*Int J Adv Life Sci Res. Volume 9(4) 92-106*
https://doi.org/10.31632/ijalsr.2026.v09i04.006

**International Journal of Advancement in Life Sciences Research**

Online ISSN: 2581-4877

*Journal homepage* http://ijalsr.org



Original Article

# Aquafaba-Based Non-Dairy Ice Cream Enriched with Ice Apple and Pomegranate

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**Abstract**

**Background:** The increasing demand for plant-based and dairy-free foods has created opportunities for nutritious alternatives to conventional dairy desserts. Aquafaba provides functional foaming and emulsifying properties, while ice apple and pomegranate contribute nutritional and bioactive components. Objectives: The study aimed to develop aquafaba-based non-dairy ice cream fortified with ice apple and pomegranate and evaluate its sensory, physical, nutritional, phytochemical, antioxidant, cholesterol, shelf-life, and cost parameters. **Methods:** Chickpea aquafaba was prepared by pressure-cooking chickpeas, collecting the cooking liquid, and whipping it into a stable foam. Three formulations (V1, V2 and V3) with varying proportions of ice apple pulp and pomegranate juice were developed using guar gum. Conventional dairy ice cream served as control. Sensory evaluation was conducted using a 9-point hedonic scale by 15 semi-trained panelists. The most acceptable formulation was further evaluated for physical, nutritional, phytochemical, antioxidant, cholesterol, microbiological, storage, and cost parameters. **Results:** V1 recorded the highest overall acceptability (8.46 ± 0.516), comparable to the control (8.53 ± 0.743). It showed 52.4% overrun, 64.7% melting resistance, 22.8 N hardness, and 1750 cP viscosity. Per 100 g, it contained 78.90 g moisture, 1.79 g fat, 0.95 g protein, 18.10 g carbohydrate, and 92.31 kcal. Phenolics, flavonoids, and alkaloids were detected, with antioxidant activity and 0.00 mg/100 g cholesterol. The product remained acceptable for 27 days at −15°C. Production cost was Rs. 54.20/kg. **Conclusion:** The product demonstrated good sensory acceptability, desirable physical and nutritional characteristics, antioxidant potential, cholesterol-free properties, storage stability, and economical production, indicating its potential as a plant-based alternative to dairy ice cream.

***Keywords:*** *Body Mass Index; Chronotype; Circadian Rhythm; Sleep Quality; Type 2 Diabetes*

## Introduction

The rising demand for plant-based and lactose-free alternatives has catalyzed innovation in the dairy industry, particularly in the development of frozen desserts (Asif *et al.*, 2026). Consumers today are increasingly seeking healthier, more sustainable options due to growing awareness of lactose intolerance, veganism, cholesterol management, and environmental concerns. In this context, the creation of non-dairy ice cream formulations using underutilized and nutritionally rich ingredients presents a promising avenue for health promotion and product diversification (Mahowald *et al.*, 2024). Aquafaba, the viscous liquid derived from cooked chickpeas, has gained significant attention in recent years as a plant-based emulsifier and foaming agent, offering functional properties comparable to egg whites. Its unique ability to provide structure and creaminess makes it an ideal base for non-dairy ice cream, especially for consumers seeking vegan, allergen-free, and cholesterol-free alternatives (Koriyama *et al.*, 2025).

*Received on : 2nd July 2025; Revised version received on :11th August 2026; Accepted: 24th August 2026*

When combined with nutrient-dense fruits, aquafaba serves not only as a functional matrix but also contributes to the overall nutritional value of the product. Ice apple (Borassus flabellifer), also known as toddy palm fruit, is a natural coolant with high water content, low calorie density, and essential electrolytes. It is recognized for its hydrating and digestive benefits but remains underutilized in value-added food products like ice cream. Pomegranate (Punica granatum), in contrast, is well known for its antioxidant-rich juice, vibrant red color, and phytochemical profile—including ellagitannins, anthocyanins, and vitamin C. The combination of these two fruits offers a unique opportunity to create a refreshing, health-promoting, and functionally enhanced non-dairy dessert (Ahmed *et al.*, 2023).

Conventional dairy-based ice creams often rely on saturated fats, cholesterol, and synthetic stabilizers. In contrast, the use of aquafaba alongside fruit-based ingredients improves the health profile of the formulation while enhancing sensory qualities such as natural flavor, color, and sweetness. Several studies have highlighted the efficacy of non-dairy formulations using alternative bases and fruit additives in achieving favorable consumer acceptance and nutritional profiles (Erem *et al.*, 2024). However, the integration of aquafaba with ice apple and pomegranate in non-dairy ice cream remains largely unexplored. This study aims to develop and evaluate a novel, aquafaba-based non-dairy ice cream fortified with ice apple and pomegranate. The research focuses on assessing its physicochemical, nutritional, sensory, and functional characteristics, and its potential to serve as a viable, health-conscious alternative to traditional dairy-based frozen desserts.

## Materials and Methods

### *Collection of Ingredients*

All ingredients used in the development of the non-dairy ice cream—namely, ice apple (Borassus flabellifer), pomegranate (Punica granatum), chickpeas, guar gum, and refined sugar—were procured from reputable local markets to ensure freshness and quality. The selection of these ingredients was based on their functional and nutritional properties relevant to non-dairy dessert formulations (Akalın *et al.*, 2024).

### *Preparation and Processing of Ingredients*

To prepare the plant-based foaming agent, chickpeas were pressure-cooked until fully softened. The resulting cooking liquid, known as aquafaba, was carefully strained and collected. This aquafaba was then whipped using a hand mixer until stable, airy foam with a creamy consistency was achieved. (Echeverria-Jaramillo & Shin, 2023). Subsequently, the prepared ice apple pulp, freshly extracted pomegranate juice, refined sugar, and guar gum were incorporated sequentially into the aquafaba cream. Each ingredient was thoroughly mixed to ensure homogeneity and a smooth texture in the final ice cream base.

