

Thermal and Structural Characterization of Traditional Trabzon Ice Cream Produced Over Prolonged Boiling

Uzun Süreli Kaynatma Yöntemiyle Üretilen Geleneksel Trabzon Dondurmasının Termal ve Yapısal Karakterizasyonu

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Abstract

This study focuses on the thermal and rheological characterization of a traditional Turkish ice cream produced via prolonged boiling; a technique rooted in the regional practices of Trabzon. In addition, its compositional and sensory properties were evaluated. The formulation, prepared without added commercial stabilizers, utilized salep, a natural thickening agent traditionally used in Turkish ice cream, and underwent extensive water evaporation, resulting in a high total solids content (36.83%) and elevated viscosity (7.50 Pa.s). Estimated protein and fat contents were 6.0% and 6.8%, respectively, contributing to the richness and elasticity of the final product. Thermal analysis using differential scanning calorimetry (DSC) revealed a crystallization peak at -14.8°C with a narrow peak width (4.9°C), and a notably low glass transition temperature (-47.0°C), suggesting a dense matrix with reduced molecular mobility only at ultra-low storage temperatures. Melting transitions occurred at elevated temperatures (melting peak: 13.1°C), further supporting the product's exceptional thermal stability. Sensory evaluation showed high ratings for texture, color, and overall acceptability, while sweetness and melting time in the mouth were rated moderately. Importantly, attributes associated with defects—such as icy structure, burnt taste, or off-flavor—received very low scores, indicating a well-controlled production process. These findings highlight the impact of traditional cooking methods on ice cream structure, stability, and consumer perception, particularly in terms of viscosity, crystallization behavior, and sensory appeal. Furthermore, the study demonstrates that such traditional techniques can produce frozen desserts with high structural integrity and desirable sensory attributes, even in the absence of commercial stabilizers or emulsifiers. This research provides a scientific basis for integrating artisanal processes into modern frozen dessert development and supports the potential for traditional Turkish products, such as Trabzon ice cream, to be introduced into broader culinary and commercial applications.

Keywords: Trabzon ice cream, Thermal behavior, Crystallization, Glass transition, Sensory analysis, Traditional dairy

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Atıf: Şen, M. A., Sezer, E. (2026). Uzun süreli kaynatma yöntemiyle üretilen geleneksel Trabzon dondurmasının termal ve yapısal karakterizasyonu. *Tekirdağ Ziraat Fakültesi Dergisi*, 23(2): 785-796.

Citation: Şen, M. A., Sezer, E. (2026). Thermal and structural characterization of traditional Trabzon ice cream produced via prolonged boiling. *Journal of Tekirdag Agricultural Faculty*, 23(2): 785-796.

