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Exploring the potential utilization of copigmented barberry anthocyanins in ice cream: Focusing on foaming aspects, and melting attributes

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ABSTRACT

Anthocyanins have emerged as promising substitutes for synthetic dyes owing to their color profiles, and potential health-boosting properties. The primary aim of this investigation was to assess the impact of copigmented, and un-copigmented barberry anthocyanins, employed at different concentrations (1, 3, and 5% w/w) as colorants in ice cream. The secondary goal was to investigate the influence of barberry anthocyanins on ice cream foaming characteristics, and melting point. The samples' physicochemical, textural, and organoleptic characteristics, total phenolic, and anthocyanin content, and antioxidant activity were determined. By increasing barberry extract concentrations in the samples, the pH levels (5.81) decreased, and overrun increased(30.0 ± 1.15%), respectively. Furthermore, the textural analysis showed that increasing barberry anthocyanins within the ice cream formulation correlated with an increase in sample hardness (113.72 ± 1.34 N). The control sample (vanilla ice cream) had the highest value of melting rate (1.09 ± 0.03 g/min), whereas the specimen containing 5% of copigmented barberry anthocyanins exhibited the lowest rate of melting (0.50 ± 0.01 g/min). The start time of melting of control sample was 1098 s and by increasing the concentration of copigmented barberry anthocyanins from 1 to 5%, this time increased from 1405.2 s to 1831.2 s ($P < 0.05$). In conclusion, barberry anthocyanins reduced the melting rate as a crucial attribute for ice cream.

1. Introduction

Barberry (*Berberis vulgaris*. L) is one of the most important medicinal plants grown mainly in Iran (Suleria et al., 2020). Food colors, encompassing both natural, and artificial variants, have extensive application in the food industry beyond visual appeal to increase various aspects of food, including taste, safety, and nutritional value like anthocyanins that are known for their antioxidative characteristics. In comparison to artificial food colorants, the utilization of natural food coloring is witnessing a global surge in popularity owing to its inherent health advantages, and minimal toxicity levels (Blumfield et al., 2022). Barberry peels are an exceptional organic reservoir of phenolic compounds, minerals, vitamins, fiber, vitamin C, malic acid, succinic acid, tannins, berbamine, berberine, chlorogenic acid, catechin, gallic acid, and anthocyanins. Similar to other types of berry fruits, barberry possesses a notable antioxidant capacity, primarily attributed to its abundant anthocyanin content. Anthocyanins, classified as flavonoids, are widely distributed throughout various plant organs, and are known to confer numerous health advantages (Condurache et al., 2020; Sarraf et al., 2021). Additionally, anthocyanins are highly sensitive pigments, and their stability is influenced by a variety of factors including heat treatment, pH, light, oxygen, and oxidases. Therefore, it is necessary to enhance the stability of these compounds under different conditions, and during industrial processing (Kowalski and de Mejia, 2021). One method to achieve this is by introducing copigments, which can enhance the stability of anthocyanins through copigmentation, thereby improving color preservation (Wang et al., 2023). Inter-molecular copigmentation is a natural process that occurs widely in anthocyanins, contributing significantly to their stability, and color preservation (Zhao et al., 2022). Furthermore, copigmentation is influenced by pH, temperature, concentration, solvent, and molecular structure (Xu et al., 2022).

Ice cream is a frozen dessert that with various components, including

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Abbreviations

DPPH	1, 1-Diphenyl-2-picrylhydrazyl-hydrate
TAC	Total anthocyanin content
C3G	Cyanidin-3-glycoside
SWVI	Simple white vanilla ice cream
1%ICBA	Ice cream containing 1% copigmented barberry anthocyanins
3% ICBA	Ice cream containing 3% copigmented barberry anthocyanins
5% ICBA	Ice cream containing 5% copigmented barberry anthocyanins
5%IUCBA	Ice cream containing 5% un-copigmented barberry anthocyanins

ice crystals, air cells, fat globules, and partially coalesced fat globule clusters. These elements are dispersed within an unfrozen serum phase, which contains sugars, proteins, and stabilizers (Warren and Hartel, 2018). Ice cream results from a complex microstructure comprising ice crystals, air cells, and a network of fused fat droplets trapped within a dense continuous phase (Liu et al., 2023). The structural elements in ice cream can be divided into four categories which are fat, air, ice, and unfrozen serum phases (Liu et al., 2023). The microstructure of ice cream plays a significant role in determining its viscoelastic behavior, hardness, and melting properties, all of which are crucial quality parameters. These properties are influenced by both the composition of the ice cream, and the production process. Therefore, the microstructure of ice cream is dependent on both its ingredients, and the manufacturing process employed (Chang and Hartel, 2002). Applying natural colorant like barberry anthocyanins can be influenced on ice cream quality. Besides the health effects of barberry anthocyanins which are from the group of polyphenols, they have a well-known binding affinity for proteins, mediated mostly by hydrogen bonding, and hydrophobic interactions, and the interaction with phenolic compounds that affect the interfacial and foaming properties of proteins (Diaz et al., 2022). Melting can be influenced by both the overrun, and the size of ice crystals present in the ice cream. Ice cream with low expansion tends to melt at a faster rate due to the efficient insulation properties of air. On the other hand, ice cream with high expansion exhibits greater resistance to melting, as it can retain its solid state for a longer duration (Tsai et al., 2020).

The preservation of these nutrients is of utmost importance in industrial processing, and storage due to the significant instability of these pigments. Consequently, intermolecular co-pigmentation of anthocyanins emerges as a highly effective approach to stabilizing these compounds (Farhadi Chitgar, Aalami, Kadkhodaee, Maghsoudlou and Milani, 2018). Barberry anthocyanins, being a natural reservoir of bioactive components, offer distinct advantages as a healthier antioxidant, and colorant (Naji-Tabasi et al., 2021). Besides, Sayar et al. (2022) investigated the antioxidant capacity, and the rheological, and textural characteristics of blueberry-flavored ice cream made from camel's milk observed that blueberry could improve ice cream's nutritional properties (Sayar et al., 2022). Despite the performance of many studies, our understanding of the exact impact of microstructural factors on the melting of ice cream is still limited. Therefore, this study aimed to evaluate the effects of copigmented, and un-copigmented barberry anthocyanins, used at concentrations of 1%, 3%, and 5%, as antioxidants, and colorants in ice cream. Additionally, the secondary main aim was examined the impact of polyphenols, copigmented, and un-copigmented barberry anthocyanins, on the enhancement, and intensification of ice cream foam, as well as the prolongation of melting time, and delay in ice cream melting, was examined. Currently, limited information is available on the effects of incorporating polyphenols, and anthocyanins into ice cream to improve its foaming properties, and resistance to melting.