### *Formulation of Non-Dairy Ice Cream by Using Selected Ingredients*

The formulation process involved designing three experimental variations (V1, V2, and V3) of non-dairy ice cream by varying the proportions of functional plant-based ingredients. Chickpea-derived aquafaba cream was used as the base in all experimental variations, while ice apple and pomegranate juice were included in different ratios to optimize nutritional and sensory attributes. Guar gum was used as a stabilizer to improve consistency and texture (Raisel *et al.*, 2026).

The control sample consisted of conventional dairy-based ingredients such as whole milk, heavy cream, and xanthan gum. In contrast, the experimental formulations substituted these with plant-based components to create a functional, cholesterol-free alternative. All ingredients were measured accurately and blended thoroughly to achieve a homogeneous mixture in each variation (Bureau of Indian Standards, 2023).

***Table 1:*** *Percentage of Formulation of Different Variations of Non-Dairy Ice Cream*

| Sl. No | Ingredients | Control % - w/w | V1 (% - w/w) | V2 (% - w/w) | V3 (% -w/w) |
|---|---|---|---|---|---|
| 1 | Chickpea aquafaba (Cream) | - | 43.48 | 43.48 | 43.48 |
| 2 | Ice apple | - | 26.09 | 30.43 | 34.78 |
| 3 | Pomegranate juice | - | 13.04 | 15.22 | 17.39 |
| 4 | Guar gum | - | 0.9g | 0.9g | 0.9g |
| 5 | White Sugar | 9.0 | 9.0 | 9.0 | 9.0 |
| 6 | Vanilla essence | 0.45 | 0.45 | 0.45 | 0.45 |
| 7 | Whole milk | 45.45 | - | - | - |
| 8 | Heavy cream | 45.45 | - | - | - |
| 9 | Xanthan gum | 0.9 | - | - | - |

** W/W - Weight/Weight*

*Development of Non-Dairy Ice Cream*

Following formulation, each mixture was subjected to the freezing process to develop the final non-dairy ice cream product. The prepared mixtures were poured into airtight containers and stored at −15 °C for a minimum of 12 hours to ensure complete freezing and proper incorporation of air, contributing to desirable texture and structure (Muse & Hartel, 2024). The development stage aimed to stabilize the product matrix through freezing and to promote uniform distribution of air cells and solids. This step is critical to achieving optimal mouthfeel and scoopability (Tang *et al.*, 2025). The control sample was similarly developed and served as the benchmark for evaluating the physical, sensory, and nutritional performance of the non-dairy alternatives.

*Sensory Analysis of the Developed Non-Dairy Ice Cream*

The sensory attributes of the formulated non-dairy ice cream variations were assessed through an organoleptic evaluation using a 9-point hedonic scale. A panel comprising fifteen semi-trained individuals (N=15) participated in the evaluation process. The panellists were familiarized with the sensory attributes and scoring system prior to the assessment to ensure consistency and reliability in responses. The sensory parameters evaluated included colour and appearance, aroma, body and texture, sweetness, flavour, and overall acceptability. Each parameter was rated on a scale ranging from 1 (dislike extremely) to 9 (like extremely). The samples were coded and served under controlled conditions to eliminate bias, and the order of presentation was randomized for each panellist. Water was provided between tastings to cleanse the palate. The data collected from the hedonic scores were statistically analysed to determine significant differences among the variations and to identify the most acceptable formulation based on overall sensory performance.

*Physical Properties of the Accepted Variation of Non-Dairy Ice Cream*

The physical properties of non-dairy ice cream play a crucial role in determining its quality, consumer acceptability, and overall eating experience. The selected formulation from the sensory evaluation was subjected to various physical tests to assess its overrun, melting resistance, hardness, and viscosity. These parameters reflect the structural integrity, aeration, stability, and mouthfeel of the final product, all of which are key determinants in frozen dessert innovation, especially for plant-based alternatives.

*Overrun*

Overrun represents the percentage increase in volume of ice cream resulting from the incorporation of air during freezing. The overrun of the accepted non-dairy ice cream was determined by weighing equal volumes of the unfrozen ice cream mix and the frozen ice cream. A fixed volume of the ice cream mix was transferred into a graduated container and weighed. The same volume of the frozen ice cream was then weighed under identical conditions. The overrun was calculated using the following equation:

**% Overrun = [(Weight of ice cream mix − Weight of frozen ice cream) / Weight of frozen ice cream] × 100**

The overrun value indicates the extent of air incorporation during freezing and contributes to the lightness, texture and scoopability of the final product.

*Melting Resistance*

Melting resistance is a key indicator of the thermal stability and structural robustness of ice cream under ambient conditions. For this study, 30g of the selected non-dairy ice cream was placed in a Buchner funnel and left to melt at 24 ± 1°C for 15 minutes. The volume of melted liquid was then measured, and melting resistance was computed using the following formula:

**Melting resistance (%) = (Initial Sample weight - Melted Sample Weight) / Initial Sample weight * 100%.**

A higher melting resistance implies superior emulsion stability and a slower melting rate, characteristics that are essential for improving shelf life and consumer experience. The presence of guar gum and the natural fiber content of ice apple likely contributed to enhanced melting resistance by stabilizing the ice matrix (Ghaderi *et al.*, 2021).

