## CHAPTER 14

# Frozen desserts formulated with plant-based milk: a comprehensive quality analysis

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**Abstract**

The consumption of dairy alternative products is increasing worldwide, particularly in the frozen dessert sector, where dairy ingredients are partially or completely replaced with plant-based alternatives. Plant-based milks, including soy, rice, coconut, cashew, hazelnut, peanut, hemp, and lupine milk, are increasingly incorporated into formulations. This substitution not only replaces animal proteins and fats with plant-based ones but also enriches products with bioactive compounds from plant raw materials or their processing by-products. Analysis of the nutritional value and key physicochemical properties of these desserts shows considerable variability depending on ingredient composition and production technology, including the methods used to process raw materials. Nonetheless, it is important that such frozen desserts maintain properties comparable to conventional dairy ice cream.

The key indicators characterizing the properties of frozen desserts were grouped into the following categories: nutritional, chemical, physical, sensory, functional, and microbiological. These indicators reflect the overall quality of frozen desserts. The grouping of indicators enabled the development of a property tree for frozen desserts. To assess their quality, a quality index was proposed, which comprehensively accounts for both the weighting of the indicator groups and the individual weight of each indicator within a group. Calculation of the quality index using the developed mathematical model facilitates the objective comparison of the quality of different products, taking into account the recommended (optimal) values of the indicators. The model can also be expanded to include additional indicators that characterize product quality.

Based on the SWOT analysis of frozen desserts containing plant-based milk, strategies for product improvement were proposed, considering their strengths and


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weaknesses, as well as the opportunities and threats. The analysis was multi-criteria, covering economic, marketing, social, technological, and quality-related characteristics of the frozen desserts. The proposed framework enables a comprehensive assessment of the quality of frozen desserts formulated with plant-based milk and supports the identification of directions for their improvement and market positioning.

**Keywords**

Frozen dessert, plant-based milk, ice cream, dairy alternative, food quality index, SWOT analysis, property tree, bioactive compounds, mathematical model of product quality.

## 14.1 Introduction

Traditional ice cream is a popular frozen dessert made from dairy ingredients such as milk and cream combined with natural or artificial sweeteners [1]. A typical ice cream formulation contains approximately 10% fat, 9–12% milk solids-non-fat, 14–17% sweeteners, 0.1–0.3% stabilizers, 0.1–0.2% emulsifiers, and 60–65% water [2]. Fat contributes to a creamy texture, foam stability, flavor enhancement, structural stability, and resistance to melting. Milk solids-non-fat provide proteins, lactose, and minerals that support emulsification, air stabilization, and water-binding capacity. Sweeteners impart sweetness, while stabilizers and emulsifiers enhance structure stability and improve air incorporation. Water serves as the continuous phase in which the ingredients are dissolved and dispersed [2]. Due to its compositional characteristics, ice cream is also considered a relatively high-energy food product [3]. However, commercial ice cream generally contains low levels of natural antioxidants, including vitamin C, pigments, and polyphenolic compounds. Consequently, improving its nutritional value through the incorporation of ingredients such as fruits, vegetables, nuts, pulses, and dietary fibers – rich sources of natural antioxidants, vitamins, and colorants – has attracted increasing attention in response to growing consumer demand for healthier food products [4].

Ice cream production involves several main stages: blending or mixing, pasteurization, cooling, homogenization, aging, aeration with freezing, and hardening [5]. The processes and equipment used in ice cream manufacturing depend on the scale of production, whether industrial (large-scale plants) or artisanal (small-scale or homemade production) [6]. Dairy ingredients, sweeteners, stabilizers, emulsifiers, and flavorings are carefully measured and mixed to obtain a uniform mixture. The ice cream mix is then pasteurized at a specific temperature for a defined period, followed by rapid cooling. During pasteurization, harmful pathogenic and spoilage microorganisms are inactivated, and hydrolytic enzymes are neutralized. The next stage is homogenization, during which a stable emulsion is formed, resulting in improved texture, consistency, and mouthfeel of the final product. Subsequently, the mixture undergoes an aging process at 4°C for 4–24 h, which prepares the mix for freezing and facilitates the partial crystallization of milk fat. During aeration with freezing, the mixture is whipped, air is incorporated, and ice crystals are formed. Finally, the ice cream is hardened by blast freezing [7].

