a series of controlled steps. Coconut milk was first heated to a temperature of 60–65°C to facilitate proper mixing of ingredients and to improve solubility. Inulin and guar gum were then added gradually under continuous stirring to prevent lump formation and ensure uniform distribution. Coconut oil was incorporated slowly into the mixture to enhance fat content and improve emulsion stability. The microencapsulated sweetener was added during the mixing stage to ensure proper dispersion throughout the mixture. Vanilla extract was introduced to enhance flavor. The entire mixture was then homogenized using a hand blender to obtain a uniform and stable emulsion. The homogenized mix was subsequently subjected to an aging process at 4°C for 4–6 hours. Aging allowed the stabilizers to hydrate fully and improved the viscosity and whipping properties of the mix.

Pasteurization, Freezing, and Storage

The prepared ice cream mix was pasteurized at 72°C for 15 seconds to eliminate microbial contamination and ensure product safety. Immediately after pasteurization, the mix was rapidly cooled to 4°C to prevent microbial growth and maintain product quality. The cooled mix was aged at 4°C for 4–6 hours to enhance fat crystallization and improve texture. Following aging, the mix was churned for 15–20 minutes using an ice cream maker to incorporate air and achieve the desired overrun. The semi-solid ice cream obtained after churning was filled into 100 mL containers. The filled containers were then subjected to hardening by placing them in a deep freezer at −18°C. The samples were stored under frozen conditions until further analysis.

Figure 3.2 Ice cream preparation flowchart

Physicochemical Analysis

Physicochemical properties of the ice cream samples were evaluated to determine product quality and stability. The pH of the samples was measured using a calibrated digital pH meter. Total soluble solids (°Brix) were determined using a refractometer to assess the sugar content and solid concentration. Viscosity of the ice cream mix was measured using a viscometer to evaluate flow behavior and texture. Overrun was calculated by comparing the weight of the ice cream mix before and after churning, which indicates the amount of air incorporated into the product. Melting resistance was assessed by placing a known quantity of ice cream at room temperature and recording the time taken for complete melting. All analyses were conducted in triplicate, and the results were expressed as mean ± standard deviation.

Nutritional Analysis

The nutritional composition of the developed ice cream was determined using standard methods. Moisture content was analyzed using the oven drying method. Fat content was calculated based on formulation data, considering the contribution of coconut milk and coconut oil. Protein content was estimated using theoretical or label-based values of the ingredients used. Carbohydrate content was calculated by difference, subtracting the sum of moisture, protein, fat, and ash from the total composition. Energy value was calculated using Atwater factors. Dietary fiber content was determined based on the amount of inulin incorporated into the formulation. This analysis helped in evaluating the nutritional benefits of the developed product compared to conventional ice cream.

Sensory Evaluation

Sensory evaluation of the ice cream samples was conducted using a 9-point hedonic scale to assess consumer acceptability. A panel of 15 semi-trained members participated in the evaluation. The samples (T1–T4) were coded and presented in random order to avoid bias. The parameters evaluated included color and appearance, texture and mouthfeel, sweetness and flavor, and overall acceptability. Panelists were asked to rate each attribute on a scale ranging from 1 (dislike extremely) to 9 (like extremely). The collected data were used to identify the most acceptable formulation.

Shelf-Life Study

The optimized formulation (T3) was selected for shelf-life evaluation. The samples were stored at −18°C and analyzed at regular intervals of 0, 7, 14, and 21 days. The parameters monitored during storage included pH, melting behavior, sensory quality, and visual characteristics such as ice crystal formation and phase separation. Changes in texture, appearance, and overall acceptability were recorded to determine the stability of the product over time. The study helped in assessing the storage stability and commercial feasibility of the developed dairy-free ice cream.