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Öz

Bu çalışma, uzun süreli kaynatma tekniğiyle üretilen geleneksel bir Türk dondurmasının bileşimsel, reolojik, termal ve duyuşal özelliklerini ortaya koymaktadır. Trabzon yöresine özgü bu üretim yönteminde, ticari stabilizatör ilavesi olmadan geleneksel olarak Türk dondurmalarında kullanılan doğal bir koyulaştırıcı olan salep kullanılmıştır. Yoğun su buharlaştırması sonucunda yüksek toplam kuru madde oranı (%36.83) ve yüksek viskozite (7.50 Pa.s) elde edilmiş; tahmini protein ve yağ içerikleri sırasıyla %6,0 ve %6,8 olarak hesaplanmış ve bu değerler ürünün zenginlik ve elastik yapısına katkı sağlamıştır. Diferansiyel Taramalı Kalorimetri (DSC) ile yapılan termal analizler, -14.8 °C'de dar bir pik genişliğine (4.9 °C) sahip kristalleşme zirvesi ve -47.0 °C gibi oldukça düşük bir cam geçiş sıcaklığı göstermiştir. Bu bulgular, yalnızca çok düşük sıcaklıklarda moleküler hareketliliğin azaldığı, yoğun bir matris yapısını işaret etmektedir. Ayrıca, yüksek sıcaklıklarda gerçekleşen erime geçişleri (erime piki: 13.1 °C), ürünün termal stabilitesini desteklemektedir. Duyusal değerlendirmeler, doku, renk ve genel beğeni açısından yüksek puanlar göstermiş; tatlılık düzeyi ve ağızda erime süresi ise orta düzeyde değerlendirilmiştir. Özellikle istenmeyen özelliklerle ilgili (donuk yapı, yanık tat, yabancı tat gibi) puanlar oldukça düşüktür ve bu durum üretim sürecinin kontrollü yürütüldüğünü göstermektedir. Elde edilen bulgular, geleneksel pişirme yöntemlerinin dondurmanın yapısı, stabilitesi ve tüketici algısı üzerindeki etkisini ortaya koymaktadır. Bu yöntemler, özellikle viskozite, kristalleşme davranışı ve duyuşal cazibe açısından ürünün yapısını şekillendirmekte ve ticari katkı maddeleri olmadan da yüksek kalite elde edilebileceğini göstermektedir. Bu araştırma, zanaatkâr üretim süreçlerinin modern dondurulmuş tatlı geliştirme çalışmalarına entegrasyonu için bilimsel bir temel sunmaktadır. Ayrıca Trabzon dondurması gibi geleneksel Türk ürünlerinin daha geniş gastronomik ve ticari alanlara tanıtılması açısından da önemli bir potansiyel taşımaktadır. Bu ürünlerin davranışını anlamak; doku optimizasyonu, uygun depolama koşulları ve tüketici memnuniyeti açısından yol gösterici olabilir.

Anahtar Kelimeler: Trabzon dondurması, Termal davranış, Kristalleşme, Cam geçişi, Duyusal analiz, Geleneksel süt ürünü

1. Introduction

Ice cream is a widely consumed frozen dessert globally, valued for its texture, flavor, and melting behavior, all of which are closely linked to its physicochemical properties such as overrun, air bubble size, and ice crystal morphology. Commercial ice creams are generally produced using standardized formulations that include stabilizers and emulsifiers to ensure consistency, shelf-life, and consumer acceptance. These additives, along with processing techniques such as high-speed whipping and rapid freezing, contribute to desirable sensory properties and structural stability (Clarke and Cox, 2024; Goff and Hartel, 2013; Markowska et al., 2023).

In contrast, traditional ice cream formulations often rely on time-intensive and additive-free methods that yield distinct textures and flavors. One such example is Trabzon ice cream, a regional Turkish product prepared using high-fat cow's milk, sugar, and salep, without added stabilizers. The product is characterized by a prolonged boiling process, which leads to significant water loss, concentration of milk solids, and partial caramelization. This process not only enhances flavor and texture but also results in a dense and elastic structure that differs substantially from conventional ice creams. Despite being produced for over 150 years in the northeastern region of Turkey, Trabzon ice cream has received little scientific attention (Kaya and Tekin, 2001; Palka and Newerli-Guz, 2018; Şen, 2024).

Traditional processing techniques—such as prolonged boiling and manual stirring—not only serve cultural preservation but also influence the product's microstructure, thermal stability, and sensory performance. These methods represent a valuable intersection between traditional culinary practices and functional food design. As consumer interest in clean-label and artisanal products grows, understanding the scientific basis of such traditional formulations becomes increasingly relevant (Balthazar et al., 2018; Kaya and Tekin, 2001; Palka and Newerli-Guz, 2018; Teichert et al., 2020).