However, the consumption of dairy-based ice cream may pose health concerns, including lactose intolerance and hypercholesterolemia [8]. Increasing concerns about sustainability and health have led more consumers to choose plant-based products, including frozen desserts made from grains, legumes, nuts, seeds, and fruits [9]. Non-dairy frozen desserts available on the market include water ices, plant-protein-based products (such as those derived from soybeans, coconuts, rice, and almonds), and fruit-based products such as sorbets, ice lollies, and smoothies [10]. Non-dairy frozen desserts are typically consumed occasionally rather than on a daily basis, with intake generally increasing during warm or hot seasons in many countries [10]. For such products, in which dairy ingredients are fully or partially replaced by plant-based raw materials, various terms are used, including plant-based ice cream (e.g., peanut ice cream, mung bean ice cream) [11], frozen desserts (e.g., frozen blueberry-soy dessert) [12], and ice cream with a combined composition. The specific name often depends on national legislation and local traditions regarding product classification and labeling.

Frozen dessert formulations incorporate plant-based milk. Plant-based milks are rich in a variety of bioactive compounds that contribute to the development of functional products. For instance, soy milk provides isoflavones and phytosterols, almond milk is a source of tocopherol and arabinose, oat milk contains $\beta$-glucans, and hemp seed milk is characterized by a high content of polyunsaturated fatty acids and essential fatty acids [13]. Bioactive enrichment of frozen desserts can be achieved through the incorporation of ingredients such as propolis [14] as well as psyllium and pectin fibers [1].

The incorporation of plant-based milk into frozen dessert formulations influences their nutritional, physicochemical, and sensory properties. Differences in the protein and fat content of plant-based milk significantly influence the texture, ice crystal formation, and overall consistency of frozen desserts [1].

The high dietary fiber content of hazelnuts can enhance the textural properties of frozen desserts due to their water-holding, gel-forming, thickening, and texturizing capacities [15]. Frozen desserts formulated with hemp milk have been reported to exhibit higher fat content, resulting in increased hardness [1]. However, these desserts may also present a slightly undesirable aroma characteristic of hemp seed milk [1]. An increase in soy milk content has been associated with reduced sensory acceptability due to the presence of a characteristic beany flavor [16]. Despite the lower total solids content in non-dairy formulations based on coconut milk, these frozen desserts exhibit a finer texture [17]. Additionally, frozen desserts containing hazelnut milk demonstrate a smoother structure and improved melt-in-the-mouth properties, which can be attributed to reduced ice crystal formation [15].

Reducing the consumption of animal-based products is considered an effective strategy for addressing environmental concerns. Growing awareness of animal welfare, environmental pollution, milk protein allergies, and lactose intolerance, along with the increasing adoption of vegetarian and vegan diets, has led to rising interest in dairy alternatives and has strengthened their perception as sustainable food options [18]. Given the rapid development of the market for such products and the expansion of their range, it is important to analyze these products in terms of their nutritional value as well as their physicochemical and sensory properties. Such analysis is necessary to identify their main advantages and disadvantages, as well as opportunities for further development in this field.

## 14.2 Properties of frozen desserts containing plant-based milk

### 14.2.1 Nutritional value

**Table 14.1** presents the nutrient composition of frozen desserts formulated with plant-based milk, including hemp, soy, rice, coconut, cashew, hazelnut, peanut, and lupine. In the analyzed formulations, dairy ingredients were either completely replaced with plant-based milk or partially substituted.

In frozen desserts formulated with plant-based milk, protein content varies widely, ranging from 1.09 to 12.12% (**Table 14.1**). In most samples, protein levels do not exceed 5.0%, whereas only certain desserts made with lupine, coconut, and hazelnut milk exhibit higher protein contents of 8.10, 10.70, and 12.12%, respectively. In contrast, some frozen desserts prepared with almond, coconut, and rice milk show very low protein levels of 1.09, 1.30, and 1.38%, respectively. Protein content primarily depends on the composition of the desserts, particularly the proportion of any dairy ingredients and the protein content of the plant-based milk used. Analysis indicates that even when plant-based milks derived from high-protein sources – such as soybeans, peanuts, almonds, lupine, hemp, and cashews – are utilized, the protein content in the final frozen desserts can remain low. This is largely due to the processing methods of the plant-based milk and its proportion in the dessert formulation. For comparison, conventional dairy ice cream contains an average of 4.1% protein [28]. Therefore, certain frozen desserts formulated with plant-based milk can serve as a dietary source of plant protein. Although protein plays an important role in the development of ice cream structure, levels above 4% may negatively affect product quality, particularly by worsening sensory properties, increasing hardness, and reducing overrun [29].

