Effects of using reduced amounts of natural sweeteners on the sensory, physical, and chemical properties of ice cream

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Summary
In this study, the effects of reducing the amount of sweetener and using acceptable low levels of saccharose, agave, and maple syrups on some chemical, physical, and sensory properties of ice cream were investigated. In the first stage, ice cream samples were prepared using saccharose (SI), and saccharose-equivalent amounts of agave syrup (AI) and maple syrup (MI) at proportion of 6, 8, 10, 12, and 15 % sweetener. At this stage, the most acceptable low sugar proportion for each of the samples was determined as 8 %. In the second stage, the samples SI, AI and MI with 8 % sweetener were reproduced and the changes were examined. According to the results, the total phenolic substance, antioxidant activity, gumminess, chewiness, and b^* colour values were higher in AI samples while the acidity, adhesiveness, resilience and hardness values were higher in MI samples. In SI samples, the values of pH, overrun, melting rate, L^* colour and cohesiveness were higher. The AI sample was found to be more acceptable in terms of sensorial evaluations. In conclusion, agave and maple syrups can successfully replace saccharose in ice cream production due to their positive effects on some physical, functional, and sensory qualities.

Keywords
ice cream; maple syrup; agave syrup; saccharose, sweetener reduction, sweetener substitution

Ice cream is generally made using milk and its products, sweeteners, stabilizers, emulsifiers, flavourings, etc., and it is consumed with pleasure by people of all ages. A wide variety of nutritive sweeteners are utilized in ice cream production, including cane and beet sugars, various corn-derived sweeteners, maple syrup, honey, fructose, molasses, malt syrup, and lactose, all of which contain simple carbohydrates (sugars). Among these, the most traditional and widely used sweetening approach involves a combination of saccharose at approximately 10–12 % and corn syrup solids ranging from 3 % to 5 %, so that the total sweetener content typically averages around 15 %, (although the exact amount can vary depending on several factors). The sweeteners play an important role because they constitute a significant portion of the dry matter and contribute to the physical and sensory qualities of ice cream [1]. However, it has been shown that long-term consumption of foods with high sugar is harmful to health [2]. The World Health Organization (WHO, Geneva, Switzerland) strongly advises that both adults and children limit their intake of free sugars (monosaccharides and disaccharides) to less than 10 % of total energy intake, as excessive consumption of added sugars is associated with obesity, type 2 diabetes, and dental problems [3]. For this reason, studies are being conducted on many artificial and natural sweetener sources as an alternative to saccharose in ice cream production. Artificial sweeteners (sucralose, acesulfam-K) have advantages such as providing zero or low energy, being economical, and providing intense sweetness [4]. However, both the contradictory results in terms of health and the negative effects it may have on the structure and texture of ice cream have increased the tendency towards the use of natural sweeteners [5]. Natural sweeteners are the sweeteners whose source is available in nature and whose structure is preserved during the production process. Honey, molasses, carob syrup, maple and agave syrups are

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some of the natural (traditional) sweeteners in this group [4].

Maple syrup is a natural sugar source obtained from trees of the Acer genus, especially *Acer nigrum* (black maple), *A. rubrum* (red maple) and *A. saccharum* (sugar maple) species. It is added in various foods and beverages as an alternative to saccharose. Maple syrup contains approximately 65 % total solids [6]. The main sugar in maple syrup is saccharose, along with smaller amounts of glucose and fructose. It also contains minerals such as calcium, magnesium, potassium, sodium, manganese, aluminium, iron, zinc; vitamins such as riboflavin, niacin, thiamine; some amino acids (arginine, threonine, proline) and organic acids (fumaric acid and malic acid) [7]. Compared to other sweeteners, maple syrup is richer in phenolic compounds and shows antidiabetic potential by reducing postprandial glucose and insulin responses [8].

Agave syrup is obtained commonly from *Agave tequilana, A. americana, A. potatorum, A. salmiana* and *A. atrovirens* species. Agave syrup is produced via traditional, semi-industrial and industrial methods. In the traditional method, the sap is heated to hydrolyse inulin into fructose. In the semi-industrial method, hydrolysis is done by heat but under the control of pH, sugar content, and temperature. In the industrial method, acid or enzyme is used. Agave syrup contains an average of 76 % total solids [9]. Inulin, protein, vitamins (B1, B2, B3, ascorbic acid) and minerals (potassium, calcium, sodium, iron, copper, magnesium, zinc, selenium) are present in the composition of the sap [10]. When the sugar composition of agave syrup is examined, mainly fructose sugar is available. However, lesser amounts of glucose and trace levels of saccharose are also found. The presence of high fructose ensures that the glycemic index value of agave syrup is low [11]. During the production of agave syrup, certain fructooligosaccharides (fructans) remain largely intact, contributing to the syrup's functional properties. Additionally, phytochemical compounds such as saponins and flavonoids present in agave have been reported to provide various health benefits, including antioxidant, antibacterial, and anticarcinogenic effects [11]. Agave and maple syrups may alter the taste of ice cream compared to saccharose, owing to their richer carbohydrate profiles, and tend to be more expensive [6, 11].