Traditional dairy-based confections such as *dulce de leche* have long employed prolonged thermal processing to create dense, elastic texture and concentrated milk matrices. While the exact origin of *dulce de leche* remains debated—with claims from Argentina, Uruguay, and other Latin American countries—it has become a staple in various desserts, including ice cream, throughout the region (Barbosa et al., 2013; Atkins and McNamee, 2023; Ranalli et al., 2012). In this context, Trabzon ice cream shares certain compositional and structural features with these confections, particularly in terms of extended boiling, reduced free water, and resulting rheological properties. Despite such similarities, ice creams produced through this type of intense thermal treatment remain largely unexplored regarding their thermal behavior, structural integrity, and storage requirements. Understanding these systems can offer valuable insights into how traditional cooking practices influence texture stability, melt resistance, and shelf-life—key factors in both artisanal and modern frozen dessert production (Kaya and Tekin, 2001; Roos and Drusch, 2015; Şen et al., 2019).

The aim of this study is to provide a detailed characterization of traditional Trabzon-style ice cream produced via prolonged boiling, focusing on its compositional, rheological, sensory, and thermal properties. In particular, special attention is given to its glass transition behavior, which is essential for understanding the product's frozen storage stability and optimizing textural attributes in gastronomy applications.

2. Materials and Methods

2.1. Materials

The ice cream samples were prepared using milk, sugar, and salep. The milk used in ice cream production was obtained from a farm in Sapanca district (Türkiye) as cow milk, while the beet sugar and commercial salep powder were purchased from a local market. All ingredients were cooked in the Application Kitchen of the Gastronomy and Culinary Arts Department of the Tourism Faculty of Sakarya University of Applied Sciences.

2.2. Production of Ice Cream

The production of Trabzon ice cream followed a meticulous process to enhance its viscosity, elasticity, and flavor profile. Initially, fresh cow's milk was assessed for coagulation stability by heating a small sample. If stable, 16,000 mL of milk was transferred to large copper kettles and continuously stirred using a traditional wooden tool, "gudal", to prevent scorching. The milk was boiled for one hour. Once boiled, 1,120 g of sugar (70 g/kg) was

gradually added with continuous stirring, and the mixture was boiled for another 45 minutes, allowing water evaporation and viscosity to increase. Salep was then incorporated to prevent clumping by first dissolving 80 g of finely ground salep in 1.5 kg of hot milk, which was slowly reintroduced into the main mixture from a height of one meter for uniform dispersion. The cooking process continued for five hours, with constant stirring to ensure a homogeneous consistency. By the end of this phase, the final mass of the prepared mix reached a final mass of 8,705 g, corresponding to a 49.4% reduction in total weight due to water loss. The endpoint of cooking was determined by a distinct tonal change in the boiling sound, a method refined through experience. The cooked mixture was transferred to a container, covered with muslin cloth, and left to cool at room temperature for 12 hours, minimizing condensation and preserving structural integrity. The aged mix obtained was then turned into an ice cream in the Valmar Smarty 7 Quick (Volčja Draga, Slovenia) ice cream machine for 10 minutes and frozen at -18 °C for 24 hours and stored at the same temperature until consumption. The approximate protein and fat content of the final product was 6.0% and 6.8%, respectively, as estimated from the formulation. Ice cream production was performed in duplicate to ensure reproducibility. The final product exhibited a firm texture and a characteristic caramel color, resulting from the prolonged heating process (Şen, 2024). The full production process is summarized in a flowchart illustrating key steps and durations (Figure 1).



Figure 1. Flowchart of the traditional production process of Trabzon ice cream

2.3. Determining the quality properties of the ice cream

2.3.1. Chemical analysis

The composition of the milk used in ice cream production was analyzed using a Milkana Express Plus milk analyzer (Mayasan Biotech, Türkiye). The detailed composition of the raw milk is presented in *Table 1*. The total solids content (%) was determined by the gravimetric method (AOAC 941.08) (AOAC, 2019). The protein and fat contents of the ice cream mix were calculated based on the dry matter content and the proportional contribution of each ingredient to the total solids. The pH of the ice cream samples was measured with a calibrated digital pH meter (Hanna Instruments, pH 211, Weilheim, Germany) at 20 ± 2 °C. The titratable acidity, expressed as lactic acid content, was determined using the titration method (AOAC 947.05) with 0.1 N NaOH (AOAC, 2019; Mehmetoğlu and Tarakçı, 2023).