**Table 14.1 Nutritional profile of frozen desserts containing plan-based milk**

| Frozen dessert | Protein, % | Fat, % | Carbohydrates, % | Dietary fiber, % |
|---|---|---|---|---|
| AlFD | 1.09–4.93 | 1.74–2.67 | n.d. | n.d. |
| HeFD | 2.04–3.94 | 3.20–9.80 | 16.00 | 0.20 |
| SoFD | 2.80–5.26 | 2.45–5.80 | 9.52–24.65 | 1.15–1.19 |
| RiFD | 1.38–4.20 | 3.32–3.98 | 26.61–27.4 | 0.14–0.30 |
| CoFD | 1.30–10.70 | 5.00–11.60 | 10.78–11.34 | n.d. |
| CaFD | 2.18–4.60 | 2.07–10.46 | 10.31–31.08 | 0.08–2.54 |
| HaFD | 4.38–12.12 | 2.73–8.02 | n.d. | n.d. |
| PeFD | 2.32–2.80 | 10.30–10.50 | n.d. | n.d. |
| LuFD | 2.13–8.10 | 1.22–10.30 | 20.28–21.38 | 0.13–0.30 |

*Source: [1, 4, 8, 13, 15–27]*
*Note: AlFD – frozen dessert with almond milk; HeFD: frozen dessert with hemp milk; SoFD: frozen dessert with soy milk; RiFD: frozen dessert with rice milk; CoFD: frozen dessert with coconut milk; CaFD: frozen dessert with cashew milk; HaFD: frozen dessert with hazelnut milk; PeFD: frozen dessert with peanut milk; LuFD: frozen dessert with lupine milk; n.d.: no data*

Fat is an important structural component of ice cream, as it contributes to the stability of the air phase and provides sensory attributes of the product [30]. In traditional dairy ice cream, the average fat content is approximately 16.0% [28], while in some countries a minimum milk fat content of 10% is required for products labeled as ice cream [30]. In the analyzed samples of frozen desserts formulated with different plant-based milks, the fat content ranges from 1.22 to 11.60% (**Table 14.1**). Reducing the fat content of a product is consistent with modern trends in healthy eating and contributes to a lower caloric value, since fat provides more energy per gram than other macronutrients. In desserts formulated with almond milk, the fat content is among the lowest, ranging from 1.74 to 2.67% [1, 18], although almonds themselves are a raw material with a high fat content. In contrast, certain frozen desserts formulated with coconut, peanut, and cashew milk contain relatively high fat levels of 11.60, 10.50, and 10.46%, respectively. This fat content is mainly determined by the product formulation and the method used to produce plant-based milk from raw materials containing a significant proportion of fat.

Carbohydrates represent the most abundant macronutrient in frozen desserts, with contents ranging from 9.52 to 31.08% (**Table 14.1**). For comparison, the average carbohydrate content in plain dairy ice cream is 20.7% [28]. The highest carbohydrate levels were observed in frozen desserts formulated with rice milk, ranging from 26.61 to 27.45% [22], which is associated with the naturally high carbohydrate content of rice and, consequently, rice milk. To a large extent, the carbohydrate content is determined by the amount of added sugar in the formulation, which is used to sweeten the product and impart flavor. In addition to sucrose, other sweeteners commonly used in frozen dessert formulations include dextrose, corn syrup, invert sugar, lactose, fructose, and malt syrup. Sucrose is the most widely used sweetener; however, recent studies have focused on developing ice cream with a low glycemic index while maintaining physicochemical properties and sensory quality similar to those of sucrose-sweetened ice cream [31]. The recommended sugar content in ice cream is 14–16% [32].

Dietary fiber is widely used as a fat replacer in ice cream formulations. The incorporation of dietary fiber significantly increases the viscosity of the ice cream mix and contributes to lower melting temperatures. Ice cream produced with inulin has been reported to be comparable to full-fat products in terms of quality. Ice cream containing oat fiber exhibits increased hardness, higher freezing point temperatures, and reduced overrun compared with products without fiber incorporation [33]. The addition of plant-based milk to frozen dessert formulations also contributes to an increase in dietary fiber content. In the analyzed frozen desserts, the fiber content ranges from 0.14 to 2.54% (**Table 14.1**), with the highest level observed in one of the samples formulated with cashew milk.

### 14.2.2 Physicochemical properties

**Table 14.2** presents the physicochemical properties of frozen desserts containing plant-based milk, including total solids, ash content, pH, specific gravity, and acidity.