*Hardness*

Hardness, defined as the resistance of ice cream to deformation under compressive forces, was evaluated using a TA. XT plus Texture Analyzer fitted with a 1 cm-diameter stainless steel cylindrical probe. The sample was stored at −22 ± 1°C for 24 hours before testing. Measurements were taken at a penetration depth of 5 cm, with a probe speed of 2.0 mm/s and a load cell capacity of 1 kN. The peak compression force (in Newtons) during penetration was recorded as the hardness value.An optimal hardness level ensures ease of scooping while maintaining product integrity. The chickpea-derived aquafaba, in combination with fruit purées and stabilizers, likely influenced the firmness and cohesiveness of the frozen matrix, offering a balance between softness and structural strength (Ghaderi *et al.*, 2021).

*Viscosity*

Viscosity describes a fluid's resistance to flow and is closely tied to the creaminess, mouthfeel, and stability of ice cream. The viscosity of the melted non-dairy ice cream sample (stored at 4°C) was measured using the Hybrid Rheometer 2 (TA Instruments, USA). This advanced equipment provides high-precision readings to assess flow behavior under controlled shear conditions.Higher viscosity typically indicates better emulsion stability and smoother texture. The presence of polysaccharides from guar gum and the natural mucilage in ice apple pulp are believed to contribute significantly to viscosity enhancement, thereby improving the sensory profile and consistency of the non-dairy ice cream (Ghaderi *et al.*, 2021).

*Nutritional Composition and Antioxidant Properties of the Accepted Non-Dairy Ice Cream Variation*

The accepted formulation of the non-dairy ice cream was evaluated for its nutritional composition and antioxidant potential to determine its functional and health-promoting properties. The analysis comprised proximate composition, vitamins and minerals, phytochemical constituents, and antioxidant activity. These assessments help establish the product's value as a nutritionally sound and health-conscious alternative to conventional dairy ice creams.

*Proximate Composition*

Proximate analysis was conducted to assess the fundamental macronutrient content of the ice cream sample, including moisture, fat, protein, carbohydrate, dietary fiber, and energy value. Moisture content was determined by oven-drying the sample at 105°C until a constant weight was achieved. Fat content was estimated through the Soxhlet extraction method, using petroleum ether as the solvent to extract lipids. Protein levels were quantified using the Kjeldahl method from Bureau of Indian Standards, 2023, which calculates nitrogen content and applies a standard conversion factor to determine crude protein. Carbohydrates were measured using High-Performance Liquid Chromatography (HPLC), a sensitive technique that allows the accurate quantification of both simple and complex sugars. Dietary fiber content was estimated using the Total Dietary Fiber Method, which

involves enzymatic-gravimetric procedures to capture both soluble and insoluble fractions. Energy content was assessed using Bomb Calorimetry from (Zena *et al.*, 2026), where the calorific value is derived by measuring the heat released during complete combustion of the sample.

*Vitamin Content*

To assess micronutrient density, both vitamin and mineral content were analyzed. Vitamin C was measured using a redox titration method involving 2,6-dichlorophenolindophenol (DCPIP), whereas vitamins E and K were quantified through High-Performance Liquid Chromatography (HPLC) with UV detection, ensuring accurate detection and separation of these fat-soluble vitamins. These vitamins play crucial roles in antioxidant defense, immune function, and cellular regulation.

*Mineral Content*

Mineral content, including calcium, magnesium, iron, potassium, and copper, was measured using advanced instrumental techniques such as Atomic Absorption Spectrophotometry (AAS) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). These analytical methods allowed for precise quantification of both macro- and trace elements, providing insights into the mineral fortification and electrolyte balance of the product. The presence of essential minerals contributes to bone health, muscle function, enzymatic activity, and overall metabolic regulation.

*Cholesterol Estimation*

Cholesterol content of the accepted non-dairy ice cream formulation was determined by the GC–MS/MS method described by Chen *et al.* (2015), with slight modifications. Approximately 1 g of the homogenized sample was saponified with 7.5% KOH in methanol and heated under reflux for 60 min. The saponified sample was extracted with n-hexane and petroleum ether (50:50, v/v). The extract was concentrated and reconstituted in n-hexane for analysis. Cholesterol was identified and quantified using a gas chromatograph coupled with tandem mass spectrometry (GC–MS/MS) using an authentic cholesterol standard. The results were expressed as mg/100 g of sample. Cholesterol below the detection/quantification limit was reported as not detected (ND) (Chen *et al.*, 2015).

*Phytochemical and Antioxidant Evaluation*

Phytochemical constituents such as phenols, flavonoids, tannins, and alkaloids were analyzed to assess the bioactive potential of the non-dairy ice cream. Total phenolic content was measured using the Folin–Ciocalteu reagent method, with results expressed in Gallic Acid Equivalents (GAE). Flavonoid levels were assessed using the aluminum chloride colorimetric method, while tannin content was evaluated using the vanillin–hydrochloric acid assay. Alkaloids were quantified by gravimetric analysis after acid-base extraction. These phytochemicals are known for their protective effects against oxidative stress and their roles in chronic disease prevention. Antioxidant capacity was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. This widely used method evaluates the ability of the sample to neutralize free radicals, reflecting its potential to reduce oxidative damage and inflammation. The high antioxidant activity of the accepted ice cream formulation is largely attributed to the presence of pomegranate juice and ice apple pulp, both rich in polyphenols and natural antioxidants.

*Chemical Analysis*

The chemical composition of the developed non-dairy ice cream was analyzed with a focus on its moisture content, which plays a critical role in defining the texture, shelf life, and overall quality of frozen desserts. The Karl Fischer titration method, a highly sensitive and accurate technique, was employed for this purpose. This method, recommended by (Bureau of Indian Standards, 2023). is particularly effective for determining low levels of water content in complex food matrices. The result provides essential insight into the product's hydration level, ensuring consistency in texture and resistance to freezer damage during storage (Erem *et al.*, 2024).