Table 1. Composition of the milk used

Properties	Values
Fat	3.72 ± 0.06
Solid non-Fat	8.59 ± 0.04
Protein	3.24 ± 0.02
Lactose	4.71 ± 0.02

Mean (n=6) ± Standard deviation

2.3.2. Physical analysis

The viscosity of the ice cream samples was measured at 5 ± 2 °C using a Fungilab Alpha H viscometer (Spain) with an R3 spindle at 60 rpm. The result was expressed in Pa.s (Dervisoglu et al., 2005; Şimşek et al., 2006).

The overrun was calculated by measuring the mass of a defined volume of ice cream mix before and after freezing, using the equation (1) (Şen et al., 2019):

$$\text{Overrun (\%)} = [(\text{Mix mass} - \text{Ice cream mass}) / \text{Ice cream mass}] \times 100 \quad (\text{Eq. 1})$$

Instrumental texture analysis of the ice cream samples was performed using a Brookfield CT3-4500 texture analyzer equipped with a TA39 probe. The penetration test was conducted at -18 ± 2 °C with a pre-test speed of 2 mm/s,

test speed of 2 mm/s, penetration distance of 10 mm, holding time of 5 s, and a trigger load of 4.5 g (Brookfield Inc., 2016; Ilansuriyan et al., 2018). The results were expressed as hardness (N) and adhesive force (N).

The melting properties were assessed by placing 35 ± 0.5 g of ice cream on a wire mesh with a 3×3 mm² pore area and allowing it to melt at 20 ± 2 °C. The time required for the first drip and complete melting was recorded (Cottrell et al., 1979).

The fat destabilization (%) occurring during ice cream formation was assessed using a spectrophotometric method based on Rossa et al. (2012). The mixes and melted ice cream samples were diluted 1:500 (v/v) with distilled water and centrifuged at 1,000 rpm for 5 min. After 10 min, absorbance (A) was measured at 540 nm, using distilled water as the blank sample. Fat destabilization was calculated using the following equation (2):

$$\text{Fat destabilization (\%)} = [(A \text{ of the mix} - A \text{ of the ice cream})/A \text{ of the mix}] \times 100 \quad (\text{Eq. 2})$$

The color properties of the ice cream samples were analyzed using a Lovibond RT 300 tintometer (UK) operating in the CIE Lab* color space. Before measurements, the device was calibrated with standard white and black calibration plates. The ice cream samples were melted (5 ± 2 °C) and placed into the liquid cuvette of the device for measurement. The measurement settings were as follows: measurement mode: SCE, observation angle: 10°, sample thickness: 1 cm, and light source: D65. The recorded L*, a*, and b* values were used to calculate whiteness index (WI) and yellowness index (YI) using the following equations (3, 4) (Balthazar et al., 2018; Teichert et al., 2020):

$$WI = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2} \quad (\text{Eq. 3})$$

$$YI = [(142.86 \text{ b})/L] \quad (\text{Eq. 4})$$

2.3.3. Sensory evaluation

Sensory evaluation was conducted with 15 pre-trained panelists using a 9-point hedonic scale. The attributes “Color and appearance”, “structure and consistency”, “taste and smell”, and “general acceptability” were rated on a scale where 1 represented “very poor”, 5 was “average”, and 9 was “excellent”. The “degree of sweetness” and “melting time in mouth” were assessed based on their balance, with 5 indicating the optimal level, while lower scores (1–4) indicated insufficient intensity and higher scores (6–9) indicated excessive intensity. The attributes “icy structure”, “burnt flavor”, and “off-flavor” were considered undesirable; a score of 0 indicated absence, which was the most favorable outcome, while 1 represented a slight presence, and scores between 1 and 9 indicated increasing intensity, with 9 representing an extremely pronounced and undesirable level. Sensory analyses were conducted one week after each production to ensure consistency (Stone et al., 2012).