Natural sweeteners such as honey, molasses, dates, and stevia have been well studied in ice cream production [2, 12, 13]. In contrast, research on maple and agave syrups is still emerging, with an increasing number of studies in recent years [14–16]. These two natural sweeteners are considered alternatives to saccharose due to their adequate sweetness, the presence of additional bioactive components, low glycemic index values, health benefits, and functional properties. Using low levels of saccharose, agave, and maple syrups can reduce the total sugar in ice cream, with agave and maple serving as natural alternatives to saccharose while preserving product quality. In this study, reducing the added sugar amount and the effect of using the most reasonable low amounts of saccharose, agave, and maple syrups on some properties of ice cream were examined.

MATERIALS AND METHODS

Material

Cow's milk cream with 42.5 % fat (Danone Tikveşli, Kırklareli, Türkiye), skim milk powder with 95.5 % dry matter and 0.7 % fat (Özgüllü Süt Mamülleri, Sakarya, Türkiye), saccharose (Keskinkılıç Gıda, İstanbul, Türkiye), maple syrup (68.5 °Bx, Özmer Pastacılık ve İçecek Ürünleri, Gebze, Türkiye), agave syrup (75.5 °Bx, Nutriagaves de México, Ayotlan, Mexico), stabilizer consisting of guar gum 50 % and xanthan gum 50 % (Smart Kimya, İzmir, Türkiye) and emulsifier glycerol mono stearate (Smart Kimya) used in ice cream production were purchased ready-made from the market.

Ice cream production

Ice cream samples were produced according to the plain ice cream recipe of Gürsel and Karacabey [17]. The samples of ice cream were produced in two stages in the study.

In the first stage, the most acceptable low amounts of saccharose, maple syrup and agave syrup for ice cream were determined. For this purpose, fat (10 %), milk solid non-fat (11.5 %), stabilizer (1.5 $g \cdot kg^{-1}$), and emulsifier (1.5 $g \cdot kg^{-1}$) contents were kept constant for each sample produced. Separate ice cream samples were prepared using saccharose, agave syrup, and maple syrup as sweeteners. Furthermore, for each type of sweetener, formulations were prepared at concentrations of 6, 8, 10, 12, and 15 % (Tab. 1). To ensure that the final products contained equivalent amounts of added sugars, larger quantities of agave and maple syrups were used due to their lower sugar concentrations. All ingredients were weighed individually according to the calculated formulation. Firstly, water and the cream were mixed and whipped. Then, stabilizer and emulsifier were mixed with some of the sugar, added into

Tab. 1. Formulations of the ice cream samples prepared in the first stage.

Constituent	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5 (control)
Fat [%]	10.0	10.0	10.0	10.0	10.0
Milk solids non-fat [%]	11.5	11.5	11.5	11.5	11.5
Added sugar content [%]	6.0	8.0	10.0	12.0	15.0
Stabilizer and emulsifier total [%]	0.3	0.3	0.3	0.3	0.3

The formulas of the samples prepared with each sweetener based on its proportion. Stabilizer and emulsifier were each added at a level of 1.5 $g \cdot kg^{-1}$.

the mixture and whipped. Finally, skimmed milk powder and the rest of the sugar were added and whipped at 39 °C. The whole mixture was then processed by a stick blender KHB-4415 (BMVA Elektronik, İstanbul, Türkiye) for 3 min to prevent clumping. Then, the mixture was heated to 50–60 °C and mixed thoroughly. In ice creams containing agave and maple syrup, the same procedure was followed in all other steps, except that the syrups were added together with the liquid ingredients. The prepared mixtures were then pasteurized at 72–74 °C for 10 min and kept in the refrigerator at 3–4 °C for an average of 20 h. Afterwards, the mixtures were frozen at –9 °C for 12 min in a vertical freezing machine L16 (Uğur, Aydın, Türkiye) and finally hardened in a deep freezer DW-40L262 (Haier Biomedical, Qingdao, China) at –40 °C [17].