2. Material and methods

2.1. Materials

Fresh *Berberis vulgaris* L was collected in September 2022 in Mashhad (Khorasan Razavi, Iran). 2-Diphenyl-1–1-picrylhydrazyl (DPPH), Folin–ciocalteu reagent, and pectin were obtained from Sigma (Sternheim, Germany). Sodium acetate (CH_3COONa), potassium chloride (KCl), and gallic acid were obtained from Merck Company (Darmstadt, Germany). Pectinase (Polygalacturonase) was obtained from Fluka. Distilled water, and other reagents, and chemicals were analytical grades. Milk cream (30% milk fat), skim milk powder, sugar, vanilla, mono- and diglyceride, and salep were purchased from a local supplier in Mashhad, Iran.

2.2. Anthocyanin extraction

In accordance with our previous research (Dara et al., 2023), the pectinase activity was measured at a concentration of 0.91 ± 0.02 U/mL. A specific concentration of polygalacturonase enzyme solution (40 mL) was added to 20 g of crushed *Berberis vulgaris* L. fruits under optimal conditions. To maintain ideal pH conditions, a solvent of 50 mM sodium acetate buffer solution was utilized. The enzymatic treatment was conducted at 30 °C with stirring at a rate 150 rpm on a thermostatically controlled orbital shaker (IKA, KS 4000 Control, Germany) under dark conditions. After enzymatic treatment, crushed fruits were combined with HCl (15:85 v/v) for 2 h at 30 °C. The mixture was filtered using Whatman filter paper (No. 4) before being stored at 4 °C until measurement (Dara et al., 2023).

2.3. Copigmentation of barberry anthocyanins

The anthocyanin solution, which had been extracted, and purified, was combined with a copigment solution (low methoxyl citrus pectin) in a specific molar ratio. The optimal conditions for copigmentation were 25 °C, 30 min, and 0.06 M ratios. Through this method, we aimed to comprehend the interaction between anthocyanin, and pectin by analyzing the wavelength shift, and absorption number increase (Cai et al., 2022).

2.4. Ice cream production

Ice cream samples were produced according to the method of Zor and Sengul (2022). To prepare ice cream, milk was heated at 50 °C while stirring, and dry ingredients, including sugar, dry milk, and emulsifier, were added to the heated liquid. Then, cream was added to the mixture, and after it was completely mixed by a hand mixer at 3000 rpm for 3 min, the resulting mixture was pasteurized at 85 °C for 20 s. Then, it was immediately cooled by a mixture of water, and ice (5 °C), and transferred to a batch ice cream machine (II Gelataio GC 6000, De'Longhi, Italy) with a capacity of 1 L for the freezing process (25 min). The samples were kept in a deep freezer at −18 °C for 24 h for hardening. Copigmented, and un-copigmented barberry anthocyanins were added to ice cream formulation in different concentrations before pasteurization. (Zor and Sengul, 2022).

The simple white vanilla ice cream (SWVI) was made without barberry anthocyanins, and ice cream containing copigmented barberry anthocyanins (ICBA) prepared at different concentrations of 1% ICBA, 3% ICBA), and 5%ICBA, and 5%un-copigmented (5%IUCBA).

2.5. Physical, and chemical properties of ice cream

2.5.1. pH

The digital pH meter (InoLab 720, Germany) was utilized to measure the pH of the ice cream mixture at room temperature (Shamshad et al., 2023).

2.5.2. Total anthocyanins content

The pH differential method proposed by Lee et al. (2005) was employed to determine the total anthocyanin content. This method utilized two buffer systems: potassium chloride buffer with a pH of 1 (0.025 M), and sodium acetate buffer with a pH of 4.5 (0.4 M). To conduct the analysis, the samples were diluted in the pH 1.0, and pH 4.5 buffers, and absorbance were taken at wavelengths of 510 nm, and 700 nm using cuvettes with a path length of 1 cm. The pigment content was then calculated, and expressed as cyanidin 3-glucoside (C3G) per 100 g of dry weight (FW). This calculation was based on an extinction coefficient (ε) of 26,900 L cm^{-1} mol^{-1}, and a molecular weight of 449.2 g/mol (Lee, Durst, Wrolstad, Kupina, & JD, 2005).

$$Anthocyanin\ content = A \times Mw \times DF \times 1000/(\varepsilon \times l) \quad \text{(Eq1)}$$

$$Where\ A = (A510\ nm - A700\ nm)pH\ 1.0 - (A510\ nm - A700\ nm)pH\ 4.5 \quad \text{Eq2}$$

M_W is the molecular weight of the main anthocyanin (C3G = 449.2 g/mol); DF is the dilution factor (10); 1000 is the mass conversion factor (g to mg); ε is the extinction coefficient of C3G (26,900 L/mol/cm); and l is the path length (1 cm).

2.5. 3. Antioxidant activity by DPPH radical-scavenging activity

The method proposed by Sayar et al. (2022) was employed to assess the scavenging activity of the DPPH (2,2-diphenyl-1 picrylhydrazyl) radical. The absorbance values of the sample solutions were recorded at a wavelength of 517 nm to determine their antioxidant potential (Sayar et al., 2022). DPPH radical scavenging activity was assessed through this method according to the following equation (3):

$$(\%)\ Inhibition = \frac{A_{blank} - A_{sample}}{A_{blank}} \times 100 \quad \text{(Eq. 3)}$$

2.5. 4. Total phenolic content

The total phenolic content (TPC) of the samples was determined using the Folin-Ciocalteu colorimetric method (Gülçin et al., 2002). To analyze the TPC, 10 ml of the ice cream, and 10 ml of ethanol (90%, v/v; Merck, Germany) were mixed in an orbital shaker for 30 min. From this solution, 1 mL of the mixture, 46 ml of deionized water, and 1 mL of Folin-Ciocalteu reagent were combined, and left for 3 min. Then, 2% sodium carbonate (w/v; Merck, Germany) was added. The solution was shaken in an orbital shaker at 210 rpm for 2 h. The absorbance values were measured using a visible spectrophotometer at 760 nm. The TPCs of the samples were calculated using a standard curve constructed with various concentrations of gallic acid (Sigma Aldrich, Canada). The results were expressed as μg GAE mg^{-1}.