2.3.4. Thermal analysis

Thermal properties of the ice cream samples were analyzed using a differential scanning calorimeter (NETZSCH DSC 200 F3, Germany). Approximately 40 mg of sample was weighed into an open aluminum crucible, and an empty aluminum pan was used as the reference. The analysis was initiated at 25 °C, followed by cooling to –80 °C at a rate of 10 °C/min. During this cooling phase, the crystallization temperature (T_c) was determined. After holding isothermally at –80 °C for 30 minutes to ensure thermal equilibrium, the sample was reheated to 25 °C at the same rate (10 °C/min), and held for 1 minute. During the heating phase, the glass transition temperature (T_g) and melting temperature (T_m) were identified from the resulting thermograms (Sezer and Ayar, 2024).

2.3.5. Statistical analysis

Chemical and physical analyses were conducted in triplicate for each of two independent production batches, resulting in a total of six measurements per parameter. Values are expressed as mean \pm standard deviation. Sensory evaluation was performed by 15 panelists for each production, yielding a total of 30 data points per sensory attribute. All sensory scores are reported as mean \pm standard deviation. Although certain attributes exhibited skewed distributions, especially for undesirable traits, the mean-based presentation was retained for consistency and clarity across attributes. Thermal transitions were analyzed once per batch using DSC, and results are presented as the average of two independent measurements. Given the limited number of replicates and the artisanal nature of the production process, no inferential statistical tests were applied.

3. Results and Discussion

3.1. Composition and physicochemical characteristics

A summary of the key compositional and physicochemical attributes of the ice cream is provided in *Table 2*. The traditional ice cream formulation used in this study was characterized by a high total solids content (36.83%), primarily due to the prolonged boiling process applied during mix preparation. This step caused significant water evaporation, concentrating the milk components and resulting in a dense matrix—a typical feature of regional Turkish ice creams such as Trabzon and Maraş types (Kaya and Tekin, 2001; Şen et al., 2019). Based on formulation data and the known composition of individual ingredients, the estimated protein and fat concentrations in the final mix were 6.0% and 6.8%, respectively. Although not directly measured, these values reflect the expected nutritional profile derived from the dry matter composition and standardized raw material contents (Goff and Hartel, 2013).

Table 2. Compositional, rheological, physical, and color properties of the ice cream

Property	Value
Compositional properties	
Total solids (%)	36.83 ± 1.50
pH	5.96 ± 0.02
Lactic acid (%)	0.43 ± 0.04
Rheological property	
Viscosity (Pa.s)	7.50 ± 0.50
Physical properties	
Overrun (%)	35.01 ± 9.63
Hardness (N)	17.30 ± 0.50
Adhesive force (N)	-0.80 ± 0.10
First Dripping (sec)	2344 ± 189
Complete Melting (sec)	3551 ± 67
Fat Destabilization (%)	37.76 ± 3.55
Color properties	
L*	67.05 ± 0.82
a*	2.75 ± 0.16
b*	14.74 ± 0.51
WI	63.80 ± 0.92
YI	31.41 ± 1.39

Mean (n=6) ± Standard deviation

The final product's pH was measured at 5.96, and titratable acidity (as lactic acid) was 0.43%, indicating a mildly acidic profile consistent with milk-based traditional desserts. This acidity level helps preserve a clean, fresh dairy flavor without introducing excessive sourness (Goff and Hartel, 2013; Ürkek et al., 2022; Sezer, 2023).

The apparent viscosity of the ice cream mix was determined to be 7.50 Pa.s at 5 ± 2 °C. This relatively high viscosity supports the thick and structured nature of the mix, enhancing resistance to melting and contributing to the elastic texture characteristic of traditional products (Kaya and Tekin, 2001). It also aligns with observations in similar regional products where heat-induced protein and lactose concentration increase viscosity (Barbosa et al., 2013; Şen et al., 2018; Şen et al., 2019). This rheological behavior is critical in shaping the final product's texture and melt resistance and distinguishes it from standard ice cream formulations (Goff and Hartel, 2013; Muse and Hartel, 2004). The high viscosity also supports the hypothesis that the resulting dense matrix may contribute to the unusually low glass transition temperature observed in this study (Roos and Drusch, 2015).

