Journal homepage: www.fia.usv.ro/fiajournal
Journal of Faculty of Food Engineering,
Ştefan cel Mare University of Suceava, Romania
Volume XXV, Issue 2 - 2026, pag. 90 - 97

FOOD AND ENVIRONMENT SAFETY

DEVELOPMENT AND PHYSICOCHEMICAL CHARACTERIZATION OF INNOVATIVE ICE CREAM FORTIFIED WITH SEED AND FRUIT CREAMS

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Received 08 December 2025, accepted 30 June 2026

Abstract: *The purpose of this paper is the development of innovative ice cream formulas, aiming to improve the nutritional and functional profile by fully replacing animal cream with oilseed creams (pine, hemp, pumpkin, sunflower and hazelnut). Additionally, blueberry jam and apple jam were used as natural ingredients, without added sugar, to increase the content of bioactive compounds. The methodology included the production of six experimental variants, subjected to rigorous physicochemical analyses. The results highlight a nutritional superiority of the plant-based variants. The dry matter increased in the experimental samples, reaching a maximum of 53.94% (S4), an essential parameter for a dense texture and resistance to ice crystallization. The protein intake was significantly improved, with ice cream with pumpkin seed cream recording 1.17%, compared to only 0.19% in the control. The mineral enrichment was remarkable, with the hazelnut cream variant reaching an ash content of 2.29%, over seven times higher than the control (0.31%). Although the lipid level remained relatively constant (13-14%), the substitution ensured a healthier fatty acid profile. At the same time, the buffering capacity of the vegetable proteins increased the pH from 3.86 to over 5.0 in some variants, offering a more balanced taste. In conclusion, the integration of seed creams allows to produce "clean label" frozen desserts, which combine high nutritional density with optimal physicochemical properties, representing a sustainable and healthy alternative to conventional products*

Keywords: *clean label, functional ingredients, nutritional products, stability*

1. Introduction

Ice cream is one of the most widely consumed frozen desserts worldwide, being a complex colloidal system consisting of partially coalesced fat globules, ice crystals, and air bubbles dispersed in an unfrozen serum [1,2]. In recent years, consumer demand for healthier products has forced the industry to explore new strategies, such as replacing animal fats and sugar with functional ingredients [1]. The use of dietary fibers, plant proteins, such as those from pea or soy, and oleogels has been documented as an effective method for improving the nutritional profile without sacrificing texture [1]. Fibers function as texturizing agents due to their high water-binding capacity and ability to form gel networks. For example, inulin has the capacity to form microcrystalline gel networks that closely mimic the texture and fatty mouthfeel of lipids in reduced-fat products [1]. Acacia gum and fruit fibers, such as apple or citrus fibers, increase the viscosity of the mix and improve stability, providing greater resistance to melting [3]. β-glucans from oats or yeast play a crucial role in controlling ice crystallization by reducing crystal size and ensuring a uniform distribution of air, which contributes to a smooth texture [4]. Plant proteins, particularly those from pea and soy, are used to replace dairy proteins, contributing to emulsification and structural stability. Pea protein microgels (PPMs) can replace up to 60% of the cream in a recipe while maintaining high structural stability and overrun, or degree of aeration, comparable to that of traditional variants [5]. Soy protein, often combined with fibers such as

DOI: https://doi.org/10.4316/fens.2026.09

pomelo fibers, effectively stabilizes vegetable oils in oil-in-water emulsions, creating a robust colloidal system that retains air bubbles and fat globules even at higher temperatures [6].

The use of faba bean protein concentrates has shown that a moderate inclusion level, approximately 8.5%, provides rheological and melting characteristics like those of premium ice cream [7]. Oleogels enable the transformation of unsaturated liquid oils into semi-solid structures, offering functionality like that of saturated fats, such as butter or hydrogenated coconut fat, but with clear benefits for cardiovascular health [5]. They consist of a three-dimensional network, formed by structuring agents such as candelilla wax, beeswax, or chitosan, which traps the liquid oil [8]. Chitosan-based oleogels incorporated after pasteurization provide ice cream with hardness and melting rates comparable to those obtained with milk fat, while also improving the fatty acid profile [9]. Formulations using hemp or olive oil oleogels increase the viscosity and elasticity of the ice cream mix, resulting in creamy and stable products that are valued for their high sensory acceptability [8]. Thus, the synergy between these functional ingredients enables the production of a "clean label" ice cream that not only satisfies modern nutritional requirements but also preserves the sensory pleasure of a classic artisanal dessert [6,10].