The ice cream samples produced with saccharose, agave syrup, and maple syrup were coded as SI, AI, and MI, respectively. The SI sample also served as the treatment control. At the first stage, only sensory analyses were performed, and the lowest acceptable sugar proportion was determined for each sweetener. In the study, ice cream with added saccharose (SI) was produced first and presented to the panellists. The ice cream sample with 15 % sweetener [17] served as the control (CI) for evaluating the sweetener proportions in the SI, AI, and MI samples. The panellists were asked which sample with the lowest amount of added saccharose they would prefer compared to the CI. The same tests were also performed for agave syrup (AI) and maple syrup (MI) ice creams. Thus, the most acceptable low sweetener proportion that could be preferred by the panellists for all three sweetener sources was determined. The syrup amounts were calculated based on Brix values to provide sugar content equivalent to the amount of saccharose added to the SI. After determining the most acceptable low proportion of the sweeteners in the ice cream samples, the second stage was started.

In the second stage, the ice cream samples containing the most acceptable low level (8 %) of saccharose, maple syrup, and agave syrup were reproduced, and some chemical, physical, colour, textural, sensory, phenolic, and antioxidant properties were compared. The ice cream mixture formulation was prepared to contain 10 % fat, 11.5 % milk solid not-fat, 8 % sweetener, 1.5 $g \cdot kg^{-1}$ stabilizer, and 1.5 $g \cdot kg^{-1}$ emulsifier. In this stage, the analyses of raw material, mixture and the samples of ice cream were performed. At the end of this stage, an attempt was made to identify the low-sugar ice cream with the best properties in terms of the analysed parameters.

The study was carried out in two repetitions. During the first stage of the study, a total of 30 samples including replicates were produced, while in the second stage, 6 ice cream samples with replicates were prepared.

Mixture analyses

The dry matter content of ice cream mixture samples was determined by drying at 105 ± 1 °C, fat content by the Gerber method, acidity by titration with 0.1 $mol \cdot l^{-1}$ NaOH using phenolphthalein as an indicator until a persistent light pink endpoint was observed, and pH using a pH meter HI 83141 (Hanna Instruments, Woonsocket, Rhode Island, USA), as described by Metin [18]. The viscosity of the mixtures was measured using a Vibro Viscometer SV-10 (AND, Tokyo, Japan), and the mean of nine measurements taken at 15-second intervals for each sample was reported as the viscometer value in millipascal seconds. The relative density was determined using the formula provided by Arbuckle [19]. For the protein stability, 5 ml of ice cream mixture were placed in each of 9 test tubes. Distilled water was added in decreasing amounts from 9 ml to 1 ml, while 95% ethanol was added correspondingly from 1 ml to 9 ml. The tubes were gently inverted 2–3 times, and the volume of 95 % ethanol added to the tube showing slight precipitation was recorded [19].

Colour values (L^*, a^* and b^*) of the ice cream mixtures were measured using a colour analyser CR-400 (Konica Minolta, Tokyo, Japan).

Ice cream analyses

The dry matter content of the ice cream samples was determined gravimetrically by drying at 105 ± 1 °C. The amount of non-fat dry matter was calculated by subtracting the fat content from the total dry matter. The protein content was calculated by determining the nitrogen value using the Kjeldahl method and multiplying it by 6.38 [18]. For the ash content determination, porcelain crucibles were pre-dried at 105 °C for 1 h to obtain constant weight. After recording the tare weights, 5 g of each sample was added and incinerated in a muffle furnace by gradually increasing the temperature to 550 °C. The samples were ashed for 6 h until they turned white, then cooled in a desiccator and weighed. The ash content was calculated gravimetrically [18]. The fat content was determined by Gerber method, acidity (expressed as grams of lactic acid equivalents per 100 g sample) by the titrimetric method and pH by a pH meter HI 83141 [18]. To calculate the total carbohydrate (*TC*) content, the amounts of water, fat, protein, and ash were first determined. The *TC* content was then calculated by difference and expressed as grams per 100 g portion (Eq. 1).

$$TC = 100 - (W + F + P + A) \quad (1)$$

where *W, F, P* and *A* represent the content of water, fat, protein and ash in grams per 100 g portion, respectively.

The total energy (*TE*) values were calculated in kilojoules using the Eq. 2 [20]:

$$TE = (17 \times TC) + (37 \times F) + (17 \times P) \quad (2)$$

where *TC*, *F* and *P* denote the content of total carbohydrates, fat and protein in grams per 100 g sample, respectively.