The total solids content significantly influences the sensory properties of frozen desserts, particularly texture, as well as hardness, melting rate, and heat shock resistance. The total solids content of the product depends on the composition of its ingredients, especially the plant-based milk used. In addition, sweeteners (e.g., sucrose), mineral fortifiers, stabilizers, and emulsifiers also contribute to the total solids content of ice cream. In the analyzed frozen desserts, the total solids content varies widely, ranging from 17.9 to 40.8% (**Table 14.2**), depending on the product formulation. The lowest total solids content (17.9%) is observed in a sample formulated with cashew milk, whereas samples formulated with peanut milk exhibit the highest values, ranging from 39.9 to 40.8% [25]. In plain dairy ice cream, the total solids content typically ranges from 33.9 to 44.1% [34]. Therefore, plain ice cream generally contains higher levels of total solids than products formulated with plant-based milk.

**Table 14.2 Physicochemical properties of frozen desserts containing plan-based milk**

| Frozen dessert | Total solids, % | Ash content, % | pH | Specific gravity, g/cm$^3$ | Acidity, % |
|---|---|---|---|---|---|
| AlFD | 30.6 | 1.27 | 6.10–7.42 | 1.09 | n.d. |
| HeFD | 29.9–35.5 | 0.50–0.70 | 3.80–6.78 | n.d. | n.d. |
| SoFD | 24.6–34.2 | 0.58–1.77 | 6.59–7.50 | 0.60–0.63 | 0.15–0.94 |
| RiFD | 32.9–35.2 | 0.31–0.40 | 6.74–7.31 | n.d. | n.d. |
| CoFD | 22.0–35.4 | 0.46–0.59 | 5.78–6.59 | 0.98–1.06 | 0.26 |
| CaFD | 17.9–37.3 | 0.62–1.85 | 5.20–7.00 | 1.01–1.09 | 0.27–0.80 |
| HaFD | 31.4–36.8 | 1.15–1.30 | 6.19–6.61 | n.d. | n.d. |
| PeFD | 39.9–40.8 | n.d. | 6.71–6.74 | n.d. | 0.11–0.12 |
| LuFD | 33.5–39.0 | 0.77–1.18 | 6.38–7.15 | n.d. | 0.70–0.72 |

*Source: [1, 4, 13, 15–26, 36–38]*
*Note: n.d. – no data*

In frozen desserts formulated with plant-based milk, the ash content ranges from 0.31 to 1.85% (**Table 14.2**). The lowest ash content (0.31%) is observed in a sample of frozen dessert formulated with rice milk, whereas a sample containing cashew milk exhibits the highest ash content (1.85%). Ash content depends on the mineral composition of the ingredients used in the formulation. The inclusion of plant-based milk contributes to an increase in the ash content of the final product. For comparison, the ash content in low-fat ice cream is approximately 1.5% [35].

Flavored ice cream typically has a pH ranging from 3.49 to 7.32 [34], whereas frozen desserts formulated with plant-based milk exhibit a pH range of 3.80 to 7.50 (**Table 14.2**). The lowest pH value (3.80) is observed in a sample of frozen dessert formulated with hemp milk, while the highest value (7.50) is recorded for a sample containing soy milk. The acidity of frozen desserts is influenced by the ratio of dairy to plant-based ingredients, particularly in products with a combined formulation. It also depends on the composition of the plant-based milk, as well as the presence and proportion of the fruit and berry components in the formulation.

The specific gravity of frozen desserts depends on their composition, particularly the content of total solids and incorporated air. In the analyzed samples, the specific gravity ranges from 0.60 to 1.09 g/cm$^3$ (**Table 14.2**). The lowest specific gravity (0.60–0.63 g/cm$^3$) is observed in frozen desserts formulated with soy milk. In contrast, samples formulated with almond and cashew milk exhibit higher specific gravity values, ranging from 1.01 to 1.09 g/cm$^3$. Therefore, the specific gravity of some frozen dessert samples exceeds that of low-fat ice cream (1.068 g/cm$^3$) [35].

Acidity of frozen desserts containing plant-based milk ranges from 0.11 to 0.94% (**Table 14.2**). Desserts containing peanut milk exhibit the lowest acidity (0.11–0.12%) [25]. In contrast, some samples formulated with soy, cashew, and lupine milk show higher acidity values of 0.94, 0.80, and 0.72%, respectively. Acidity significantly affects the sensory properties of frozen desserts. Optimal acidity enhances the intensity of taste and aroma, whereas both lower and higher values may lead to a deterioration in the overall sensory quality of the product.