2.5. 5. Color measurement

The images of the sample were taken with a scanner (Scanjet G2710 HP, China) then the color properties were analyzed in $L^*a^*b^*$ color space by Image J software (Version 1.45 s) (Gengatharan et al., 2021).

2.5. 6. Texture analysis

The textural properties of ice cream were investigated by penetration test. To perform the penetration test, the ice cream samples were prepared in identical molds (diameter 7 cm and height 8 cm), and were placed in room conditions for 5 s. The penetration test (TA.XTplus C Stable Micro Systems, Texture Analyzer, England) was performed with a penetration depth of 15 mm at a speed of 1 mm/s at room temperature using a texture analyzer equipped with a cylindrical probe with a diameter of 3 mm (Shadordizadeh, Mahdian and Hesarinejad, 2023).

2.5. 7. Ice cream overrun

The increase in the coefficient of volume, and the effect of anthocyanin on the foam content, and stability of ice cream foam were investigated. Containers with specific volumes were used to measure overrun. The weight of a specific volume of ice cream before, and after the freezing stage was measured, and the following formula was used to calculate the overrun (Shadordizadeh et al., 2023).

$$Overrun = (weight\ of\ mixture - weight\ of\ ice\ cream\ )/weight\ of\ ice\ cream \times 100 \quad \text{(Eq.4)}$$

2.5. 8. Temperature of ice cream mixture

The temperature of the ice cream mixture was measured using a thermometer immediately after the ice cream leaves the ice cream maker (David-Birman et al., 2022).

2.5. 9. Melting rate determination

To determine the melting resistance of ice cream after one day of hardening, the following tests were performed:

The behavior of ice cream to maintain its shape during melting was evaluated through image analysis method by the image j software (version 1.54 j) based on average height of several points. Approximately, 100 g of cylindrical sample of ice cream (18 °C, 24 h) was placed on an iron plate with a temperature of 24 °C. Photographs of the samples were recorded during the melting test with a camera under standard conditions at fixed time intervals of 5 min, and the height was recorded for a certain length of time (Tsai et al., 2020).

To measure the melting rate (g/min), 50 g of ice cream was placed on a metal strainer, and allowed to melt to 100% at room temperature. The mass of melted ice cream was recorded every 5 min with the aim of obtaining a sigmoidal curve as the kinetics of the melting process.From the linear region of the curve, the most probable straight line was calculated, the slope of which shows the melting rate (g/min) (Tsai et al., 2020).

In order to determine the melting time, 100 g of ice cream was kept at a temperature of 20 °C until it completely melted in the chamber. In this test, the initial temperature of the ice cream was set at −70 °C. The first dripping time of ice cream was measured by determining the starting point of weight change (Choi and Shin, 2014).

2.5. 10. Sensory properties

The ice creams (−18 °C, 30 g) were labeled with three-digit random codes, and presented to 20 trained panelists throughout several sessions. Sensory characteristics including taste, color, texture, mouthfeel, resistance to melting, and overall acceptance were evaluated with the cooperation of trained panelist, and on a five-point hedonic scale that lukewarm water was given among each samples. A group of 20 panelists, including academic staff, and undergraduate, and graduate students traind in food science, and technology institute, conducted a sensory assessment of various ice cream samples. The panelists rated the samples on a scale of 1–5, with 1 indicating dislike, and 5 indicating a strong preference. To prevent any mistakes or uncertainties, unnecessary information was excluded from the evaluators, and distinct codes were assigned to the samples. Room-temperature water was employed. The location, requirements, and equipment of sensory evaluation tools were all consistent, and conducted concurrently (Shadordizadeh et al., 2023).

2.6. Measurement of critical micelle concentration (CMC), and surface tension

The du Noüy ring method was used to measure the surface tension of the barberry (polyphenols) tensiometer (k100, kruss, Germany) (Lunkenheimer and Wantke, 1978). The critical micelle concentration (CMC) of barberry polyphenols was assessed through the ring technique, employing a solvent molarity of 55.40 [mol/l], and 4.98 solutions mol mass [g/mol]. The concentration of the barberry extract (barberry anthocyanins, and polyphenols) was measured at 484.93 [mg/l]. Furthermore, the brix value was determined to be 19.58, and the concentration of casein, and whey protein were 1:10, and the brix of milk was 12%, and also the brix of ice creams were among 34–37% (Kim et al., 2018).

2.7. Statistical analysis

The statistical analysis was conducted using a completely randomized design through analysis of variance (ANOVA). All measurements were conducted in triplicate, and the resulting average values were reported. To perform the Duncan's multi-range test, SPSS 27 software was utilized at a significance level of 0.05. Additionally, the curves were plotted using Origin Pro 2022 software.

3. Results and discussion

3.1. Physicochemical characteristics of ice cream

The impact of the treatments on the pH of the barberry anthocyanins-enriched ice cream is presented in Table 1. The results clearly demonstrate a significant reduction in the pH of the ice cream following the treatments ($P < 0.05$). It can be deduced that the control group (SWVI) exhibited the highest pH value, with a mean of 6.48 ± 0.24. The pH of copigmented ice cream (5% ICBA) increased compared to non-copigmented ice cream (5% IUCBA). Homayouni et al. (2008) emphasized that pH plays an important role in the perception of the taste of dairy product (Homayouni et al., 2008). The findings of Goraya, and Bajwa in (2015) were in agreement with our research that the quantities of fiber, total phenols, tannins, ascorbic acid, and antioxidant activity all demonstrated a rise as the quantity of amla integrated into the ice cream increased. The addition of processed amla improved the resistance to melting of the ice cream while reducing the overrun. The samples containing 5% amla shreds, and pulp, 10% amla preserve, and candy, and 0.5% amla powder received the greatest overall acceptability ratings (Goraya and Bajwa, 2015).