Overrun, first dripping time, melting rate, and shape factor were determined according to the methods described by Gürsel and Karacabey [17]. To calculate overrun, an empty beaker was first weighed, then filled with the ice cream mixture and weighed again. The same beaker was subsequently filled to the same level with the finished ice cream and weighed. Overrun (*O*) was calculated as percentage using Eq. 3:

$$O = \frac{(MiW - IW)}{IW} \times 100 \quad (3)$$

where *MiW* is the mixture weight and *IW* is the ice cream weight.

For the first dripping time and melting rate analysis, the ice cream samples were placed on a tared beaker fitted with a wire mesh and allowed to melt at room temperature. The time of the first drip was recorded and the melted portions were collected. To calculate the melting rate, initial weights were recorded before melting started, and final weights were measured after keeping the samples at room temperature for 120 min. Melting percentage was then calculated using Eq. 4:

$$MR = \frac{MeW}{IW} \times 100 \quad (4)$$

where *MR* is the melting rate, *MeW* is the melted weight, and *IW* is the ice cream weight.

To determine shape factor (shape retention capability), ice cream samples were similarly placed on a wire mesh and left to melt at room temperature. Length and height of the ice cream block were measured initially (before melting) and again after a 120-minute holding period at room temperature (25 ± 1 °C). These values were used to calculate the shape factor as described in Eq. 5:

$$SF = \frac{IL}{IH} \times \frac{FH}{FL} \times 100 \quad (5)$$

where *SF* represents shape factor as percentage, *IL* is the initial length, *IH* is the initial height, *FH* is the final height, and *FL* is the final length.

Colour measurements of the samples were performed using a colorimeter CR-400. The measurements were based on the CIE (International Commission on Illumination) colour system. After calibration, L^*, a^* and b^* values were recorded.

The Folin-Ciocalteu method [21] was used for the determination of total phenolic substance and measurements were performed at 735 nm using a UV-1700 spectrophotometer (Shimadzu, Kyoto, Japan). The 2,2-diphenyl-1-picrylhydrazyl (DPPH) method [21] was used for the determination of antioxidant activity of the ice creams. Absorbances were measured at 517 nm using the same spectrophotometer.

Texture analyses of the ice cream samples were performed using a 2 mm diameter stainless steel cylindrical probe (P2) on the TexturePro CT V1.4 Build 17 device (Brookfield Engineering, Middleboro, Massachusetts, USA). Analysis parameters were set as load cell weight 5 g, penetration depth 20 mm and penetration speed 3.3 mm·s^{-1} [22]. The results for hardness, adhesiveness, gumminess, chewiness were reported as gram-force by the instrument, while cohesiveness and resilience were shown as dimension-less values.

In the sensory analysis of the ice cream samples produced in the first stage, the “Preference test”

was used [23]. At this stage, the characteristics of the ice cream samples such as colour and appearance, structure and texture, taste and aroma were examined. Also, the most acceptable low saccharose, agave and maple syrup proportions to be used in ice creams for the next stage were determined. Sensory analyses of the samples produced in the second stage were carried out using a 9-point hedonic scale, as described by DRAKE [23]. On the 9-point hedonic scale, 1 indicates 'dislike extremely' and 9 indicates 'like extremely'. Scores from 1 to 4 reflect decreasing dislike, 5 represents a neutral response, and scores from 6 to 9 reflect increasing levels of liking. Sensory evaluation was carried out by 10 trained panellists in both stages.

In statistical analyses, the data was primarily evaluated with normality and homogeneity tests. According to the results of these tests, One Way Anova-Tukey, Games Howell or Kruskal Wallis tests were applied to the data and the significance of difference between samples was tested at a 95% confidence level [24]. Minitab 17 package program (Minitab, Coventry, United Kingdom) was used in the statistical analysis.

RESULTS AND DISCUSSION

The lowest acceptable sweetener proportion

In order to determine the minimum acceptable level of sweetener for use in ice cream production, formulations were prepared with saccharose, maple syrup, and agave syrup such that the final products contained 6, 8, 10, 12 and 15 % added sugar. Due to the lower dry matter content of maple and agave syrups compared to saccharose, proportionally higher quantities of these syrups were incorporated to achieve equivalent sugar concentrations across formulations. Subsequently, each formulation group was subjected to independent sensory evaluation. As seen in Tab. 2, 8 panellists preferred the sample containing 8 % added saccharose (SI), 13 panellists preferred the sample containing 8 % added sugar from agave syrup (AI), and 12 panellists preferred the sample containing 8 % added sugar from maple syrup (MI). Although the sweetener types differed, the most preferred samples in all three groups corresponded to the formulations containing 8 % added sugar in the final product. Notably, in all three sweetener groups (SI, AI, and MI), the samples with the highest sweetener level (15 %), referred to as control ice cream (CI), were not favoured by any of the panellists.