*Microbiological Analysis*

Microbiological safety is a critical quality attribute in the development of frozen food products. The viable fungal count, including yeast and mold, was assessed in accordance with standard procedures to ensure the hygienic quality of the non-dairy ice cream. The spread plate method was employed to enumerate yeasts and molds, while the pour plate method was used to determine the total bacterial count, both conducted at an incubation temperature of 25°C, as specified in standard microbiological testing protocols. These methods help detect microbial contamination, ensuring the product's compliance with food safety regulations and confirming its suitability for human consumption (FSSAI, 2024).

*Cost Calculation of the Accepted Non-Dairy Ice Cream Variation*

Cost analysis is a key factor in evaluating the commercial viability of newly developed food products. The production cost of the accepted non-dairy ice cream formulation was calculated based on the market prices of the raw materials—such as ice apple, pomegranate, chickpeas (for aquafaba), guar gum, and sugar—at the time of procurement. In addition to raw material costs, the analysis accounted for processing expenses, including cooking, freezing, and packaging operations. This economic assessment provides insight into the affordability of the product for consumers and the potential profitability for producers.

*Shelf-Life Evaluation*

To determine product stability and safety, a shelf-life study was conducted over a one-month period. The prepared non-dairy ice cream sample was stored in an airtight container at –15°C, mimicking typical commercial storage conditions. The pH of the ice cream was measured at 5-day intervals, following the ISO 2802-2022 standard. Monitoring pH levels over time allows for the detection of microbial spoilage or biochemical changes, ensuring that the product maintains its quality throughout the intended storage period.

*Packaging and Labelling*

A systematic packaging and labelling strategy were developed for the non-dairy ice cream, particularly focusing on quality assurance and consumer information. High-quality, food-grade, airtight containers were selected for packaging to maintain product integrity, prevent contamination, and extend shelf life. Labels were designed to include all mandatory information such as the product name, ingredient list, nutritional facts, allergen declarations, storage and handling instructions, manufacturing and expiry dates, and manufacturer contact details. Furthermore, to support consumer awareness and transparency, additional information about the health benefits of the ingredients—such as antioxidants from pomegranate and hydration from ice apple—was provided. Product branding and aesthetic elements were incorporated to enhance consumer appeal and differentiate the ice cream from conventional dairy products on the market.

*Statistical Analysis*

To analyze the experimental data, descriptive and inferential statistical analyses were performed using IBM SPSS Statistics Software. Descriptive statistics included means and standard deviations, providing an overview of the variability and central tendency of the measured attributes. For comparing the variations among different samples, a One-Way ANOVA was conducted, followed by Duncan's Multiple Range Test (DMRT) to determine statistically significant differences between means at a defined confidence level. This statistical approach allowed for a robust evaluation of sample performance and consumer preference. The methodology aligns with similar studies in food science research (Ghorbani *et al.*, 2023).

## Results

*Organoleptic Evaluation of Developed Non-Dairy Ice Cream*

The sensory characteristics of the developed non-dairy ice cream samples were evaluated using a 9-point hedonic scale by panel of semi-trained evaluators (N=15). The organoleptic parameters assessed included color and appearance, aroma, body and texture, sweetness, flavor, and overall acceptability. The results are presented in Table 2.

***Table 2**: Organoleptic Evaluation of Developed Non-Dairy Ice Cream*

| Sl.No | Organoleptic Evaluation | Control | V1 | V2 | V3 |
|---|---|---|---|---|---|
| 1 | Color and Appearance | 8.06±0.59 | 8.0±0.845 | 6.13±0.639 | 7.13±0.639 |
| 2 | Aroma | 8.00±0.755 | 7.73±0.593 | 6.20±0.941 | 6.00±0.534 |
| 3 | Body & Texture | 8.06±0.593 | 7.93±0.883 | 6.26±0.961 | 5.80±0.941 |
| 4 | Sweetness | 8.13±0.833 | 8.13±0.743 | 6.53±0.833 | 6.06±0.703 |
| 5 | Flavor | 8.06±0.593 | 7.80±0.861 | 6.46±0.639 | 6.00±0.755 |
| 6 | Overall Acceptability | 8.53±0.743 | 8.46±0.516 | 6.33±0.816 | 6.13±0.516 |
| 7 | P value | 0.00 | 0.00 | 0.00 | 0.00 |

The control sample, which contained dairy-based ingredients, consistently scored highest across all sensory attributes, with an overall acceptability score of 8.53 ± 0.743, indicating excellent consumer preference. Among the non-dairy variations, V1, which included 60g of ice apple and 40g of pomegranate juice, received the highest scores across most sensory parameters within the non-dairy group, with an overall acceptability of 8.46 ± 0.516. In contrast, V2 and V3, which had increased proportions of pomegranate juice (50g and 60g, respectively), showed a decline in sensory scores. Specifically, V2 and V3 exhibited reduced scores in terms of texture, flavor, and sweetness, potentially due to the overpowering tartness and moisture content contributed by the higher pomegranate concentration.

The results of the one-way ANOVA and Duncan's Multiple Range Test (DMRT) confirmed that there were statistically significant differences ($p < 0.05$) among the control and non-dairy variations for all sensory attributes evaluated. The p-values for all samples were 0.00, indicating a high level of statistical significance. These findings suggest that while the control was most preferred, V1 emerged as the most acceptable non-dairy alternative, successfully mimicking the sensory profile of traditional dairy-based ice cream to a considerable extent. Overall, the sensory analysis reveals that the formulation of non-dairy ice cream using chickpea aquafaba, ice apple, and pomegranate juice can yield a product with favorable organoleptic properties, especially when the ingredient balance is optimized, as demonstrated by variation V1.