The overrun was calculated as 35.01%, which is significantly lower than the values typically found in commercial ice creams (>80%). This reduced aeration contributes to the dense, chewy mouthfeel expected from artisanal ice creams (Muse and Hartel, 2004). It also aligns with the sensory preference for compact textures in regional products (Arslan et al., 2023).

Texture profile analysis showed a hardness of 17.30 N, and adhesive force was measured at -0.80 N, indicating a firm yet cohesive product structure. These mechanical properties enhance bite resistance and mouth-coating behavior,

both of which are appreciated in elastic ice cream varieties (Kaya and Tekin, 2001; Muse and Hartel, 2004; Şen et al., 2019).

The melting behavior was assessed through first dripping time and complete melting time, measured as 2344 seconds and 3551 seconds, respectively. These prolonged melting times are consistent with the high solid content and low overrun, which slow the diffusion of heat and water loss, thus preserving the shape and texture of the product longer under ambient conditions (Goff and Hartel, 2013; Muse and Hartel, 2004).

The degree of fat destabilization was recorded as 37.76%, suggesting moderate aggregation of fat globules during freezing. This level supports partial coalescence, which enhances structural integrity without creating graininess, aligning with optimal texture in low-overrun formulations (Goff and Hartel, 2013; Muse and Hartel, 2004).

Colorimetric analysis yielded the following values: $L^* = 67.05$, $a^* = 2.75$, and $b^* = 14.74$, indicating a light cream color with slight red and yellow tones typical of milk-based products. These values correspond to a Whiteness Index (WI) of 63.80 and Yellowness Index (YI) of 31.41, which are associated with the perception of freshness and dairy richness in milk-based products (Hirschler, 2015).

Overall, the product's compositional and physicochemical attributes reflect its artisanal production method and regional identity. Each parameter—solid content, acidity, viscosity, aeration, mechanical resistance, melt behavior, fat structure, and visual appearance—contributes to a distinctive texture and flavor profile, suitable for consumers seeking authentic sensory experiences rooted in tradition (Balthazar et al., 2018; Goff and Hartel, 2013; Kaya and Tekin, 2001; Roos and Drusch, 2015).

3.2. Sensorial characteristics

The final product exhibited a firm, elastic structure and a caramelized appearance characteristic of prolonged heating (Figure 2). Descriptive sensory scores across multiple attributes are presented in Table 3.



Figure 2. Appearance of the final Trabzon ice cream

Table 3. Organoleptic characteristics of the ice cream (9-point scale)

Properties	Scores
Color and Appearance	7.73 ± 1.05
Structure and Consistency	7.53 ± 1.28
Taste and Smell	7.50 ± 1.07
Degree of Sweetness	5.15 ± 1.16
Melting Time in Mouth	5.27 ± 0.74
Icy Structure	2.27 ± 2.47
Burnt Flavor	1.52 ± 1.91
Off-flavor	0.65 ± 1.19
General Acceptability	7.53 ± 1.01

Mean (n=30) ± Standard deviation

The highest score was recorded for Color and Appearance (7.73), reflecting a visually appealing product despite the absence of artificial coloring. The natural caramelization that occurs during extended boiling appears to have contributed positively to consumer perception in this category (Barbosa et al., 2013). Structure and Consistency

received a score of 7.53, supporting the notion that the product’s dense, chewy, and elastic texture—resulting from its low overrun and high viscosity—is aligned with traditional expectations for regional Turkish ice creams such as those from Maraş and Trabzon (Kaya and Tekin, 2001; Şen et al., 2018). Taste and Smell, rated at 7.50, suggest the formulation successfully delivers on traditional dairy flavor profiles, likely influenced by the concentration of milk solids and absence of overpowering additives (Goff and Hartel, 2013). The score for General Acceptability was 7.53, indicating that the product was well-received overall, despite its departure from typical commercial ice creams in terms of texture and appearance.