Statistical Analysis

All experimental data obtained from physicochemical, nutritional, and sensory analyses were subjected to statistical evaluation to determine the significance of differences among the formulations. The experiments were conducted in triplicate, and the results were expressed as mean ± standard deviation. One-way analysis of variance (ANOVA) was performed to evaluate the effect of different formulations on the measured parameters. A significance level of $p < 0.05$ was considered to determine statistically significant differences. Post-hoc analysis was carried out using Tukey's test to identify specific differences between treatment means. Statistical analysis ensured the reliability and validity of the experimental results and aided in the selection of the optimized formulation.

RESULTS AND DISCUSSION

Physicochemical Properties

The physicochemical properties of the developed dairy-free ice cream formulations (T1–T4) were evaluated to understand the influence of microencapsulated sweetener and inulin on product quality. The parameters analyzed included pH, total soluble solids (°Brix), viscosity, overrun, and melting resistance. The pH of all formulations was found to be in the range of 6.2–6.5, which is considered acceptable for coconut milk-based ice cream. This indicates that the addition of microencapsulated sweetener and inulin did not significantly alter the acidity of the product. Maintaining pH within this range is important for both microbial stability and sensory acceptability. The total soluble solids (°Brix) showed an increasing trend with higher levels of maltodextrin and gum Arabic used in the encapsulation process. This increase in °Brix reflects higher solid content, which contributes to improved body and texture of the ice cream. The presence of encapsulating agents also enhances the overall structure of the product.

Viscosity of the ice cream mix increased with the addition of inulin and encapsulated sweetener. Higher viscosity is desirable as it improves the creaminess and stability of the ice cream. The increased viscosity also supports better air incorporation during churning, leading to improved overrun. Overrun values were observed to increase across formulations due to better stabilization of air cells. The presence of stabilizers such as guar gum and encapsulated particles contributed to improved air retention, resulting in a lighter and smoother product.

Melting resistance was significantly improved in formulations containing microencapsulated sweeteners. The encapsulation matrix, along with inulin, enhanced the structural stability of the ice cream, reducing the rate of melting at room temperature. This indicates improved product quality and consumer acceptability. Overall, the physicochemical analysis demonstrated that microencapsulation positively influenced the structural and functional properties of dairy-free ice cream.

Table 5.1 Physicochemical data (pH, °Brix, viscosity, overrun, melting)

Parameter	**Control (Direct Stevia)**	**(Microencapsulated Stevia)**	**Observation**
pH	6.10 ± 0.02	6.25 ± 0.03	Slightly higher due to maltodextrin coating
Total Soluble Solids (°Brix)	18.5 ± 0.5	20.2 ± 0.4	Increased due to wall materials
Viscosity (cP)	820 ± 15	1050 ± 20	Higher viscosity due to inulin + encapsulate solids
Overrun (%)	28 ± 2	35 ± 3	Improved air incorporation
Melting time (First drip, min)	18 ± 1	26 ± 2	Better melting resistance

Nutritional Composition

The nutritional composition of the developed dairy-free ice cream was analyzed to evaluate its potential as a healthier alternative to conventional ice cream. The parameters studied included moisture content, fat content, protein, carbohydrate, energy value, and dietary fiber. The fat content of the product was primarily derived from coconut milk and coconut oil, contributing to the creamy texture of the ice cream. Despite being plant-based, the fat content was sufficient to provide desirable mouthfeel. Carbohydrate content was moderate due to the presence of maltodextrin and inulin. However, the use of stevia as a sweetener significantly reduced the overall sugar content of the product compared to traditional ice cream.

Protein content was relatively low, as expected in a plant-based formulation without added protein sources. However, this does not significantly affect the overall acceptability of the product. One of the key highlights of the formulation was the increased dietary fiber content, approximately 3.5%, attributed to the addition of inulin. This enhances the functional value of the product and supports digestive health. The estimated energy value of the developed ice cream was around 200–220 kcal per 100 mL, which is lower than conventional dairy ice cream. This makes the product suitable for health-conscious consumers and individuals seeking low-calorie alternatives. Overall, the nutritional analysis confirms that the developed product is a clean-label, sugar-reduced, and fiber-enriched dairy-free dessert.