*Physical Properties of The Accepted Variation of Non-Dairy Ice Cream*

***Table 3:** Physical Properties of the Accepted Non-Dairy Ice Cream V*

| Parameter | Value | Units | Interpretation |
|---|---|---|---|
| Overrun | 52.4 | % | Indicates good air incorporation |
| Melting Resistance | 64.7 | % | High resistance to melting |
| Hardness | 22.8 | Newton (N) | Moderate firmness, easy to scoop |
| Viscosity | 1750 | cP | High consistency, smooth texture |

Table 3 shows the Physical Properties of the Accepted Non-Dairy Ice Cream Variation (V1) were evaluated in terms of overrun, melting resistance, hardness, and viscosity. These parameters are critical indicators of structural integrity, mouthfeel, and consumer acceptability, particularly in plant-based frozen desserts. Overrun of the accepted sample was recorded at 52.4%, indicating satisfactory air incorporation during the churning and freezing process. This value falls within the typical range observed in commercial non-dairy frozen desserts (30–60%) and slightly below that of conventional dairy ice creams (60–100%) (Wu *et al.*, 2019). The inclusion of aquafaba, known for its foaming and emulsifying capacity, likely contributed to the favorable overrun by enhancing air

entrapment without the need for dairy proteins. This result suggests improved textural lightness and scoop ability while maintaining flavor intensity, as excessive aeration can dilute sensory properties (He *et al.*, 2021).

The melting resistance of the sample was 64.7%, which is indicative of high structural and thermal stability under ambient conditions. This parameter is comparable to premium dairy ice creams, where values typically range between 60–70% depending on formulation (Muse & Hartel, 2004). The improved melting resistance in the present study can be attributed to the synergistic effect of guar gum, a commonly used plant-based stabilizer, and the natural mucilage content of ice apple pulp, both of which enhance water-binding capacity and stabilize the ice cream matrix. Hardness was measured at 22.8 N, indicating a moderately firm consistency conducive to ease of scooping and consumption. This value aligns well with earlier reports on scoopable ice cream, where hardness generally ranges between 20–40 N depending on fat and solid content (Muse & Hartel, 2004).

The balanced firmness observed here is likely due to the structural contributions of aquafaba and fruit purées, which interact with stabilizers to maintain consistency even at sub-zero temperatures. The viscosity of the melted ice cream sample was found to be 1750 cP, reflecting a high degree of flow resistance. This level of viscosity exceeds that of many commercial dairy-based counterparts, which typically range from 800–1500 cP depending on emulsifier and stabilizer content (Martínez *et al.*, 2020). The elevated viscosity observed is likely attributable to the presence of soluble fibers and polysaccharides from ice apple and guar gum, which not only contribute to creaminess but also enhance emulsion stability, delaying phase separation during storage and melting. Collectively, these physical properties demonstrate that the accepted non-dairy ice cream formulation (V1) achieves quality characteristics comparable to conventional dairy ice cream while offering a plant-based alternative with superior melt resistance and desirable mouthfeel.

*Nutritional Composition of the Developed Non-Dairy Ice Cream*

The nutritional profile of the accepted non-dairy ice cream formulation demonstrates its potential as a functional plant-based frozen dessert, incorporating both essential nutrients and bioactive compounds.

*Proximate Composition*

***Table 4:*** *Proximate Composition of the Accepted Non-Dairy Ice Cream (per 100g)*

| Sl. No. | Parameter | Value | Unit |
|---|---|---|---|
| 1 | Moisture | 78.90 | % |
| 2 | Fat | 1.79 | g |
| 3 | Crude fiber | Below detection level | g |
| 4 | Protein | 0.95 | g |
| 5 | Carbohydrate | 18.10 | g |
| 6 | Energy | 92.31 | kcal |

The non-dairy ice cream exhibited a moisture content of 78.90 g/100 g, contributing to its soft and scoopable texture. This high moisture content aligns with typical ranges for fruit-based frozen desserts and plays a significant role in ensuring a refreshing mouthfeel (Güven & Karaca, 2002). The fat content, recorded at 1.79 g/100 g, is considerably lower than that of traditional dairy ice creams, which can contain 10–16% fat (Tang *et al.*, 2025). This reduction in fat content makes the product a suitable alternative for individuals seeking low-fat dietary options. The protein content (0.95 g/100 g) is relatively modest, likely due to the absence of dairy and incorporation of fruit-based ingredients. However, the inclusion of aquafaba contributes trace plant proteins, which also aid in emulsion stability (Tang *et al.*, 2025). Carbohydrate content (18.10 g/100 g) provides the necessary sweetness and energy (92.31 kcal/100 g), positioning the product as a light, guilt-free dessert option compared to conventional counterparts.

*Vitamin Content*

***Table 5:*** *Vitamin Content of the Accepted Non-Dairy Ice Cream (per 100g)*

| Sl. No. | Vitamin | Value | Unit |
|---|---|---|---|
| 1. | Vitamin C | 0.25 | mg |
| 2. | Vitamin E | 0.81 | mg |
| 3. | Vitamin K | 1.25 | mcg |

The product contained moderate levels of essential vitamins, including vitamin C (0.25 g/100 g), vitamin E (0.81 mg/100 g), and vitamin K (1.25 mcg/100 g). Vitamin C supports immune function and collagen synthesis, while vitamin E contributes to lipid membrane stability and antioxidant defense. The inclusion of plant-derived ingredients rich in these vitamins aligns with findings by Alberts *et al.* (2025), who emphasized the nutritional benefits of plant-based fortification in processed foods.