Lower ratings were observed in attributes where traditional processes diverge from modern preferences. For instance, Degree of Sweetness scored 5.15, reflecting a moderately sweet profile—likely appropriate for traditional consumers but potentially less appealing to those accustomed to high-sugar commercial varieties. Melting Time in Mouth received a moderate score of 5.27, consistent with the product’s elastic and less aerated matrix, which may delay melting compared to softer commercial alternatives (Goff and Hartel, 2013; Muse and Hartel, 2004; Stone et al., 2012). Notably, Icy Structure was rated relatively low (2.27), suggesting minimal ice crystallization and a smooth texture—an indication of proper freezing and mix stability. Sensory attributes associated with processing defects, such as Burnt Flavor and Off-Flavor, were scored very low (1.52 and 0.65, respectively), confirming that the prolonged heating did not negatively affect overall taste and that no undesirable notes were introduced during production.

Taken together, the sensory evaluation supports the conclusion that this product delivers a well-balanced experience rooted in traditional ice cream craftsmanship. While certain aspects like color and sweetness may benefit from fine-tuning, the current formulation demonstrates clear potential for niche consumer segments seeking natural, “clean label” frozen desserts with regional authenticity (Clarke and Cox, 2024).

3.3. Thermal characteristics

The thermal behavior of the traditional Trabzon-style ice cream was investigated by differential scanning calorimetry (DSC), with a focus on key transitions including crystallization (T_c), glass transition (T_g), and melting (T_m). Duplicate measurements from two independent production replicates yielded consistent thermal profiles, supporting the reproducibility of the results. The obtained thermograms are presented in *Figure 3*, while the onset, peak, and offset temperatures for each thermal event are summarized in *Table 4*.

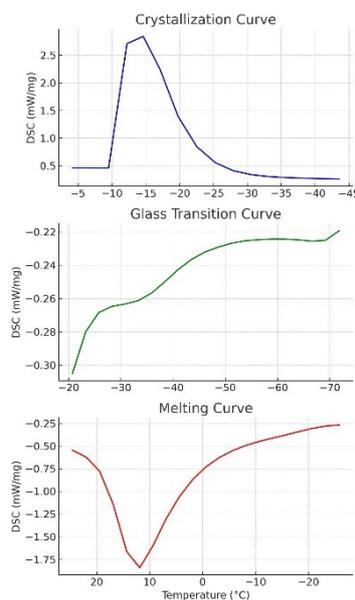


Figure 3. Differential scanning calorimetry (DSC) curves of the ice cream

During the cooling phase, the crystallization onset, peak, and offset temperatures were recorded as $-12.4\text{ }^{\circ}\text{C}$, $-14.8\text{ }^{\circ}\text{C}$, and $-17.3\text{ }^{\circ}\text{C}$, respectively. The relatively narrow crystallization peak width of approximately $4.9\text{ }^{\circ}\text{C}$ indicates a sharp and uniform phase change, reflecting homogeneous ice nucleation and growth within the concentrated matrix. This narrow profile suggests effective freezing without significant phase separation, which is beneficial for achieving a smooth texture and contributes to the product’s characteristic elasticity and melt resistance (Giudici et al., 2021).