This article focuses on the development of artisanal ice cream variants enriched with blueberry jam, apple jam, and various seed creams, including pine, hemp, pumpkin, sunflower, and hazelnut creams, evaluating their impact on physicochemical characteristics.

2. Materials and methods

The experimental materials used included natural ingredients obtained without added sugar: blueberry jam, apple jam, liquid cream for the control sample, and creams made from oleaginous seeds, including pine, hemp, pumpkin, sunflower, and hazelnut, for the experimental variants.

The nutritional composition of these ingredients (lipids, carbohydrates, and proteins) was used as the basis for formulating the recipes (Table 1).

Table 1

Chemical composition of ingredients - raw materials for obtaining ice cream samples

Ingredient	Lipids [%]	Proteins [%]	Carbohydrates [%]
Blueberry jam	0.8	0.9	12
Apple jam	0.3	0.5	53
Cream	35	2.4	2.3
Pine seeds	68	14	13
Pumpkin seeds	49	32	8.8
Sunflower seeds	51.5	20.8	20
Hazelnut	60.7	15	16.7

Six ice cream variants were produced (Table 2):

- **CS - Control Sample:** based on liquid cream (400 g).
- **S1 - S5:** variants in which the liquid cream was substituted with seed creams (400 g), while maintaining constant amounts of blueberry jam (400 g), apple jam (100 g), and water (100 g).

The manufacturing process involved homogenization of the mix, followed by pasteurization, ageing, and freezing using laboratory equipment. Final storage was carried out at -18 ± 2 °C.

The physicochemical analyses focused on determining dry matter content, proteins, lipids, soluble solids, ash, titratable acidity, pH, and water activity (a_w). These methods are essential for ensuring microbiological stability and sensory quality, with the parameters being evaluated in accordance with relevant international standards. The determination of dry matter content represents an essential quality indicator, reflecting the total concentration of solid components, including proteins, sugars, fats and minerals. A high value is associated

Table 2

Manufacturing recipe for 1 kg of finished product

Ice cream	Cream [g]	Cream seeds [g]	Blueberry jam [g]	Apple jam[g]	Water [g]
CS – Control sample	400	-	400	100	100
S1 – pine seeds	-	400	400	100	100
S2 – hemp seeds	-	400	400	100	100
S3 – pumpkin seeds	-	400	400	100	100
S4 – sunflower seeds	-	400	400	100	100
S5 – hazelnut	-	400	400	100	100

with a denser and creamier ice cream, as well as increased resistance to ice crystallization. This parameter is analysed using gravimetric drying methods at controlled temperatures of 105 °C until constant weight is reached (Kern DBS60-3, Germany).

Protein and lipid contents are crucial for the formation of the structural network and the complex colloidal system. Proteins were determined using the Kjeldahl method, as they contribute to emulsification, aeration capacity, and structural stability. Lipids were analysed using the Gerber method, as they play a role in reducing ice crystal formation and stabilizing air bubbles, providing a smooth mouthfeel during tasting.

Other fundamental parameters analysed included:

- **Ash:** Determined by incineration at 550 °C, this parameter provides information on the total mineral content, including calcium, magnesium, and phosphorus, contributing to the nutritional value and ionic balance of the product. The ash content was determined according to the sample calcination method.
- **Soluble solids (°Brix):** Measured refractometrically, these directly influence the freezing point, density, and intensity of perceived sweetness.
- **Titratable acidity and pH:** These parameters indicate the freshness of the mix and influence the interaction between proteins and fats; an optimal pH between 4.5 and 6.7 ensures mix stability and sensory acceptability. The pH was determined with a pH meter Meter 766 Calimatic, (Germany).
- **Water activity (a_w):** This is a critical parameter for assessing microbiological stability, with values below 0.98 indicating reduced water availability for microbial development and showing a direct correlation with the rheological behavior of the mixture. The water activity (a_w) was determined with Lab Swift-aw CH8853 (Switzerland). All determinations were made in triplicate.