Tab. 2. Number of panellists selecting each sample as the lowest acceptable level of sweetness.

Proportion of added sugar	Preference (number of panellists)		
	SI	AI	MI
6 %	1	2	1
8 %	8	13	12
10 %	7	4	5
12 %	4	1	2
15 % (control)	0	0	0

Each value represents the sum of two replicates.
SI – ice cream with saccharose, AI – ice cream with agave syrup, MI – ice cream with maple syrup.

Reduced sweetener ice cream mixtures

After determining the acceptable level of low sugar proportion as 8 %, the ice cream mixtures with the addition of saccharose (SM), agave syrup (AM) and maple syrup (MM) were reproduced with this sugar proportion. The properties of these mixtures are seen in Tab. 3.

As can be understood from the examination of the table, dry matter content appeared to be nearly unchanged between the samples, although statistically, the difference between SM and MM reached significance. No significant differences were observed regarding the fat content, titratable acidity, relative density, or the protein stability. The pH was significantly reduced in MM samples ($p < 0.05$). The viscosity was significantly higher in the AM samples ($p < 0.05$) and non-significantly higher in the MM ($p > 0.05$) samples. The L^* colour values were significantly decreased in both AM and MM samples ($p < 0.05$). Conversely, the colour components a^* ($p < 0.05$) and b^* ($p < 0.05$) were higher in AM and MM mixture samples.

As a result, it can be said that viscosity, a^* and b^* values increased in the mixtures with AM and MM additions compared to SM, whereas the brightness (L^*) decreased. The highest viscosity value was found in the AM sample. Therefore, the addition of agave and maple syrups to the ice cream mixture affects its properties.

Ice cream with reduced sweetener amount

Chemical properties

Tab. 4 presents some chemical properties of the samples of SI, AI and MI produced from the mixture with the lowest acceptable sugar proportion (8 %).

As can be understood from the table, using agave and maple syrups as the source of sugar in ice cream production did not significantly change

Tab. 3. Properties of ice cream mixtures containing 8 % added sugar.

Properties	Ice cream mixture		
	SM	AM	MM
Dry matter [g]	31.893 ± 0.027 [a]	31.677 ± 0.027 [ab]	31.541 ± 0.265 [b]
Fat [g]	10.825 ± 0.236 [a]	10.750 ± 0.289 [a]	10.750 ± 0.379 [a]
Acidity [g]	0.225 ± 0.024 [a]	0.243 ± 0.021 [a]	0.260 ± 0.018 [a]
pH	6.485 ± 0.017 [a]	6.448 ± 0.021 [a]	6.380 ± 0.012 [b]
Viscosity [mPa·s]	57.929 ± 3.330 [b]	81.658 ± 4.040 [a]	63.274 ± 3.560 [b]
Relative density	1.077 ± 0.001 [a]	1.076 ± 0.001 [a]	1.075 ± 0.001 [a]
Colour *L**	80.473 ± 0.494 [a]	78.978 ± 0.535 [b]	79.085 ± 0.549 [b]
Colour *a**	–3.680 ± 0.070 [c]	–3.015 ± 0.121 [b]	–2.623 ± 0.074 [a]
Colour *b**	10.153 ± 0.085 [c]	11.880 ± 0.277 [a]	10.653 ± 0.025 [b]
Protein stability [ml]	4.500 ± 0.577 [a]	4.500 ± 0.577 [a]	4.500 ± 0.577 [a]

The values represent mean ± standard deviation ($n = 2$). The means shown with different superscript letters in the same row are different from each other ($p < 0.05$), those shown with the same superscript letters are not different ($p > 0.05$).
Dry matter and fat are expressed per 100 g mixture. Acidity is expressed as grams of lactic acid equivalents per 100 g mixture.
Protein stability refers to the volume of alcohol needed to precipitate 5 ml of the mixture diluted with water.
SM – saccharose added mixture, AM – agave syrup added mixture, MM – maple syrup added mixture.

Tab. 4. Chemical composition of the ice cream samples containing 8 % added sugar.