## 14.3 A mathematical approach to comparative quality evaluation of frozen desserts

The properties that characterize the quality of frozen desserts formulated with plant-based milk can be classified into the following groups: nutritional (protein, fat, carbohydrates), chemical (total solids, ash, pH, acidity), physical (specific gravity, viscosity, overrun, hardness, melting rate), sensory (appearance, taste, aroma, consistence, color), functional (vitamins, minerals, dietary fiber, flavonoids, pectins, carotenoids, omega-3 and omega-6, amino acids), and microbiological (mesophilic aerobic and facultative anaerobic microorganisms, etc.). Each group is defined by a specific set of indicators, as presented in **Fig. 14.1**. This representation of product properties is referred a property tree.

As a result of evaluating the significance of these indicators by seven experts using the methodology described in [39], weighting coefficients were determined for both the groups and the individual indicators. The weighting coefficients for the groups are as follows: nutritional indicators – $m_1 = 0.211$; chemical indicators – $m_2 = 0.061$; physical indicators – $m_3 = 0.157$; sensory indicators – $m_4 = 0.252$; functional indicators – $m_5 = 0.122$; microbiological indicators – $m_6 = 0.197$. Thus, according to expert assessment, sensory indicators represent the most significant group in evaluating the quality of frozen desserts, whereas chemical indicators are the least significant.

The weighting coefficients of the indicators within each group are presented in **Table 14.3**. Among the nutritional indicators, protein content has the highest importance ($m_{11}$ = 0.452), while among the chemical indicators, total solids content is the most significant ($m_{21}$ = 0.400). Overrun is the most important physical indicator of frozen desserts ($m_{33}$ = 0.324). Among the sensory indicators, taste has the highest weighting coefficient ($m_{42}$ = 0.305), whereas color has the lowest ($m_{45}$ = 0.086). Within the group of functional indicators, vitamin content ($m_{51}$ = 0.218) and mineral content ($m_{52}$ = 0.155) are the most significant.