There were significant differences in the total phenolic content of the different treatments, as shown in Table 1. The sample with 5% barberry anthocyanins had the highest amount of total phenolics (2.59 ± 0.05 (μg/mg)), while the SWVI sample had the lowest amount (0.12 ± 0.01 (μg/mg)). The increase in total phenolic content of, 1% ICBA, 3% ICBA, 5% ICBA, and 5% IUCBA samples, was attributed to the increase in the percentage of polyphenol in the anthocyanin added to the ice cream mixture. There was statistically significant difference in the amount of phenolic compounds ($P < 0.05$), even though there was no significant variance in the levels of phenolic compounds between copigmented, and unpigmented samples, as they were nearly identical.

The anthocyanin contents of ice cream are summarized in Table 1. The anthocyanin contents of copigmented ice cream 5% ICBA were lower than non-copigmented ice cream (5% IUCBA) ($P < 0.05$). Regarding the mean values of DPPH IC50 (mg/L), it can be inferred that there were significant variations among the samples. The lowest value for this trait was recorded for the SWVI sample, while the highest value was observed for the 5%ICBA sample (1.67 ± 0.02). The difference in DPPH levels between copigmented, and uncopigmented samples was not found to be statistically significant, as they exhibited close resemblance ($P < 0.05$). Shamshad et al. (2023) findings were in agreement with the results of this study (Shamshad et al., 2023).

Table 1
PH, total phenolic, total anthocyanins content, and antioxidant activity of ice creams.

samples (percentage)	Polyphenols (μg/mg)	TAC (mg/100 g)	DPPH IC50 (mg/L)	pH
SWVI	0.12 ± 0.01^{d}	N. S	56.19 ± 0.34^{a}	6.48 ± 0.04^{a}
1% ICBA	2.23 ± 0.02^{c}	1.07 ± 0.03^{d}	55.93 ± 0.17^{a}	6.12 ± 0.03^{b}
3% ICBA	2.37 ± 0.05^{b}	1.26 ± 0.02^{c}	54.23 ± 0.14^{b}	5.95 ± 0.02^{c}
5% ICBA	2.56 ± 0.03^{a}	1.63 ± 0.01^{b}	52.62 ± 0.26^{c}	5.81 ± 0.07^{d}
5%IUCBA	2.59 ± 0.05^{a}	1.67 ± 0.02^{a}	0.97 ± 0.10^{d}	5.64 ± 0.01^{e}

[a] Values are presented as means ± standard deviation (n = 3). Data with different superscript letters within each column are significantly different ($P < 0.05$).

3.2. Color measurement

The color of ice creams containing copigmented barberry anthocyanins is a significant indicator of quality, as it reflects the appeal, and overall excellence of the ice cream produced during manufacturing (Diaz et al., 2022). Additionally, it plays a crucial role in determining the acceptance of the final product in which the copigmented barberry anthocyanins are utilized. The color parameters of copigmented barberry anthocyanins ice creams were presented in Table 2. The findings indicated that the concentration of copigmented barberry anthocyanins had a significant impact on the lightness (L^*) of the samples ($p < 0.05$), with a decrease observed as the concentration increased. Conversely, the a^* values, which represent the redness of the samples, increased with the addition of copigmented barberry anthocyanins.

Furthermore, the b^* values, which indicate the yellowness of ice cream samples, were lower compared to the control sample. Barberry is known to contain compounds such as anthocyanins, and flavonoids (Lin et al., 2017). Anthocyanins are responsible for the red color, while flavonoids contribute to both red, and blue colors (Moyer et al., 2002). Therefore, the chemical components of barberry can potentially influence the color parameters of ice cream samples. A prior research was carried out by Kotan (2018) that was consistent with these findings (Kotan, 2018).

3.3. Texture analysis

According to Table 3, increasing the anthocyanin percentage of copigmented barberry in ice cream significantly increased the hardness, consistency, and adhesiveness of ice cream samples ($p < 0.05$). The addition of polyphenols in a certain amount can lead to the strengthening of the texture because it makes the proteins to be better placed in a strong, and stable network, which can help increase the stability, and resistance of the ice cream texture. Intermolecular interactions between milk proteins, and anthocyanins could be owing to the formation of clots, which prevent premature melting, and enhance texture over time, can be influenced by coalescence, non-coalescence chemical interactions, and also intermolecular bonds. (Shadordizadeh et al., 2023). The strength of these interactions directly impacts the texture of ice

Table 2
Color measurement of ice creams.

Sample	L^*	a^*	b^*
Barberry anthocyanins	23.63 ± 0.74^{e}	38.81 ± 0.12^{a}	26.77 ± 0.685^{a}
SWVI	78.51 ± 0.57^{a}	−0.78 ± 0.25^{f}	0.22 ± 0.14^{b}
1% ICBA	70.97 ± 0.55^{b}	5.10 ± 0.27^{e}	−0.65 ± 0.42^{d}
3% ICBA	68.24 ± 0.53^{c}	8.42 ± 0.61^{d}	−1.93 ± 0.17^{c}
5% ICBA	67.46 ± 0.37^{c}	10.63 ± 0.09^{c}	−1.88 ± 0.08^{c}
5%IUCBA	51.62 ± 0.47^{d}	13.82 ± 0.44^{b}	−0.27 ± 0.70^{e}

[a] Values are presented as means ± standard deviation (n = 3). Data with different superscript letters within each column are significantly different ($P \leq 0.05$).

Table 3
Means for textural parameters of ice creams containing copigmented, and uncopigmented barberry anthocyanins.

samples	Hardness (N)	Adhesiveness (N. sec)	Consistency (N.sec)
SWVI	88.60 ± 1.12[c]	−0.04 ± 0.01[d]	313.40 ± 13.98[a]
1%ICBA	36.31 ± 1.61[d]	−0.36 ± 0.09[c]	148.51 ± 13.32[c]
3%ICBA	113.72 ± 1.34[a]	−0.81 ± 0.22[b]	326.71 ± 12.73[a]
5%ICBA	106.03 ± 1.45[b]	−0.98 ± 0.18[a]	276.70 ± 14.37[b]
5%IUCBA	16.95 ± 2.08[e]	−0.10 ± 0.03[a]	60.02 ± 15.07[d]

[a] Values are presented as means ± standard deviation (n = 3). Data with different superscript letters within each coloumn are significantly different ($P \leq 0.05$).

cream, and contributes to its improved preservation. On the other hand, adding polyphenols to the mixture of ice cream can act as antioxidants against the oxidative activities in ice cream, and prevent premature oxidation of fats in ice cream, which has a significant effect, and can indirectly improve the texture of ice cream, and help maintain the quality and life of ice cream (Shadordizadeh et al., 2023).