Properties	Ice cream samples		
	SI	AI	MI
Dry matter [g]	30.968 ± 0.456 [a]	30.710 ± 0.607 [a]	30.529 ± 0.648 [a]
Non-fat dry matter [g]	21.144 ± 0.474 [a]	20.961 ± 0.642 [a]	20.780 ± 0.688 [a]
Fat [g]	9.825 ± 0.222 [a]	9.750 ± 0.238 [a]	9.750 ± 0.238 [a]
Protein [g]	4.378 ± 0.004 [a]	4.365 ± 0.020 [a]	4.356 ± 0.004 [a]
Total carbohydrate [g]	15.729 ± 0.429 [a]	15.558 ± 0.588 [a]	15.394 ± 0.655 [a]
Ash [g]	1.038 ± 0.061 [a]	1.038 ± 0.061 [a]	1.030 ± 0.050 [a]
Acidity [g]	0.215 ± 0.013 [b]	0.233 ± 0.015 [ab]	0.258 ± 0.010 [a]
pH	6.518 ± 0.015 [a]	6.483 ± 0.015 [b]	6.428 ± 0.010 [c]
Total energy [kJ]	705 ± 10 [a]	699 ± 11 [a]	696 ± 13 [a]

The values represent mean ± standard deviation ($n = 2$). The means shown with different superscript letters in the same row are different from each other ($p < 0.05$), those shown with the same superscript letters are not different ($p > 0.05$).
Values are expressed per 100 g of ice cream. Acidity is expressed as grams of lactic acid equivalents.
SI – ice cream with saccharose, AI – ice cream with agave syrup, MI – ice cream with maple syrup.

the dry matter, non-fat dry matter, fat, protein, total carbohydrate and ash values of the ice cream samples ($p > 0.05$). This result may be caused by the similar compositions of the ice creams, the use of the same recipe and the same sweetener amount. According to the Turkish Food Codex Ice Cream Communiqué [25], high-fat ice cream is defined as a product containing 8–12% milk fat and at least 36% dry matter. The samples produced in this study meet the fat requirement and can be considered fatty ice cream. However, their dry matter values were slightly below the specified minimum. This is an expected result since the ice cream samples produced within the scope of the research were prepared with low sugar. As is known, sweetener is one of the most important dry matter sources for ice cream. The dry matter and ash values obtained in our study were lower than those reported by Saadi et al. [26] for ice creams produced with maple syrup. The fat contents of ice creams formulated with mulberry and grape molasses as natural sweeteners were found to be comparable to those determined in the present study, whereas their protein contents were lower than the values obtained in our formulations [27].

As can be seen in Tab. 4, the pH values of ice creams with natural sweeteners (AI and MI) were slightly lower than that of the sample prepared

with saccharose (SI) ($p < 0.05$). Conversely, the acidity value of the MI sample was found to be marginally higher compared to the others. The change in pH and acidity values of AI and MI samples may be due to the natural acidic structures and low pH values of the syrups. The obtained pH values were most similar to those reported by BEKIROGLU et al. [12] in ice cream samples made with cow and walnut milk, and lower than the values found by OZDEMIR et al. [2] in stevia-added samples.

When the total energy values of the SI, AI and MI samples produced in the study were examined (Tab. 4), the energy values of the samples produced with the addition of natural sweeteners (AI, MI) were lower, but this was not found to be significant ($p > 0.05$). The fact that the energy values of the ice cream samples were close to each other may be due to the calculation of the sugar proportions of syrup-added ice creams based on their Brix degrees.

Physical properties

The data regarding overrun, first dripping time, melting rate and shape factor of the ice cream samples are presented in Tab. 5. The highest overrun value in the study was obtained in the SI group ($p < 0.05$). This group was followed by the AI and MI samples, respectively, but the difference between these two groups was found to be insignificant ($p > 0.05$). Typical ice cream has an overrun of around 120 %, whereas premium varieties generally have lower overruns between 60 % and 90 %, while super-premium ice creams have even less, typically ranging from 20–40 % [28]. Accordingly, the AI and MI samples exhibited higher quality with respect to their overrun values. OZDEMIR et al. [2] found the overrun value of plain ice cream samples as 14.1 % with saccharose and a dry matter value of 30.8 %; and the overrun rate of ice cream with stevia sugar and a dry matter value of 31.8 % to be 8.5 % in their study.