The rigorous evaluation of these physicochemical parameters, in correlation with viscosity and texture analyses, including firmness, consistency, and cohesiveness, enables the optimization of recipes to obtain a “clean label” artisanal product with high stability during storage.

Sensory evaluation of ice cream samples

The sensory evaluation of the ice cream samples was carried out by 11 panellists aged between 20 and 60 years, in accordance with the SR 6345:1995 method. For each sensory attribute, scores ranging from 0 to 5 were assigned, together with an importance coefficient, or weighting factor, *f*w.

The weighting factors were as follows: appearance, colour, consistency, and smell each had *f*w = 0.5, while taste had *f*w = 2.

The non-weighted average score, *S*a/n-w, was calculated for each sensory attribute as the arithmetic mean of the scores awarded by the panellists. The weighted average score for each ice cream sample was then calculated by multiplying the non-weighted average score for each sensory attribute by the corresponding weighting factor:

$$Sa/w = Sa/n\text{-}w \times fw \qquad (1)$$

The total weighted average score was obtained by summing all the weighted average scores corresponding to the sensory attributes of each analysed sample. Based on the overall average score, the sensory quality level of the ice cream samples was assessed on a scale from 0 to 20 points and compared with the standard.

3. Results and discussion

The physicochemical characteristics of the samples are summarized in Table 3. Based on the values presented in this table and on the specialized literature consulted, the significant impact of replacing animal cream with oleaginous seed creams on the physicochemical profile of artisanal ice cream is highlighted. According to the data presented in Table 3, the values for dry matter content ranged from 52.50% (CS) to 53.94% (S4). This increase in total solids in the variants fortified with seed creams (S1–S5), compared with the control sample, is a determining factor for the quality of the final product, as dry matter reflects the total concentration of proteins, sugars, fats, and minerals. The specialized literature emphasizes that a high solids content is directly correlated with obtaining a denser and creamier ice cream, while also providing increased resistance to ice crystallization by reducing the amount of free water in the system. In similar studies, it has been demonstrated that the structural stability of frozen desserts critically depends on the total concentration of solid components; for example, the use of apple fibers or plant proteins significantly increases the viscosity of the mix and its water-binding capacity. While a low solids content may lead to a coarse texture, the inclusion of functional plant-based ingredients compensates for the absence of dairy proteins by actively contributing to the formation of a robust structural network [1]. Soluble solids (°Brix) showed values ranging from 37.30% (CS) to 39.40% (S1). These parameters directly influence the freezing point, mix density, and intensity of perceived sweetness, with a higher soluble solids content favoring slower melting and a smoother texture [11].

This improvement in the sensory and physicochemical profile using alternative ingredients, such as stevia or functional seeds, is widely documented in recent literature, including the research of Velotto et al. [12], which highlights the importance of these compounds in optimizing artisanal ice cream [12]. A major difference can be observed in terms of protein content, where the control sample (CS) recorded a minimum level of 0.19%, while the variants enriched with seed creams showed substantial increases, with variant S3 (pumpkin seeds) reaching a value of 1.13% [1].

This trend of increasing nutritional density through the addition of plant-based by-products or protein concentrates is widely documented in the specialized literature. For example, Aydemir et al. [13] demonstrated that the use of fermented hazelnut press cake, a protein-rich by-product, significantly improved the nutritional profile of vegan ice cream, providing a protein content of up to 3.67% in the final product [13]. Compared with other referenced sources, it can be observed that protein fortification may reach even higher levels depending on the functional ingredient selected.

Teixeira et al. [7] reported increases in protein content from 2.73% in the control sample to 12.16% using faba bean protein concentrate (Vicia faba), emphasizing that these levels transform ice cream into a "source of protein" according to legislation [7].

Table 3

Physico-chemical characteristics of the developed ice cream samples

Characteristic	CS	S1	S2	S3	S4	S5
Dry matter content, %	52.50	53.90	53.78	52.86	53.94	52.98
Protein, %	0.19	0.63	1.00	1.13	0.53	0.88
Lipid, %	14.00	13.80	13.40	13.50	13.80	13.20
Soluble substances, %	37.30	39.40	39.20	37.60	38.90	38.80
Ash, %	0.31	1.02	1.87	1.54	1.15	2.29
Acidity	45	50	55	53	54	53
pH	3.86	4.86	5.25	5.06	4.75	4.40
a_W	0.91	0.92	0.90	0.89	0.91	0.90

Similarly, enrichment with oat okara made it possible to obtain values of up to 7.72% protein, demonstrating that by-products of the plant-based industry are excellent vectors for increasing biological value [14]. Plant proteins play a crucial role not only nutritionally but also technologically, through the emulsification and stabilization of air bubbles, providing a robust structure that retains fats even at elevated temperatures [5].