*Mineral Content*

***Table 6:*** *Mineral Content of the Accepted Non-Dairy Ice Cream (per 100g)*

| Sl. No. | Mineral | Value | Unit |
|---|---|---|---|
| 1. | Calcium | 73.07 | mg |
| 2. | Magnesium | 104.81 | mg |
| 3. | Iron | 0.99 | mg |
| 4. | Potassium | 39.77 | mg |
| 5. | Copper | 18.71 | mcg |

The mineral analysis revealed appreciable levels of magnesium (104.81 mg/100 g) and calcium (73.07 mg/100 g). These levels are beneficial, particularly for consumers with lactose intolerance or those avoiding dairy for ethical or dietary reasons. Magnesium plays a crucial role in enzyme activity and bone health, while calcium is essential for skeletal strength and metabolic functions (Alberts *et al.* 2025). Furthermore, the presence of copper (18.71 mcg/100 g) and potassium (39.77 mg/100 g) supports electrolyte balance and antioxidant enzyme systems.

*Phytochemical and Antioxidant*

***Table 7:*** *Phytochemical and Antioxidant Content (per 100g)*

| Sl. No. | Component | Value | Unit |
|---|---|---|---|
| 1. | Alkaloids | 1.73 | mg |
| 2. | Flavonoids | 1.56 | mg |
| 3. | Tannin | BLQ (LOQ – 0.01) | mg |
| 4. | Phenols | 5.11 | mg |
| 5. | Total Antioxidant Level | 90.60 | % |

**BLQ -Below Limit of Quantification *LOQ - Limit of Quantification*

The ice cream showed the presence of alkaloids (1.73 mg/100 g), flavonoids (1.56 mg/100 g), and phenolic compounds (5.11 mg/100 g). These bioactive compounds are well-documented for their antioxidant and anti-inflammatory activities. The total antioxidant capacity (90.60%) of the product indicates a strong potential to scavenge free radicals, thereby reducing oxidative stress. The incorporation of natural ingredients like pomegranate and ice apple likely enhanced these phytochemical concentrations (Magangana *et al.*, 2020).

*Cholesterol Content*

***Table 8:*** *Cholesterol Content*

| Sl. No. | Component | Value | Unit |
|---|---|---|---|
| 1. | Cholesterol | 0.00 | mg |

Importantly, the cholesterol content was found to be 0.00 mg/100 g, which is a significant nutritional advantage over dairy-based ice creams. The formulation contained no detectable cholesterol,

supporting its potential as a cholesterol-free alternative to conventional dairy ice cream (Latif *et al.*, 2026).

*Shelf Life of the Accepted Variation of Non-Dairy Ice Cream*

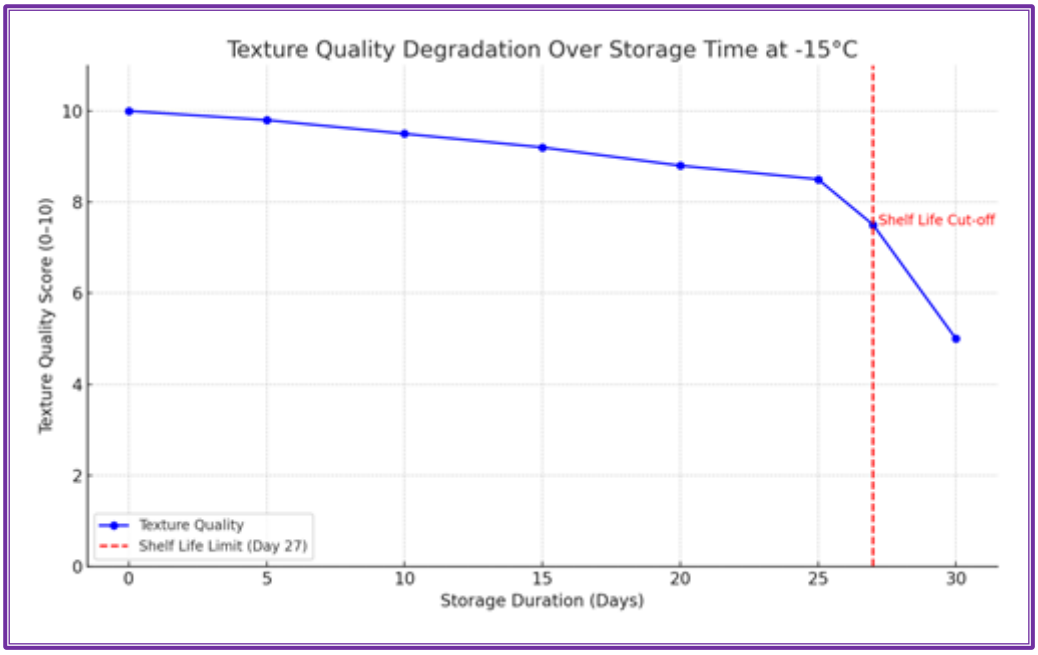



***Figure 1:*** *Graphical Representation of Texture Quality Degradation*

The shelf life of the selected non-dairy ice cream formulation was evaluated under controlled storage conditions. The product was stored in an airtight food-grade container at a constant freezer temperature of −15 °C and monitored weekly over a period of one month. Observations focused on sensory quality, physical stability, and textural integrity. The ice cream remained acceptable for 27 days. No significant changes in color, flavor, or texture were detected during this period. However, beyond this point, noticeable changes were observed, particularly in texture. These changes are attributed to the recrystallization process—each time the ice cream was removed from the freezer for evaluation, partial melting occurred. Upon refreezing, the small ice crystals originally formed during the churning and freezing process aggregated into larger crystals. This phenomenon, commonly known as ice recrystallization, adversely affected mouthfeel and led to a coarser, harder product texture (Muse & Hartel, 2004). These findings underscore the importance of minimizing temperature fluctuations during storage and distribution. Incorporation of stabilizers such as guar gum and the natural fibers present in ice apple contributed to maintaining the emulsion structure and slowing down crystal growth, which helped preserve the ice cream's quality during the observed shelf life.