Table 5.2 Nutritional values of developed product

Parameter	Developed Product (per 100 g)
Moisture (%)	62.5
Fat (%)	9.8
Protein (%)	1.6
Carbohydrates (%)	24.3
Dietary Fiber (%)	3.5
Energy (kcal)	185

Sensory Evaluation Results

Sensory evaluation was conducted using a 9-point hedonic scale with 15 semi-trained panelists to assess the acceptability of the developed formulations (T1–T4). The parameters evaluated included color and appearance, texture and mouthfeel, sweetness and flavor, and overall acceptability. The results indicated a significant improvement in sensory attributes for formulations containing microencapsulated sweetener compared to those with direct sweetener incorporation. The encapsulation process effectively reduced the bitterness commonly associated with stevia, leading to improved sweetness perception.

Texture and mouthfeel were enhanced due to the presence of inulin and the improved structural stability provided by encapsulated particles. Panelists reported a smoother and creamier consistency in optimized formulations. Among the four formulations, T3 achieved the highest overall acceptability score (>8), indicating strong consumer preference. This formulation exhibited the best balance between sweetness, texture, and flavor.

The sensory data were statistically analyzed using ANOVA followed by Tukey's test, which confirmed that the differences between formulations were significant ($p < 0.05$). Overall, the sensory evaluation demonstrated that microencapsulation significantly enhances the acceptability of dairy-free ice cream by improving taste and texture.

Table 5.3 Sensory scores (T1–T4)

Parameter	Control	Microencapsulated Sample
Color & Appearance	7.2	8.1
Texture & Mouthfeel	6.8	8.3
Sweetness	6.5	8.4
Flavor	6.3	8.2
Overall Acceptability	6.6	8.5

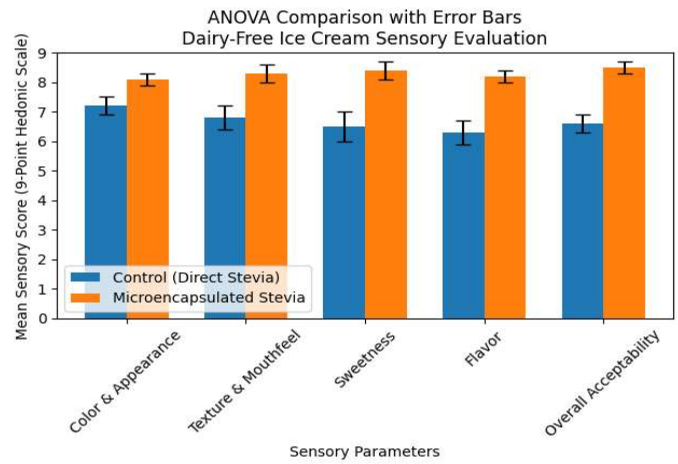

Figure 5.1 Sensory evaluation of Dairy-free Icecream

Shelf-Life Analysis

The shelf-life stability of the optimized formulation (T3) was evaluated over a period of 21 days under frozen storage conditions (−18°C). The parameters monitored included melting resistance, pH changes, sensory quality, and visual observations. Melting resistance showed a slight decrease over the storage period; however, the product maintained acceptable stability. This indicates that the structural integrity of the ice cream was largely preserved during storage. The pH of the product remained relatively stable throughout the storage period, suggesting minimal microbial activity and good product safety.

Sensory evaluation indicated no significant deterioration in quality over the 21-day period. The product retained its desirable taste, texture, and overall acceptability. Visual observations revealed no significant ice crystal growth or phase separation, which are common issues in frozen desserts. The texture remained smooth, indicating effective stabilization by encapsulation and inulin. Overall, the shelf-life study confirmed that the developed dairy-free ice cream is stable for at least 21 days under frozen storage conditions.