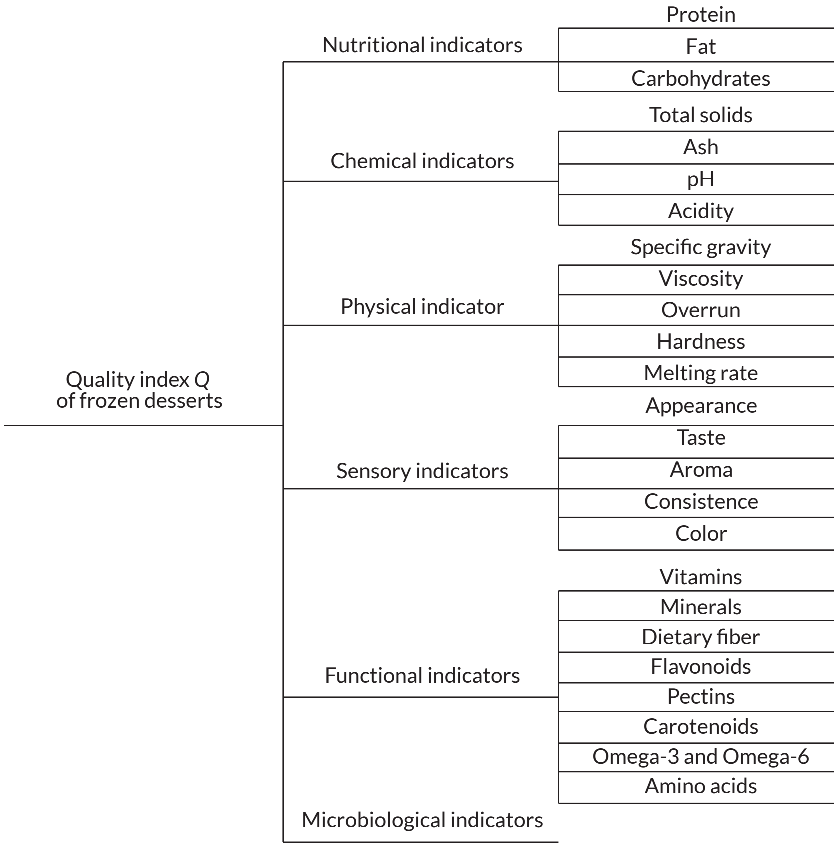


**Fig. 14.1** Groups of specific indicators characterizing the quality of frozen desserts (property tree)

**Table 14.3 Weighting coefficients of quality indicators for frozen desserts formulated with plant-based milk**

| Quality indicators | Weighting coefficients | Quality indicators | Weighting coefficients |
|---|---|---|---|
| **Nutritional indicators** | | **Physical indicator** | |
| Protein | $m_{11} = 0.452$ | Specific gravity | $m_{31} = 0.114$ |
| Fat | $m_{12} = 0.262$ | Viscosity | $m_{32} = 0.152$ |
| Carbohydrates | $m_{13} = 0.286$ | Overrun | $m_{33} = 0.324$ |
| **Chemical indicators** | | Hardness | $m_{34} = 0.181$ |
| Total solids | $m_{21} = 0.400$ | Melting rate | $m_{35} = 0.229$ |
| Ash | $m_{22} = 0.186$ | **Functional indicators** | |
| pH | $m_{23} = 0.257$ | Vitamins | $m_{51} = 0.218$ |
| Acidity | $m_{24} = 0.157$ | Minerals | $m_{52} = 0.155$ |
| **Sensory indicators** | | Dietary fiber | $m_{53} = 0.119$ |
| Appearance | $m_{41} = 0.209$ | Flavonoids | $m_{54} = 0.087$ |
| Taste | $m_{42} = 0.305$ | Pectins | $m_{55} = 0.091$ |
| Aroma | $m_{43} = 0.171$ | Carotenoids | $m_{56} = 0.060$ |
| Consistence | $m_{44} = 0.229$ | Omega-3 and Omega-6 | $m_{57} = 0.131$ |
| Color | $m_{45} = 0.086$ | Amino acids | $m_{58} = 0.139$ |

The quality index of frozen desserts formulated with plant-based milk is calculated using the following equation

$$Q = m_1 \sum_{i=1}^{3} m_{1i} q_{1i} + m_2 \sum_{j=1}^{4} m_{2i} q_{2i} + m_3 \sum_{k=1}^{5} m_{3k} q_{3k} + m_4 \sum_{l=1}^{5} m_{4l} q_{4l} + m_5 \sum_{t=1}^{8} m_{5t} q_{5t} + m_6 q_6,$$

where $Q$ – the quality index of frozen desserts; $m_1$, $m_2$, $m_3$, $m_4$, $m_5$, $m_6$ – the weighting coefficients of the groups of indicators; $m_{1i}$, $m_{2j}$, $m_{3k}$, $m_{4l}$, $m_{5t}$ – the weighting coefficients of individual indicators within each groups (**Table 14.3**); $q_{1i}$, $q_{2j}$, $q_{3k}$, $q_{4l}$, $q_{5t}$, $q_6$ – the relative quality indicators of the product.

Relative quality indicators of the product are calculated using the equations:

$$q^* = \frac{P}{P_{rec}} \text{ or } q^{**} = \frac{P_{rec}}{P},$$

where $P$ – the measured value of a frozen dessert indicator (e.g., vitamin content, protein content, total solids content, taste score, overrun, specific gravity, etc.); $P_{rec}$ – the recommended (optimal) value of the frozen dessert indicator.

The relative quality indicator $q^*$ is calculated when an increase in the value of the indicator $P$ has a positive effect on product quality. For example, if the taste of the product is rated 4 points on a 5-point scale, the corresponding relative indicator for taste is $q^* = q_{42} = 4/5 = 0.8$. The relative quality indicator $q^{**}$ is calculated when an increase in the value of the indicator $P$ has a negative effect on product quality. For instance, if the number of mesophilic aerobic and facultative anaerobic microorganisms in 1 g of the product is $0.8 \cdot 10^5$ CFU, while the permissible limit is $1 \cdot 10^5$ CFU, then $q^{**} = q_6 = 1 \cdot 10^5 / (0.8 \cdot 10^5) = 1.25$.

The quality index $Q$ is useful for comparing different products, providing an objective and comprehensive numerical assessment. A product with the higher $Q$ value is considered to have superior quality.

### 14.4 SWOT analysis of frozen desserts containing plant-based milk

A multi-criteria SWOT analysis was conducted to evaluate frozen desserts formulated with plant-based milk [40]. Specifically, the economic, marketing, social, technological and quality-related strengths and weaknesses of these products, as well as the associated opportunities and threats, were assessed.