*Cost Calculation of The Accepted Variation of Non-Dairy Ice Cream*

***Table 9:*** *Cost Calculation of The Accepted Variation of Non-Dairy Ice Cream*

| Sl. No. | Component | Cost (INR) |
|---|---|---|
| 1 | Chickpeas (Aquafaba) | Rs. 15.00 |
| 2 | Ice Apple Pulp | Rs. 15.00 |
| 3 | Pomegranate Juice | Rs. 12.00 |
| 4 | Guar Gum | Rs. 0.20 |
| 5 | Sugar | Rs. 1.00 |
| 6 | Vanilla Essence | Rs. 6.00 |
| 7 | Utilities (Electricity, Water) | Rs. 5.00 |
| | Total Production Cost | Rs. 54.20 |
| | Profit Margin (30%) | Rs. 16.26 |
| | Estimated Selling Price | Rs. 70.46 |

The total cost of producing 1 kg of the accepted non-dairy ice cream formulation (V1) was Rs. 54.20. By applying a standard 30% profit margin, the recommended selling price was estimated at Rs. 70.46. This pricing positions the product competitively in the growing market for plant-based frozen desserts. The cost structure highlights that major expenses are attributed to chickpeas, ice apple pulp, and pomegranate juice, which serve both functional and nutritional roles. Aquafaba, a cost-effective foaming agent derived from chickpea cooking water, replaces dairy-based emulsifiers and supports sustainable utilization of legume by-products (Yazici *et al.*, 2022). Ice apples, rich in water and dietary fiber, enhance texture while contributing to the product's local and seasonal appeal. From a marketability standpoint, the proposed price point of approximately Rs. 70 per kilogram remains affordable compared to branded plant-based ice creams (Rs. 120–Rs. 150 per 500 ml) while offering added health benefits such as cholesterol-free content and high antioxidant levels. The low-cost, nutrient-dense profile makes the product a suitable candidate for commercialization in both urban and semi-urban settings. This analysis supports the economic viability of the product, especially for micro-entrepreneurs and small-scale food processing units aiming to enter the non-dairy frozen dessert sector.

## Discussion

The present study was undertaken to develop and evaluate a non-dairy ice cream using chickpea aquafaba, ice apple pulp and pomegranate juice as plant-based ingredients. The findings demonstrated that the developed formulation could achieve acceptable sensory characteristics along with desirable physical properties, nutritional attributes, storage stability and economic feasibility. The findings are supported by recent research demonstrating the potential of plant-based functional ingredients and pomegranate juice in frozen dessert formulations. In particular, Indirajati *et al.* (2026) reported that incorporation of pomegranate juice significantly influenced the physicochemical and sensory characteristics of pomegranate-based mellorine, including viscosity, overrun, melting time and sensory attributes. Similarly, Fernandes *et al.* (2026) demonstrated that aquafaba possesses important foaming and emulsifying functionality associated with its protein and polysaccharide components. The present study extends these findings by combining chickpea aquafaba with ice apple pulp and pomegranate juice in a single non-dairy ice cream formulation.

### *Sensory Characteristics*

The sensory evaluation showed that the control sample received the highest scores for the evaluated attributes, while V1 was the most acceptable among the non-dairy formulations. The comparatively higher acceptability of V1 may be attributed to the balanced proportion of ice apple pulp and pomegranate juice, which provided a desirable combination of sweetness, flavour and texture. In contrast, the lower sensory scores observed in V2 and V3 may be associated with the increased proportion of pomegranate juice. The higher amount of pomegranate juice could have contributed to increased tartness and acidity, thereby influencing sweetness and flavour perception.

These findings are supported by recent research on pomegranate-based frozen desserts. Indirajati *et al.* (2026) reported that variation in pomegranate juice concentration significantly affected the sensory characteristics of mellorine, including colour, aroma, taste and texture. Their findings indicate that the concentration of pomegranate juice is an important factor in determining the sensory quality and consumer acceptability of frozen desserts. Therefore, the present finding that V1 was preferred over formulations containing higher levels of pomegranate juice suggests that an appropriate balance of fruit ingredients is important for maintaining sensory acceptability.

### *Physical Properties*

The physical properties of the accepted formulation indicated satisfactory structural characteristics. The overrun observed in V1 suggests effective incorporation and retention of air during processing. This finding is consistent with previous research demonstrating the suitability of aquafaba as a foaming ingredient in frozen desserts. Recent evidence further supports the functional role of aquafaba in aerated food systems. Fernandes *et al.* (2026) demonstrated that the polysaccharide

fraction of aquafaba contributes to foam stability and that higher concentrations of polysaccharides can enhance the firmness of emulsions. These findings provide a possible explanation for the ability of chickpea aquafaba to facilitate air incorporation and contribute to the structural characteristics observed in the present non-dairy ice cream.

*Nutritional Characteristics*

The nutritional composition demonstrated that the developed non-dairy ice cream had a relatively low fat content compared with conventional dairy-based ice cream. This characteristic may be primarily attributed to the replacement of dairy cream and other dairy ingredients with plant-based components. The protein content of the developed formulation was relatively low, which may be expected because the formulation was primarily composed of fruit-based ingredients and aquafaba rather than concentrated plant protein sources. Nevertheless, aquafaba contributed important functional properties to the product in addition to providing a plant-derived ingredient. The carbohydrate content contributed to the sweetness and energy value of the formulation.

The presence of vitamin C, vitamin E and vitamin K demonstrates the contribution of the plant-based ingredients to the micronutrient profile of the product. Similarly, the detected calcium, magnesium, iron, potassium and copper contents indicate that the formulation provides measurable amounts of essential minerals. Indirajati *et al.* (2026) reported measurable vitamin C and other nutritional characteristics in pomegranate-based mellorine and demonstrated that pomegranate juice concentration influenced the physicochemical characteristics of the frozen dessert. Differences between the nutrient values reported in previous studies and those observed in the present study may be related to differences in fruit variety, ingredient proportions, processing conditions and formulation composition.