Sulejmani and Demiri (2020) observed that the addition of fruit increases the hardness value of ice cream sampleswhich was in line with the results of our study (Kurultay, ÖKsÜZ, & GÖKÇEbaĞ, 2010).

3.4. Surface tension (ST)

The addition of surfactant lowers the interfacial energy of the solution, and removes hydrophobic groups from the surface of the surfactant in contact with water. Barberry extract, which is a rich source of polyphenols that polyphenolic compounds act as surfactants, can react with alkaloids, polysaccharides, proteins, metal ions, and other compounds (Chen et al., 2024). As shown in Table 4 the addition of polyphenols to milk proteins significantly decreased surface hydrophobicity, and surface tension. Also, the surface tension of ice cream samples decreased by increasing copigmented barberry anthocyanins concentration. The stability of foams is essential for their effective application. Aqueous foams can break due to three mechanisms: (i) drainage caused by gravity, and capillarity, (ii) coarsening from gas transfer between bubbles due to capillary pressure variations, and (iii) bubble coalescence from film rupture between bubbles (Chen et al., 2024). Generally, within this trio of mechanisms, foam drainage, denoting the liquid component of foams, plays a pivotal role in the phenomena of bubble coalescence, and coarsening (Chen et al., 2024).

The surface tensions at equilibrium provide insight into the surface-active elements, and have the ability to decrease surface tension. The measurements of surface dilational visco-elasticity demonstrate the presence of adsorption layers with elastic characteristics. Furthermore, there is a significant relationship between foamability, and foam stability with dynamic surface properties (Chen et al., 2024).

Li et al. (2023) conducted a previous investigation that aligned with these results (Chen et al., 2024).

Table 4
Surface tension of barberry anthocyanins, 1% ICBA, 3% ICBA, 5% ICBA mixture.

Sample	Surface tension [mN/m]
Barberry polyphenols	45.09 ± 0.27[a]
Barberry extract in milk	41.91 ± 0.06[b]
1% ICBA	40.46 ± 0.02[d]
3% ICBA	39.73 ± 0.01[c]
5% ICBA	36.16 ± 0.16[e]

*Values are presented as means ± standard deviation (n = 3). Data with different superscript letters within each column are significantly different ($P \leq 0.05$).

3.5. Temperature of ice cream mixture, and overrun

According to Table 5, exit temperatures of ice cream samples from the ice cream maker from the most to the least were SWVI, 1% ICBA, 5% IUCBA, 3% ICBA, and 5% ICBA. Air plays a vital role in the formation of the structure of ice cream. The amount of air that is introduced during the freezing process influences the size of the ice crystals, with larger crystals being present in ice cream with lower overrun. It has been noted that overrun has an effect on the texture of ice cream, and its melting rate (Markowska et al., 2023).

Based on Tables 5 and 6, the correlation between overrun, and melting rate is evident. The ice cream sample with 5% copigmented barberry anthocyanins exhibited the slowest melting rate, primarily attributed to its highest percentage of overrun. This implies that increasing the concentration of copigmented barberry anthocyanins in the ice cream formulation has resulted in an expansion of both volume, and air within the ice cream. Consequently, the presence of air acts as an insulator, reducing the rate at which the ice cream melts. The overrun of copigmented ice cream 5% ICBA increased compared to non-copigmented ice cream 5% IUCBA, and the copigmented ice cream 5% ICBA exhibited a lower exit temperature from the ice cream maker compared to the non-copigmented ice cream 5% IUCBA. Gelled structure of the protein, which is the most effective factor in the formation of the gel around the bubbles, creates the stability of the crystal system, and preserves it during production, and consumption (Shadordizadeh et al., 2023).

3.6. Melting properties

The melting characteristics of ice cream depend on many factors, such as ice cream, emulsifier characteristics, total solids, size of ice crystals, and fat, and proteins. High fat can reduce the melting rate of ice cream due to reduced thermal penetration (Akbari et al., 2016). According to Table 6, the effect of different concentrations of the barberry extract on the melting rate of ice cream was significant ($p < 0.05$). The highest melting rate was related to the control sample, and the lowest melting rate was related to the sample containing 5% Copigmented barberry anthocyanins. Increasing the concentration of pigmented barberry anthocyanins in the ice cream formulation increased the volume, and air entrapment inside the ice cream, which reduced the melting rate of the ice cream due to the insulation of the air.

The second reason is the delay in melting by adding different percentages of copigmented barberry anthocyanins it is that polyphenols can interact with proteins, and alter the functionality of dairy products. Many studies have proven that proteins can stick to polyphenols. When polyphenols stick to proteins, they might change the way certain amino acids are used, and also the shape of the proteins, which can affect how well they work. Polyphenols can connect proteins, and create a big network. When this protein, and polyphenols come together, they make

Table 5
Temperature of ice cream mixture, and overrun.

samples (percentage)	Exit temperature from the ice cream maker (°C)	overrun (%)
SWVI	−5±0.02[a]	21.0 ± 1.47[e]
1% ICBA	−4.87 ± 0.01[b]	23.0 ± 1.86[d]
3% ICBA	−4.80 ± 0.01[d]	26.0 ± 1.15[c]
5% ICBA	−4.76 ± 0.02[e]	30.0 ± 1.15[a]
5%IUCBA	−4.85 ± 0.01[c]	28.0 ± 1.07[b]

[a] Values are presented as means ± standard deviation (n = 3). Data with different superscript letters in each coloumn are significantly different ($P < 0.05$).