#### 14.4.1 Strengths of frozen desserts containing plant-based milk

The strengths of frozen desserts formulated with plant-based milk can be categorized as follows:

S1. Economic-related strengths: the possibility of utilizing low-cost local raw materials; affordable product pricing when using locally sourced ingredients; the ability to use different types of plant-based raw materials throughout the year, taking into account their seasonal availability; the potential use of by-products (e.g., okara) generated during plant-based milk production; and potential for cost optimization through simplified storage and longer shelf life of certain plant-based ingredients (e.g., plant-based milk powders).

S2. Marketing-related strengths: alignment with healthy eating trends; the possibility of positioning the product as vegan; the potential for marketing it as a low-calorie product free from animal-derived ingredients; the expansion of the frozen dessert assortment; and opportunities for clean-label positioning.

S3. Social-related strengths: support for healthy eating concepts; suitability for individuals with milk protein allergies and lactose intolerance; promotion of plant-based products; and increasing consumer interest in environmentally friendly lifestyles (e.g., sustainable consumption patterns, reduced environmental footprint).

S4. Technological-related strengths: processing methods that do not significantly differ from plain ice cream production; the possibility of using various types of plant-based milk in the formulations; the use of powdered plant-based milk; the potential to combine different types of plant-based milk or both plant- and animal-based ingredients; flexibility in formulation design to tailor texture, flavor, and nutritional profile; and the potential to develop products containing functional ingredients (e.g., probiotics, dietary fiber, bioactive compounds).

S5. Quality-related strengths: a wide range of flavors; a texture comparable to that of plain dairy ice cream; the presence of dietary fiber; lower fat content; reduced caloric value; the potential for enrichment with bioactive compounds derived from plant-based ingredients; in most cases, the absence of lactose; and, in some instances, the products with specific functional or health-promoting properties.

### 14.4.2 Weaknesses of frozen desserts containing plant-based milk

The weaknesses of frozen desserts formulated with plant-based milk can be grouped into the following categories:

W1. Economic-related weaknesses: the need to store plant-based raw materials due to seasonal production or processing cycles; some types of plant-based milk (e.g., almond, peanut, and cashew milk) are more expensive than cow's milk; potential additional costs for imported raw materials (e.g., coconuts, almonds, peanuts); and instability in the supply of imported ingredients.

W2. Marketing-related weaknesses: consumer preference for dairy products; the requirement for extensive advertising campaigns to communicate the benefits of plant-based frozen desserts; and challenges in building consumer trust in new products.

W3. Social-related weaknesses: prejudiced attitude towards plant-based dairy analogues; and conservatism among certain consumer segments.

W4. Technological-related weaknesses: in some cases, the need to use stabilizers and emulsifiers to achieve the desired texture; the need to incorporate flavors to mask undesirable aromas and tastes from certain raw materials (e.g., hemp seeds, legumes); and the need to add colorants to achieve an appealing appearance.

W5. Quality-related weaknesses: the potential presence of allergens (e.g., soybeans, nuts); undesirable beany or atypical flavors; in some cases, a texture inferior to dairy ice cream; and unconventional coloration depending on the plant-based ingredients used.

### 14.4.3 Opportunities for frozen desserts containing plant-based milk

The opportunities for frozen desserts formulated with plant-based milk can be organized into the following categories:

O1. Economic-related opportunities: wide availability of plant-based raw materials; potential for expanding the market for products derived from plant-based ingredients; opportunities to export products to countries with higher demand for frozen plant-based desserts; and increasing consumer demand for functional and health-promoting products.

O2. Marketing-related opportunities: the potential to develop new brands of healthy desserts; growing popularity of vegan products; expansion of the functional dessert ranges through diverse combinations of raw materials; and promotion of products via eco-markets, social media platforms, and targeted marketing campaigns.

O3. Social-related opportunities: a growing population with lactose intolerance; increasing consumer interest in ecological and ethical food consumption; the spread of vegetarian diets; and enhanced consumer awareness of sustainable lifestyles.

O4. Technological-related opportunities: development of plant-based milk production methods that minimize nutrient losses; potential use of plant-based substitutes for animal fats, particularly carbohydrate-based alternatives; innovation in stabilizers and texturizers to improve product quality; application of advanced homogenization techniques to enhance texture and mouthfeel.

O5. Quality-related opportunities: the use of organic plant raw materials; development of novel flavor combinations; creation of functional frozen desserts enriched with vitamins, minerals, and bioactive additives; and the potential for clean-label products.

### 14.4.4 Threats for frozen desserts containing plant-based milk

The threats for frozen desserts formulated with plant-based milk can be organized into the following categories:

T1. Economic-related threats: fluctuations in the prices of plant-based raw materials due to crop failures and increasing costs of energy and fertilizers; economic instability that reduces consumer purchasing power; high competition in the ice cream and frozen dessert market; and dependence on imported raw materials in some regions.