It should, however, be emphasized that the presence of these nutrients does not necessarily imply that the product can be considered a major dietary source of the respective micronutrients. The nutritional contribution should be interpreted in relation to the serving size and the overall dietary intake.

*Phytochemical and Antioxidant Characteristics*

The presence of alkaloids, flavonoids and phenolic compounds indicates that the developed product contained bioactive constituents derived from the incorporated plant ingredients. Pomegranate is particularly relevant to the phytochemical characteristics of the formulation because it is a rich source of phenolic compounds and other antioxidant constituents. The observed antioxidant activity in the present study is therefore consistent with previous research demonstrating that pomegranate-derived ingredients can contribute antioxidant compounds to frozen desserts. However, the magnitude of antioxidant activity may differ according to the plant material used, extraction method, concentration of bioactive compounds and analytical method employed. In the present study, both pomegranate juice and ice apple pulp contributed to the plant-based composition and may have collectively influenced the phytochemical profile (Arshad *et al.*, 2026).

The antioxidant result should be interpreted as an analytical property of the formulation rather than as direct evidence of a health benefit in consumers. Further investigations involving bioavailability, digestion and biological activity would be required before specific health effects could be established (Ramadhan, 2026).

*Cholesterol Content*

The cholesterol content of the accepted non-dairy ice cream was not detected under the analytical conditions used. This finding is consistent with the plant-based nature of the formulation, as cholesterol is associated predominantly with animal-derived foods. The absence of detectable cholesterol is therefore an expected and nutritionally relevant characteristic of a formulation in which dairy-derived ingredients have been replaced with chickpea aquafaba and fruit ingredients (Latif *et al.*, 2026).

This characteristic further supports the suitability of the product as a plant-based alternative to conventional dairy ice cream. However, the result should be reported specifically as “not detected” under the analytical conditions used rather than as absolute absence of cholesterol, since analytical detection depends on the sensitivity and detection limit of the method.

*Shelf-Life Characteristics*

The accepted formulation remained acceptable during storage for 27 days at −15 °C, indicating satisfactory short-term storage stability under the conditions evaluated. The changes observed after the acceptable storage period were mainly associated with texture. Repeated removal of the product from frozen storage for evaluation may have resulted in partial melting followed by refreezing, promoting ice crystal growth and recrystallization.

The stabilizing effect of guar gum and the water-binding characteristics of the formulation may have contributed to maintaining product quality during storage (Zena *et al.*, 2026). Previous research on pomegranate-enriched ice cream has also demonstrated the feasibility of maintaining acceptable physicochemical and sensory characteristics in formulated frozen products. However, storage stability is strongly influenced by temperature fluctuations, formulation composition and packaging conditions. Therefore, maintaining a consistent frozen-storage temperature would be important for preserving the desirable texture of the developed product.

*Economic Feasibility*

The cost analysis indicated that the accepted formulation could be produced at a relatively low cost. Chickpea aquafaba, ice apple pulp and pomegranate juice constituted the major ingredient costs, while guar gum and sugar contributed comparatively lower costs. The use of aquafaba also provides an opportunity for value addition through utilization of a chickpea cooking by-product.

This aspect is supported by Balivo *et al.* (2024), who highlighted the potential of aquafaba as a value-added ingredient obtained from chickpea processing and its usefulness in developing lower-fat frozen products. Thus, utilization of aquafaba in the present formulation may have both nutritional and sustainability-related advantages.

The estimated selling price suggests potential economic feasibility for small-scale production. However, commercial feasibility would also depend on large-scale processing, packaging, cold-chain requirements, raw material availability and consumer willingness to purchase plant-based frozen desserts. Therefore, further pilot-scale production and consumer-market studies would be necessary before commercial introduction.

*Limitations*

The study was conducted using a limited number of sensory panel members and a single selected formulation, which may limit the generalizability of the findings. Further studies with larger consumer panels and comprehensive nutritional and storage evaluations are warranted.

*Future Scope*

Further research may focus on optimizing the formulation, evaluating longer-term storage stability and conducting consumer acceptability studies. The potential for scale-up production, packaging optimization and commercial application of the developed non-dairy ice cream can also be explored.

## Conclusion

This study successfully developed a novel plant-based, non-dairy ice cream formulation utilizing ice apple (Borassus flabellifer), pomegranate juice, and aquafaba derived from chickpeas as key functional ingredients. Among the three variations tested, the formulation designated as V1 demonstrated the highest sensory acceptability and was subsequently subjected to comprehensive evaluation, including analyses of its physicochemical properties, nutritional and antioxidant composition, microbial stability, shelf life, cost efficiency, and organoleptic quality. The findings

indicate that the integration of aquafaba as a foaming and stabilizing agent, in combination with the hydrating and nutrient-rich profile of ice apple and the antioxidant potential of pomegranate, resulted in a nutritionally enriched, cholesterol-free, and sensory-appealing frozen dessert.

The accepted formulation not only meets the dietary needs of vegan and lactose-intolerant consumers but also aligns with current consumer trends favoring clean-label, functional, and sustainable food products. Moreover, the product's favorable shelf stability, microbial safety, and cost-effectiveness underscore its promise for commercial viability in the growing market of non-dairy frozen desserts. This study contributes to the advancement of plant-based innovation in food science, particularly in the domain of non-dairy ice creams. Future research could focus on scale-up processes, long-term consumer acceptability studies, and the incorporation of additional bioactive compounds or probiotics to enhance the product's health-promoting potential and market competitiveness.

## Conflict of Interest

The authors declare no conflicts of interest in this work

## Acknowledgement

The authors sincerely acknowledge the support and facilities provided by the Department of Nutrition and Dietetics, Periyar University, Salem, Tamil Nadu, for carrying out this research.

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