Table 6
Measuring the melting rate, and duration of the first dripping, and complete melting of ice creams.

samples (percentage)	First dripping time (min)	Duration of complete melting (min)	melting rate (g/min)
SWVI	18.30 ± 1.40[e]	80 ± 1.17[e]	1.09 ± 0.03[a]
1% ICBA	23.42 ± 1.13[d]	90 ± 1.32[d]	0.70 ± 0.02[b]
3% ICBA	26.49 ± 1.18[b]	103 ± 1.13[c]	0.63 ± 0.01[c]
5% ICBA	30.52 ± 1.26[a]	114 ± 1.28[a]	0.50 ± 0.01[e]
5%IUCBA	25.17 ± 1.15[c]	108 ± 1.24[b]	0.55 ± 0.01[d]

[a] Values are presented as means ± standard deviation (n = 3). Data with different superscript letters within each coloumn are significantly different ($P < 0.05$).

a gel that can hold onto different substances. Incorporating polyphenols into the ice cream mixture results in the formation of a robust gel that has the ability to trap air bubbles, fat cells, and ice crystals, even when exposed to high temperatures. Consequently, even if the ice within the mixture melts, the gel matrix remains intact, preserving the shape, and characteristics of the product. This phenomenon is attributed to the presence of polyphenolic compounds, which effectively retard the melting process (Yildirim-Elikoglu and Erdem, 2018).

The start time of melting in different samples also had a statistically significant difference ($p < 0.05$), so the control sample started melting after 18.30 min. By increasing the concentration of barberry copigmented anthocyanins from 1 to 5%, this time increased from 23.42 to 30.52 min (Table 6). In a similar study, Bilbao-Sainz et al. (2019) stated the functionality of freeze-dried berry powder on frozen dairy desserts (Bilbao-Sainz et al., 2019). The melting rate, and changes in melting height of ice creams in different samples also had a statistically significant difference ($p < 0.05$), so that the highest melting rate was recorded for the SWVI sample, and the lowest melting rate was recorded for the 5% ICBA sample.

Based on the melting height over time (Fig. 1), the SWVI sample exhibited the lowest height, suggesting a rapid melting rate. Conversely, the 5% ICBA, 5% IUCBA, 3% ICBA, and 1% ICBA samples displayed the highest melting heights, indicating slower melting rates compared to the SWVI sample. According to the melting height curve, the copigmented ice cream 5% ICBA increased compared to non-copigmented ice cream 5%IUCBA that this increasing of melting height in the copigmented sample 5% ICBA means that the sample melted later, and it can also be related to the melting rate, which as reported in Table 6, the melting rate of the copigmented sample 5% ICBA is less than the 5% IUCBA non-copigmented sample, so it is concluded that the 5% ICBA copigment sample is more stable, and resistant to melting than the non-copigmented 5% IUCBA sample.

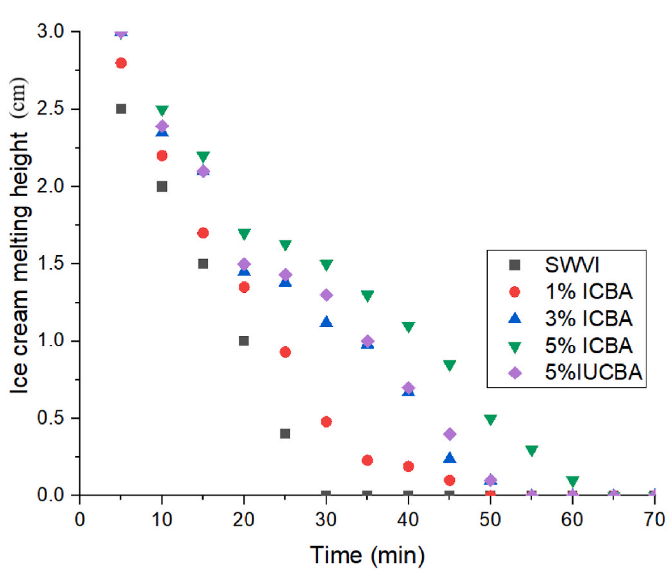

Fig. 1. Changes in ice cream height during melting.

3.7. Sensory properties

Based on (Fig. 2), there was a significant difference in the color scores of ice cream samples with varying concentrations of copigmented barberry anthocyanins compared to the control sample ($p < 0.05$). The sensory evaluators rated the color score of the control sample lower than the samples containing 1, 3, and 5% extract concentrations. This indicates that the ice cream sample with a 3% concentration can rival commercial samples in terms of color. Meanwhile, the ice cream sample with 3% of copigmented barberry anthocyanins had overall acceptance. Holzwarth et al. (2013) investigated the effect of adding different concentrations of strawberry pulp on the color score, and appearance of ice cream, and reported that strawberries had a significant effect on improving the score of overall acceptance (Holzwarth et al., 2013). Goraya, and Bajwa in (2015) indicated that by elevating the level of red grape pulp in the ice cream formulation, due to the reduction of the sweet taste of the initial ice cream, the sensory evaluation score about the taste decreased. However,in large quantities, it causes inappropriate sensory characteristics such as an unpleasant taste with medicine (Goraya and Bajwa, 2015). According to the results obtained from the evaluators about the melting of ice creams, it was as follows that the control sample melted faster, and the samples containing different percentages of copigmented barberry anthocyanin started to melt later in the order of increasing percentage. The color of copigmented ice cream 5% ICBA was lower than non-copigmented ice cream 5% IUCBA, The flavor of copigmented ice cream 5% ICBA increased compared to non-copigmented ice cream 5% IUCBA, the copigmented ice cream with 5% ICBA exhibited a superior texture compared to the non-copigmented ice cream with 5% IUCBA, the copigmented ice cream with 5% ICBA demonstrated a greater resistance to melting compared to the non-copigmented ice cream with 5% IUCBA, and also for overall acceptance the copigmented ice cream with 5% ICBA exhibited a superior compared to the non-copigmented ice cream with 5% IUCBA.

4. Conclusion

The objective of this study was to assess the impact of copigmented barberry anthocyanins, at concentrations of 1%, 3%, and 5%, and comparison with ice creams containing non-copigmented barberry. The addition led to improvements in pH, total phenolic content, antioxidant activity, consistency, and color. Overrun increased with increasing anthocyanin concentrations, resulting in better foaming characteristics. The ice cream with 5% copigmented anthocyanins demonstrated the slowest melting rate, and highest overall acceptance compared to non-copigmented samples. Overall, the results align with the study's objectives, So it can be concluded that the addition of copigmented, and non-copigmented anthocyanins to ice cream increased foaming, and melting stability, and decreased melting rate. In these cases, copigmented anthocyanins were stronger than non-copigmented ones. For future prospects, it was suggested that a combination of anthocyanins from different sources with different polyphenols could be used in ice cream, and their synergistic effect on foaming properties, and the melting rate of ice cream could be investigated.