High-quality ice cream usually starts to melt visibly within 15–20 min at room temperature after dipping [1]. The first dripping time was the highest in the SI sample (35.14 min), followed by the samples of MI (34.24 min) and AI (30.09 min) (Tab. 5). This situation was also found to be statistically significant ($p < 0.05$). It has been reported that the air in the composition of the ice cream acts as an insulator and delays heat transfer [29]. Based on this result, it was determined that the SI sample, which has a higher overrun value, was also the most resistant ice cream sample to melting.

As can be seen in Tab. 5, the melting rates of the syrup-added samples (AI and MI) were found to be lower ($p < 0.05$). It is estimated that the decrease is due to the difference in the sugar composition of the syrups. On the other hand, the shape factor values of the SI, AI and MI samples produced within the scope of the research also gave results supporting the melting rate. The SI sample, which exhibited the highest melting at the end of the 120-minute period, also showed the lowest shape factor during the same timeframe ($p < 0.05$). The obtained results are in agreement with the values of meltdown of ice cream with 2 $g \cdot kg^{-1}$ stabilizer and 150 $mg \cdot kg^{-1}$ polysorbate 80 reached between 240 min and 360 min in a study conducted by WU et al. [29].

The colour values of the low sweetener (8 %) ice cream samples prepared using different sugar sources are presented in Tab. 5. As can be understood from the table, the MI samples had the lowest L^* value (brightness/darkness) ($p < 0.05$),

Tab. 5. Physical properties of ice cream samples containing 8 % added sugar.

Properties	Ice cream samples		
	SI	AI	MI
Overrun [%]	28.0 ± 0.9 [a]	21.7 ± 1.2 [b]	19.9 ± 1.5 [b]
First dripping time [min]	35.14 ± 0.76 [a]	30.09 ± 0.42 [b]	34.24 ± 0.90 [a]
Melting rate [%]	48.2 ± 2.7 [a]	34.9 ± 1.2 [b]	37.8 ± 1.6 [b]
Shape factor [%]	36.4 ± 1.1 [c]	51.8 ± 2.0 [a]	45.9 ± 1.2 [b]
Colour L^*	91.24 ± 0.65 [a]	90.03 ± 0.99 [a]	87.78 ± 0.82 [b]
Colour a^*	–2.85 ± 0.13 [b]	–2.30 ± 0.29 [a]	–2.04 ± 0.17 [a]
Colour b^*	13.19 ± 0.73 [a]	14.97 ± 1.00 [a]	14.00 ± 0.34 [a]

The values represent mean ± standard deviation ($n = 2$). The means shown with different superscript letters in the same row are different from each other ($p < 0.05$), those shown with the same superscript letters are not different ($p > 0.05$).
SI – ice cream with saccharose, AI – ice cream with agave syrup, MI – ice cream with maple syrup.

and the SI group had the lowest a^* value (greenness/redness) ($p < 0.05$). Although the AI samples showed the highest b^* (blueness/yellowness) value numerically, the difference was not statistically significant ($p > 0.05$). The low L^* values observed in ice creams with natural sweetener are due to the colour of the syrups. Because of their natural colour, syrups affect the appearance of the final product. For example, maple syrup ranges from golden to very dark, which inevitably impacts the colour of the ice cream [6].

Total phenolic substance and antioxidant activity

In recent years, there has been growing interest in functional dairy products enriched with natural bioactive compounds [30]. Agave and maple syrups, rich in phenolic substances, exhibit antioxidant activity [8, 11] and may enhance the functional quality of ice cream when used as sweeteners. The values of phenolic substance and antioxidant activity of the ice cream samples produced in the study are given in Tab. 6. As expected, the phenolic content and antioxidant activity (DPPH) of the AI and MI samples were higher than those of the SI sample, consistent with the phenolic profiles of the syrups used. Among the syrup-added samples, the AI sample had the highest phenolic content ($p < 0.05$).

It has been reported that the antioxidant activity of agave syrups varies in a wide range from 8.7 % to 52.2 % [11]. Although ice cream naturally contains antioxidant substances such as milk vitamins (A, C, E), phenolic compounds, proteolytic enzymes, peptides, casein, and β-lactoglobulin, it is generally considered to have weak antioxidant properties; hence, many studies have focused on enriching it with additional bioactive compounds to enhance its functional value [31]. It can be said that the use of natural sweeteners instead of saccharose in ice cream increases the antioxidant activity and phenolic substances, thus contributing to obtaining a functional product.