Table 4. Thermal characteristics of the ice cream

Properties	°C
Tc (onset)	-12.4 ± 0.2
Tc (peak)	-14.8 ± 0.2
Tc (offset)	-17.3 ± 0.1
Tg	-47.0 ± 0.1
Tm (onset)	4.4 ± 0.0
Tm (peak)	13.1 ± 1.2
Tm (offset)	15.6 ± 1.2

Mean (n=2) ± Standard deviation

The glass transition temperature (T_g) was determined as -47.0 ± 0.05 °C based on linear extrapolation from the baseline. This value is markedly lower than T_g values reported for standard ice creams (typically -20 °C to -25 °C) and even lower than those found in fiber- or probiotic-enriched formulations (-28 °C to -32 °C) (Sezer et al., 2023). The exceptionally low T_g is attributed to the product's concentrated solid content and reduced free water, both outcomes of the prolonged boiling process. At conventional storage temperatures (e.g., -18 °C or -25 °C), the product remains in a rubbery state above T_g, a condition that promotes molecular mobility and may accelerate structural and sensory degradation during storage. Maintaining the product below T_g—such as at -50 °C—is necessary to ensure preservation in the glassy state (Roos and Drusch, 2015).

Upon reheating, the ice cream exhibited a distinct melting transition, with onset, peak, and offset temperatures measured at 4.4 °C, 13.1 °C, and 15.6 °C, respectively. These melting points are substantially higher than those typical of milk-based commercial ice creams, which usually begin to melt below 0 °C. The elevated melting temperatures observed here are consistent with formulations rich in solids and low in free water, where increased matrix viscosity and density delay melting. This thermal behavior aligns with previous reports on concentrated or superheated dairy matrices, which similarly show increased thermal stability in the absence of stabilizers or emulsifiers (Carvalho et al., 2022; Goff and Hartel, 2013; Muse and Hartel, 2004).

To date, thermal transition data specific to traditional products such as Maraş or *dulce de leche*-style ice creams remain limited. However, the compositional similarities—particularly high sugar content and dense matrices—suggest that these products may exhibit comparable thermal behaviors. The present findings therefore provide valuable contributions to the understanding of regional, high-solid frozen desserts and underscore the need for tailored storage and formulation strategies in the development and distribution of such artisanal products (Barbosa et al., 2013).

In summary, the combination of a narrow crystallization peak, exceptionally low T_g, and delayed melting transition highlights the unique thermal stability of Trabzon-style ice cream. These characteristics are directly linked to traditional processing methods and have important implications for product texture, shelf-life, and distribution. If scaled for broader markets, such products may require ultra-low temperature storage solutions to maintain their sensory and structural integrity (Charoenrein and Harnkarnsujarit, 2017; Sezer and Ayar, 2024).

4. Conclusions

This study provides a comprehensive evaluation of a traditional Turkish ice cream produced via prolonged boiling; a method that results in a dense, elastic product with distinctive physicochemical and thermal characteristics. Key findings include a high solid content, low overrun, and an exceptionally low glass transition temperature, which together contribute to the product's enhanced thermal stability and chewy texture. The sharp crystallization peak and delayed melting transition further support its structural integrity during storage and consumption. Sensory evaluations confirmed strong acceptability in texture and appearance, although sweetness and melt-in-mouth attributes suggest room for optimization depending on target market preferences. Such functional attributes collectively contribute to the product's notable stability and desirable sensory profile, underscoring the effectiveness of the traditional prolonged boiling method. These results demonstrate how traditional processing can yield functionally stable products with unique sensory appeal. For broader application in gastronomy and food science, adapting such traditional methods may offer valuable opportunities for clean-label, high-performance frozen desserts.

Acknowledgment

The authors would like to thank T. Çetinkaya and M. Çelik for their support with the DSC analyses.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study. The ice cream analyzed is a traditional product made with safe, commonly consumed ingredients, and no novel formulation or health-related intervention was involved. Sensory evaluation was carried out with adult volunteers who provided informed consent, including permission for the use of their anonymized data, by signing a participation and data use consent form prior to the study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Şen, M. A., Sezer, E.; Design: Şen, M. A., Sezer, E.; Data Collection or Processing: Şen, M. A., Sezer, E.; Statistical Analyses: Şen, M. A., Sezer, E.; Literature Search: Şen, M. A., Sezer, E.; Writing, Review and Editing: Şen, M. A., Sezer, E.

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