Table 5.4 pH changes

Day	pH
0	6.25
7	6.23
14	6.20
21	6.18

Table 5.5 Sensory stability

Day	Overall Acceptability
0	8.5
7	8.3
14	8.0
21	7.8

Table 5.6 Microbial Analysis

Parameter	Day 0	Day 7	Day 14	Day 21	Permissible Limit	Interpretation
Total Plate Count (CFU/g)	1.2×10^2	1.5×10^2	1.8×10^2	2.1×10^2	$< 10^4$ CFU/g	Slight increase but within safe limit
Yeast & Mold (CFU/g)	Not detected	Not detected	< 10	< 10	$< 10^2$ CFU/g	No significant growth
Coliform Count	Absent	Absent	Absent	Absent	Absent	Good hygienic quality

Optimization and Selection of Best Formulation

Based on the combined evaluation of physicochemical properties, nutritional composition, sensory analysis, and shelf-life stability, formulation T3 was identified as the optimized formulation.

T3 demonstrated:

- Highest overall sensory acceptability
- Significant reduction in bitterness
- Optimal viscosity and melting resistance
- Stable storage performance

The balance between microencapsulated sweetener and inulin in T3 contributed to improved product quality. Therefore, T3 was selected for further analysis and considered the best formulation for potential commercialization.

CONCLUSION

The present study successfully demonstrated the development of a dairy-free ice cream using microencapsulated natural sweeteners, addressing the key challenges associated with plant-based frozen desserts. The increasing demand for lactose-free and low-sugar products necessitates innovative approaches to maintain product quality while improving nutritional value. In this research, microencapsulation of stevia using maltodextrin and gum Arabic proved to be an effective strategy for masking bitterness and enhancing sweetness perception. The use of coconut milk as a base provided desirable creaminess, while the incorporation of inulin contributed to improved texture and functional benefits. The study effectively combined these components to produce a clean-label, plant-based frozen dessert with improved characteristics. The physicochemical evaluation of the developed formulations revealed that the addition of microencapsulated sweetener and inulin significantly improved key quality parameters such as viscosity, overrun, and melting resistance. The pH values remained within the acceptable range, ensuring product stability and safety. The increase in total soluble solids due to encapsulating agents contributed to better body and texture of the ice cream. These improvements indicate that microencapsulation not only enhances sweetness but also positively influences the structural properties of dairy-free ice cream. The results highlight the importance of formulation optimization in achieving a balance between functional and sensory attributes.

Nutritional analysis confirmed that the developed product can be considered a healthier alternative to conventional dairy ice cream. The use of stevia reduced the sugar content, while inulin increased dietary fiber, contributing to improved nutritional quality. The moderate calorie content makes the product suitable for health-conscious consumers. Sensory evaluation further validated the success of the formulation, with the optimized sample (T3) achieving the highest acceptability score. The reduction in bitterness and improvement in mouthfeel were particularly notable, demonstrating the effectiveness of microencapsulation in enhancing consumer perception.

The statistical analysis supported the significance of these improvements, confirming the reliability of the results. The shelf-life study indicated that the optimized formulation remained stable for up to 21 days under frozen storage conditions, with minimal changes in physicochemical and sensory properties. The absence of significant ice crystal growth and phase separation suggests good structural stability of the product. Overall, the study concludes that microencapsulation is a promising technique for improving the quality of dairy-free ice cream and can be effectively applied to develop innovative, sugar-reduced frozen desserts. The findings of this research provide valuable insights for future product development and highlight the potential for commercialization of such functional food products.

Acknowledgements:

The authors sincerely acknowledge the support and guidance of their respective institutions and laboratories during the preparation of this review.

Funding:

This work was not supported by any Funding Agency, which provided financial assistance for literature procurement, data compilation, and manuscript preparation. Additional support from Department of Food Technology, JCT College of Engineering and Technology for access to research facilities and analytical resources is gratefully acknowledged.

Conflicts of Interest:

The authors declare that there are no conflicts of interest associated with this publication. All opinions, analyses, and conclusions presented in this review are solely those of the authors and do not necessarily reflect the views of the funding agencies or affiliated institutions.

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