Ethics approval, and consent to participate

Not applicable. This article does not contain any studies with human or animal subjects.

Consent to participate

Not applicable.

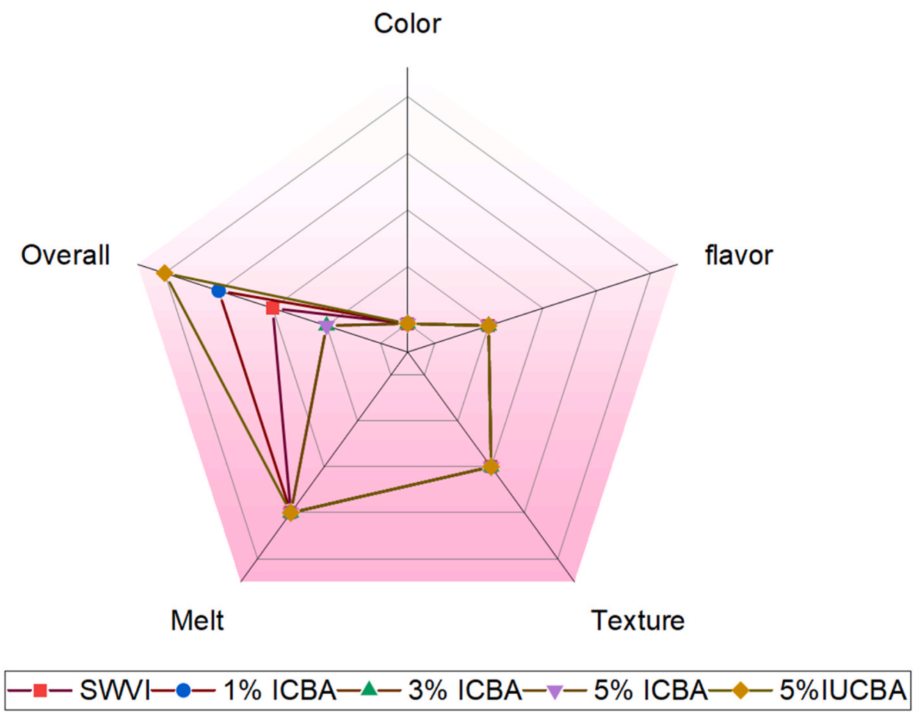

Fig. 2. Sensory attributes for the evaluation of ice-cream samples.

Consent for publication

The authors hereby consent to the publication of the work.

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CRediT authorship contribution statement

Arash Dara: Methodology, Investigation, Writing – original draft, Formal analysis. **Sara Naji-Tabasi:** Conceptualization, Supervision, Resources, Data curation, Writing – review & editing. **Javad Feizy:** Conceptualization, Supervision, Resources, Data curation, Writing – review & editing. **Ebrahim Fooladi:** Writing – review & editing. **Ali Rafe:** Writing – review & editing.

Declaration of competing interest

The authors declare that they do not have any conflict of interest.

Data availability

Data will be made available on request.

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References

Akbari, M., Eskandari, M.H., Niakosari, M., Bedeltavana, A., 2016. The effect of inulin on the physicochemical properties and sensory attributes of low-fat ice cream. Int. Dairy J. 57, 52–55. https://doi.org/10.1016/j.idairyj.2016.02.040.

Bilbao-Sainz, C., Thai, S., Sinrod, A.J.G., Chiou, B.-S., McHugh, T., 2019. Functionality of freeze-dried berry powder on frozen dairy desserts. J. Food Process. Preserv. 43 (9), e14076 https://doi.org/10.1111/jfpp.14076.

Blumfield, M., Mayr, H., De Vlieger, N., Abbott, K., Starck, C., Fayet-Moore, F., Marshall, S., 2022. Should we 'eat a rainbow'? An umbrella review of the health effects of colorful bioactive pigments in fruits and vegetables. Molecules 27 (13), 4061.

Cai, D., Li, X., Chen, J., Jiang, X., Ma, X., Sun, J., Pan, Z., 2022. A comprehensive review on innovative and advanced stabilization approaches of anthocyanin by modifying structure and controlling environmental factors. Food Chem. 366, 130611.

Chang, Y., Hartel, R.W., 2002. Development of air cells in a batch ice cream freezer. J. Food Eng. 55 (1), 71–78. https://doi.org/10.1016/S0260-8774(01)00243-6.

Chen, J., Frempong, K.E.B., Ding, P., He, G., Zhou, Y., Kuang, M., Zhou, J., 2024. Plant polyphenol surfactant construction with strong surface activity and chelation properties as efficient decontamination of UO22+ on cotton fabric. Int. J. Biol. Macromol. 254, 127451 https://doi.org/10.1016/j.ijbiomac.2023.127451.

Condurache, N.N., Aprodu, I., Grigore-Gurgu, L., Petre, B.A., Enachi, E., Râpeanu, G., Stănciuc, N., 2020. Fluorescence spectroscopy and molecular modeling of anthocyanins binding to bovine lactoferrin peptides. Food Chem. 318, 126508 https://doi.org/10.1016/j.foodchem.2020.126508.

Dara, A., Feizy, J., Naji-Tabasi, S., Fooladi, E., Rafe, A., 2023. Intensified extraction of anthocyanins from Berberis vulgaris L. by pulsed electric field, vacuum-cold plasma, and enzymatic pretreatments: modeling and optimization. Chemical and Biological Technologies in Agriculture 10 (1), 93. https://doi.org/10.1186/s40538-023-00464-x.

Diaz, J.T., Foegeding, E.A., Stapleton, L., Kay, C., Iorizzo, M., Ferruzzi, M.G., Lila, M.A., 2022. Foaming and sensory characteristics of protein-polyphenol particles in a food matrix. Food Hydrocolloids 123, 107148. https://doi.org/10.1016/j.foodhyd.2021.107148.

Farhadi Chitgar, M., Aalami, M., Kadkhodaee, R., Maghsoudlou, Y., Milani, E., 2018. Effect of thermosonication and thermal treatments on phytochemical stability of barberry juice copigmented with ferulic acid and licorice extract. Innovat. Food Sci. Emerg. Technol. 50, 102–111. https://doi.org/10.1016/j.ifset.2018.09.004.