The consulted sources specify that proteins act as surface-active agents at the oil–water interface, forming a dense viscoelastic layer that prevents the coalescence of fat globules. The use of pea protein microgels has shown high emulsifying activity index (EAI) and emulsion stability index (ESI) values, facilitating the replacement of saturated fats without compromising texture [5]. Moreover, proteins contribute to water-holding capacity and to increased mix viscosity, which limits the mobility of water molecules and, consequently, the rate of ice crystal growth during storage [4,7].

The sources indicate that an optimal protein content, between 2.20% and 3.50% in some studies, ensures a uniform distribution of the air phase and increased resistance to melting, since the protein network can support the shape of the product even after ice melting [4,15].

The increase in protein content observed in variants S1–S5, especially in S3 and S2 with 1.00%, represents an essential step toward obtaining a balanced artisanal dessert capable of mimicking the sensory qualities of traditional dairy-based ice cream. According to the experimental data presented in Table 3, the lipid content of the analysed samples varied within a narrow range, from 14% in the control sample (CS) to 13.20% in variant S5 (hazelnut), while the other samples (S1–S4) remained between these values, ranging from 13.40% to 13.80%. Although these figures are quantitatively similar, the transition from animal cream to oleaginous seed creams, such as pine nut, hemp, pumpkin, and sunflower, marks a major qualitative change in the lipid profile by replacing saturated fats with unsaturated fatty acids beneficial to health [16]. For example, hemp seeds are recognized for their high content of linoleic acid (50–60%) and linolenic acid (20–30%), while olive or sunflower oil provides a significant intake of oleic acid, thereby contributing to the reduction of cardiovascular disease risk [16]. Fat performs essential technological functions in the colloidal system of ice cream, acting as a palate-lubricating agent and contributing to a smooth and creamy texture [1, 6]. It plays a critical role in reducing the formation of large ice crystals by limiting the mobility of water molecules and ensuring the stabilization of air bubbles during the freezing process [17]. During the maturation and freezing stages, fat globules undergo a process of partial coalescence, forming a three-dimensional network that surrounds and supports air cells, preventing structural collapse and providing resistance to melting [9]. Recent research on oleogels, such as Ropciuc et al. [8], confirms that these structured vegetable fats can effectively replace animal saturated fats without compromising quality parameters [8]. The use of structuring agents such as candelilla wax, at concentrations of 3–9%, or chitosan allows liquid oils to be trapped within a crystalline network that mimics the rheological behavior of solid fats [8]. Studies have shown that oleogel-based ice cream can maintain hardness and melting rates comparable to traditional variants, while also providing superior air stability in the mix [9]. In addition, the oxidative stability of these plant-based formulations is high, ensuring an adequate shelf life and the preservation of sensory properties appreciated by consumers [8]. Ash analysis indicates remarkable mineral enrichment of the experimental samples. Sample S5 (hazelnut) reached an ash content of 2.29%, compared with only 0.31% in the control sample [1]. This transforms the product into an important source of micronutrients, including calcium, magnesium, and phosphorus. Similar results have been reported in the fortification of ice cream with okara powder or date peel, where mineral content increased proportionally with the level of inclusion [14].

Acidity and pH: The control sample had the lowest pH (3.86) and the lowest acidity (45 °T).

The seed-based samples (S1–S5) showed a higher pH, ranging from 4.40 (S5) to 5.25 (S2) [1]. This increase in pH in the presence of plant proteins suggests their buffering capacity, facilitating a more balanced taste experience and reducing the perception of excessive acidity derived from the fruits.

Water activity (aw): Values ranged from 0.89 (S3) to 0.92 (S1).