T2. Marketing-related threats: instability of food trends; the possibility of product imitation by competing manufacturers; and market saturation with similar plant-based products.

T3. Social-related threats: possible negative perception of non-dairy alternatives to traditional products; and aging populations in many countries, which tend to be more conservative in their product choices.

T4. Technological-related threats: technological challenges associated with the use of novel raw materials.

T5. Quality-related threats: possible inconsistency in product properties compared to traditional dairy products.

### 14.4.5 SWOT-based strategic development for frozen dessert formulated with plant-based milk

SO Strategy: use healthy eating trends, lactose-free properties, and formulation flexibility (S2, S4, S5) to meet the growing demand for functional and plant-based products (O1, O2, O5). This strategy involves developing functional, clean-label frozen non-dairy desserts enriched with bioactive compounds, vitamins, and dietary fiber.

SO Strategy: use the availability of diverse and cost-effective local plant-based raw materials and by-products (S1, S4) to broaden the assortment of non-dairy frozen desserts (O1, O2). This strategy involves expanding the product range through the development of new flavor combinations based on local raw materials, thereby enhancing market competitiveness and supporting local agricultural systems.

WO Strategy: use advances in processing technology and ingredient innovation (O4, O5) to address shortcomings related to undesirable flavors and non-traditional textures (W4, W5). This strategy involves applying novel stabilizers, enhanced homogenization techniques, and optimized plant-based milk production methods to improve product quality and consumer acceptance.

ST Strategy: use strengths such as vegan positioning, environmental benefits, and functional properties (S2, S3, S5) to mitigate threats related to market competition and product imitation (T1, T2, T3). This strategy focuses on developing a strong brand identity based on sustainability, health benefits, and ethical consumption, thereby ensuring a lasting competitive advantage.

## 14.5 Conclusions

Given the increasing prevalence of diets among consumers that involve the partial or complete replacement of animal-based foods with plant-based alternatives, as well as the growing market demand for functional products, the development of novel products that align with these trends is highly relevant. Among such products are frozen desserts formulated with plant-based milk. In these products, dairy ingredients are partially or completely replaced with plant-based milk, such as soy, almond, hemp, rice, peanut, and others. This substitution contributes to the enrichment of products with bioactive compounds and enhances their sensory diversity, while most of the key chemical, physical, and textural properties remain comparable to those of plain dairy ice cream.

The analysis of nutritional and physicochemical properties of frozen desserts formulated with plant-based milk revealed a wide variation depending on product formulation and the processing methods used for the ingredients, particularly plant-based milk. At the same time, this analysis made it possible to identify the main groups of indicators influencing product quality, namely nutritional, chemical, physical, sensory, functional, and microbiological. This approach enabled the construction of a property tree for frozen dessert quality indicators and the development of a mathematical model based on it for evaluating the quality of such products. The proposed model is based on the use of weighting coefficients that reflect the importance of each group of indicators and individual indicators, and it also takes into account the recommended (optimal) values of each indicator by comparing them with the corresponding values of the product. The calculation of quality indices for different frozen desserts enables a comprehensive numerical comparison and the identification of the most preferable product. The model can be further expanded by incorporating additional quality indicators.

The SWOT analysis of frozen desserts containing plant-based milk made it possible to identify their strengths and weaknesses, as well as the associated opportunities and threats. This provided a basis for developing strategic directions for the advancement of such products, including the maximum utilization of local raw materials, particularly organic plant-based ingredients; enrichment with bioactive compounds to create functional products; diversification of sensory properties through the combination of different raw materials; and the application of advanced technologies and innovative ingredients to improve product quality and support brand positioning in terms of sustainability, health benefits, and ethical consumption.

Further research should focus on exploring the potential for combining different types of plant-based milk in frozen dessert formulations to achieve a balanced nutritional profile.

## Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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The study was performed without financial support.

## Data availability

Manuscript has no associated data.

## Use of artificial intelligence statement

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

## Authors' contributions

**Igor Dudarev**: Supervision, Conceptualization, Investigation, Data curation, Formal analysis, Resources, Validation, Writing – original draft.
**Tamara Sydoruk**: Conceptualization, Investigation, Data curation, Formal analysis, Visualization, Resources, Writing – original draft.
**Mykola Andrushchenko**: Conceptualization, Data curation, Formal analysis, Resources, Writing – original draft, Writing – review and editing.

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