Gengatharan, A., Dykes, G., Choo, W.S., 2021. Betacyanins from Hylocereus polyrhizus: pectinase-assisted extraction and application as a natural food colourant in ice cream. J. Food Sci. Technol. 58, 1401–1410.

Goraya, R.K., Bajwa, U., 2015. Enhancing the functional properties and nutritional quality of ice cream with processed amla (Indian gooseberry). J. Food Sci. Technol. 52 (12), 7861–7871. https://doi.org/10.1007/s13197-015-1877-1.

Gülçin, İ., Oktay, M., Küfrevioğlu, Ö.İ., Aslan, A., 2002. Determination of antioxidant activity of lichen Cetraria islandica (L) Ach. J. Ethnopharmacol. 79 (3), 325–329.

Holzwarth, M., Korhummel, S., Siekmann, T., Carle, R., Kammerer, D.R., 2013. Influence of different pectins, process and storage conditions on anthocyanin and colour retention in strawberry jams and spreads. LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 52 (2), 131–138. https://doi.org/10.1016/j.lwt.2012.05.020.

Homayouni, A., Azizi, A., Ehsani, M., Yarmand, M., Razavi, S., 2008. Effect of microencapsulation and resistant starch on the probiotic survival and sensory properties of synbiotic ice cream. Food Chem. 111 (1), 50–55.

Kim, J., Kim, M.-J., Lee, J., 2018. The critical micelle concentration of lecithin in bulk oils and medium chain triacylglycerol is influenced by moisture content and total polar materials. Food Chem. 261, 194–200.

Kotan, T.E., 2018. Mineral composition and some quality characteristics of ice creams manufactured with the addition of blueberry. Gıda 43 (4), 635–643.
Kurultay, Ş., ÖksÜZ, Ö., GökçebaĞ, Ö., 2010. The influence of different total solid, stabilizer and overrun levels in industrial ice cream production using coconut oil. J. Food Process. Preserv. 34 (s1), 346–354. https://doi.org/10.1111/j.1745-4549.2009.00418.x.
Lee, J., Durst, R.W., Wrolstad, R.E., Kupina, C., Jd, S.M., 2005. Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: collaborative study. J. AOAC Int. 88 (5), 1269–1278.
Lin, B.W., Gong, C.C., Song, H.F., Cui, Y.Y., 2017. Effects of anthocyanins on the prevention and treatment of cancer. British. J. Pharmacol. 174 (11), 1226–1243. https://doi.org/10.1111/bph.13627.
Liu, X., Sala, G., Scholten, E., 2023. Structural and functional differences between ice crystal-dominated and fat network-dominated ice cream. Food Hydrocolloids 138, 108466. https://doi.org/10.1016/j.foodhyd.2023.108466.
Lunkenheimer, K., Wantke, K., 1978. On the applicability of the du Nouy (ring) tensiometer method for the determination of surface tensions of surfactant solutions. J. Colloid Interface Sci. 66 (3), 579–581.
Markowska, J., Tyfa, A., Drabent, A., Stępniak, A., 2023. The physicochemical properties and melting behavior of ice cream fortified with multimineral preparation from red algae. Foods 12 (24). https://doi.org/10.3390/foods12244481.
Naji-Tabasi, S., Emadzadeh, B., Shahidi-Noghabi, M., Abbaspour, M., Akbari, E., 2021. Physico-chemical and antioxidant properties of barberry juice powder and its effervescent tablets. Chemical and Biological Technologies in Agriculture 8 (1), 23. https://doi.org/10.1186/s40538-021-00220-z.
Sarraf, M., Beig-Babaei, A., Naji-Tabasi, S., 2021. Optimizing extraction of berberine and antioxidant compounds from barberry by maceration and pulsed electric field-assisted methods. J. Berry Res. 11 (1), 133–149.
Sayar, E., Şengül, M., Ürkek, B., 2022. Antioxidant capacity and rheological, textural properties of ice cream produced from camel's milk with blueberry. J. Food Process. Preserv. 46 (3), e16346.
Shadordizadeh, T., Mahdian, E., Hesarinejad, M.A., 2023. Application of encapsulated Indigofera tinctoria extract as a natural antioxidant and colorant in ice cream. Food Sci. Nutr. 11 (4), 1940–1951. https://doi.org/10.1002/fsn3.3228.
Shamshad, A., Iahtisham Ul, H., Butt, M.S., Nayik, G.A., Al Obaid, S., Ansari, M.J., Ramniwas, S., 2023. Effect of storage on physicochemical attributes of ice cream enriched with microencapsulated anthocyanins from black carrot. Food Sci. Nutr. 11 (7), 3976–3988. https://doi.org/10.1002/fsn3.3384.
Sulejmani, E., Demiri, M., 2020. The effect of stevia, emulsifier and milk powder on melting rate, hardness and overrun of ice cream formulations during storage. Mljekarstvo: časopis za unaprjeđenje proizvodnje i prerade mlijeka 70 (2), 120–130.
Suleria, H.A., Barrow, C.J., Dunshea, F.R., 2020. Screening and characterization of phenolic compounds and their antioxidant capacity in different fruit peels. Foods 9 (9), 1206.
Tsai, S.-Y., Tsay, G.J., Li, C.-Y., Hung, Y.-T., Lin, C.-P., 2020. Assessment of melting kinetics of sugar-reduced silver ear mushroom ice cream under various additive models. Appl. Sci. 10 (8) https://doi.org/10.3390/app10082664.
Warren, M.M., Hartel, R.W., 2018. Effects of emulsifier, overrun and dasher speed on ice cream microstructure and melting properties. J. Food Sci. 83 (3), 639–647. https://doi.org/10.1111/1750-3841.13983.
Yildirim-Elikoglu, S., Erdem, Y.K., 2018. Interactions between milk proteins and polyphenols: binding mechanisms, related changes, and the future trends in the dairy industry. Food Rev. Int. 34 (7), 665–697. https://doi.org/10.1080/87559129.2017.1377225.
Zor, M., Sengul, M., 2022. Possibilities of using extracts obtained from Rosa pimpinellifolia L. flesh and seeds in ice cream production. J. Food Process. Preserv. 46 (2), e16225.