All samples were below the threshold of 0.98, indicating reduced water availability for microbial growth and ensuring microbiological stability during storage at freezing temperatures. In conclusion, the physicochemical characteristics obtained, corroborated with bibliographic sources, demonstrate that the use of seed creams not only improves the nutritional profile, particularly in terms of proteins and minerals, but also contributes to obtaining a product with physicochemical properties superior to those of traditional cream-based ice cream.

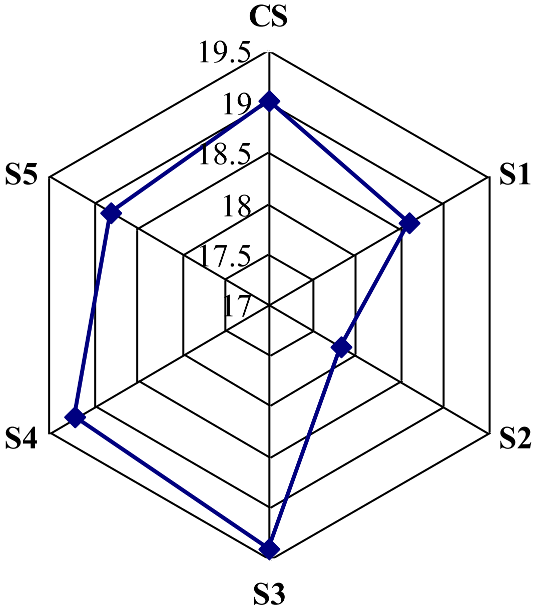

Fig. 1. Graphical representation of sensory analysis of ice cream samples

The radar chart shows that the sensory quality of the ice cream samples was generally high, with most scores close to the upper range of the scale. Sample S3, ice cream with pumpkin seeds received the highest overall sensory score, followed by CS and S4, indicating the best acceptability. Sample S2 had the lowest score, suggesting weaker sensory performance compared with the other samples.

4. Conclusion

The substitution of animal cream with oleaginous seed creams generated a substantial improvement in nutritional density, particularly in terms of mineral and protein content.

Sample S5 (hazelnut) represents the most successful formulation in mineral fortification, reaching an ash content of 2.29%, more than seven times higher than that of the control sample (0.31%). This confirms that seed residues and pastes are excellent carriers of essential micronutrients such as calcium and magnesium. Sample S3 (pumpkin seeds) stood out by recording the highest protein level (1.13%), offering a viable alternative for increasing the biological value of frozen desserts without the use of concentrated dairy proteins.

Dry matter content proved to be the critical parameter that determines sensory quality and melting stability. All experimental variants (S1–S5) recorded higher dry matter values than the control sample (52.50%), reaching a maximum of 53.94% in sample S4 (sunflower seeds). A high level of total solids, above 52%, is associated with a denser ice cream, a smoother mouthfeel, and increased resistance to ice crystal growth during storage, eliminating the need for synthetic stabilizers.

Although the total lipid content remained relatively constant, around 13–14% for all samples, the fat source was completely changed. The use of seed creams allows the replacement of saturated milk fats with unsaturated fatty acids, including omega-3 and omega-6, while maintaining the emulsification and aeration properties required for a creamy texture. Vegetable lipids from pine nuts (S1) or sunflower seeds (S4) ensure air bubble stability and a controlled melting rate, like that of premium products.

The acidity and pH parameters demonstrate better compatibility of the ingredients in the functional variants. The increase in pH from 3.86 in the control sample (CS) to values above 5 in samples S2 and S3 indicates a high buffering capacity of plant proteins. This leads to a product with a more balanced taste, in which the intense acidity of blueberries is attenuated, resulting in enhanced sensory acceptability. Water activity (aw) values ranging from 0.89 to 0.92 are optimal for preventing microbial development, ensuring product stability throughout the cold chain.

The study concludes that the most promising variants for large-scale artisanal production are S3 (pumpkin), intended for consumers seeking a high protein intake and the lowest water activity value (0.89), and S5 (hazelnut), which provides maximum nutritional benefits due to its high mineral content and elevated soluble solids content (54 °Brix), intensifying the perception of natural sweetness.

Overall, the use of seed creams and fruits without added sugar enables the production of a “clean label” ice cream that meets modern nutritional requirements without compromising the sensory pleasure of a high-quality dessert. Future research could optimise these formulations by further analysing their antioxidant profile and instrumental texture.

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