Textural properties

Tab. 7 presents the textural analysis results of the SI, AI, and MI ice cream samples. Hardness values were higher in the syrup-added samples compared to the SI sample. Among the samples, the MI sample exhibited the highest value ($p < 0.05$). The high hardness values of ice creams containing natural sweeteners can be associated with the difference in the sugar composition of the syrups and the low overrun values. As shown in Tab. 5 and Tab. 7, the MI sample, which has the highest hardness value, also exhibits the lowest overrun value. Overrun can be influenced by formulation differences [29]. Higher protein and fat levels in the mixture cause air bubbles to be smaller and more compressed, reducing overrun. The hardness values in this study were lower than those determined by Karaman et al. [13] (4 521.89–16 545.37 g).

Among the low-sweetener ice cream samples, the cohesiveness (internal stickiness) of the MI sample was significantly lower ($p < 0.05$) (Tab. 7). Pon et al. [22] investigated the various properties of ice creams with different amounts of stevia powder (0.6 %, 1.1 % and 1.7 %) instead of sugar, and determined the cohesiveness values of the samples between 0.04 and 0.15. In another study, the cohesiveness value of ice creams with different amounts of grape wine sediment and carboxymethyl cellulose was reported between 0.16 and 0.29 [21].

In the study, the adhesiveness (external stickiness) values of the SI, AI and MI samples were determined as 134.5 g, 138.5 g and 192.8 g, respectively (Tab. 7). Among the analysed ice creams, the adhesiveness value of the MI samples was found to be significantly higher than those of the SI and AI samples ($p < 0.05$). Crizel et al. [32] used orange fibres as a fat replacer in lemon ice cream. They determined the adhesiveness values of the analysed samples to be between 135 $g \cdot s^{-1}$ and 413 $g \cdot s^{-1}$. The obtained adhesiveness values are consistent with these studies.

Tab. 6. Phenolic substance and antioxidant activity of the ice cream samples containing 8 % added sugar.

Properties	Ice cream samples		
	SI	AI	MI
Phenolic substance [$mg \cdot kg^{-1}$]	363.78 ± 4.87^{c}	470.89 ± 2.42^{a}	433.67 ± 1.32^{b}
Antioxidant activity [%]	14.3 ± 0.4^{c}	26.9 ± 0.2^{a}	22.9 ± 0.9^{b}

The values represent mean ± standard deviation ($n = 2$). The means shown with different superscript letters in the same row are different from each other ($p < 0.05$), those shown with the same superscript letters are not different ($p > 0.05$).
Content of phenolic substances is expressed as milligrams of gallic acid equivalents per kilogram of ice cream wet weight. The antioxidant activity is expressed as a percentage decrease in absorbance caused by the sample, relative to the initial absorbance of the control DPPH solution [21].
SI – ice cream with saccharose, AI – ice cream with agave syrup, MI – ice cream with maple syrup.

Tab. 7. Texture profile of the ice cream samples containing 8 % added sugar.

Texture parameters	Ice cream samples		
	SI	AI	MI
Hardness [g]	561.00 ± 274.00 ^{b}	924.80 ± 95.00 ^{ab}	1097.00 ± 2.89 ^{a}
Cohesiveness	0.14 ± 0.04 ^{a}	0.09 ± 0.02 ^{a}	0.05 ± 0.01 ^{b}
Adhesiveness [g]	134.50 ± 78.50 ^{b}	138.50 ± 22.50 ^{ab}	192.80 ± 21.70 ^{a}
Resilience	0.85 ± 0.09 ^{a}	0.83 ± 0.13 ^{a}	0.87 ± 0.06 ^{a}
Gumminess [g]	67.45 ± 30.30 ^{ab}	79.35 ± 5.14 ^{a}	50.05 ± 7.22 ^{b}
Chewiness [g]	59.45 ± 32.00 ^{ab}	65.40 ± 5.77 ^{a}	43.25 ± 3.41 ^{b}

The values represent mean ± standard deviation (n = 2). The means shown with different superscript letters in the same row are different from each other ($p < 0.05$), those shown with the same superscript letters are not different ($p > 0.05$).
The results for hardness, adhesiveness, gumminess, chewiness were reported as gram-force by the instrument, while cohesiveness and resilience are dimension-less values.
SI – ice cream with saccharose, AI – ice cream with agave syrup, MI – ice cream with maple syrup.

As can be seen in Tab. 7, there was no statistical difference between the resilience values of the SI, AI and MI samples ($p > 0.05$). The obtained values were close to the values (0.82–0.91) determined by CRIZEL et al. [32].

The gumminess values of the ice cream samples prepared with low proportions of different sweeteners ranged between 50.05 and 79.35 (Tab. 7). Among the analysed ice cream samples, the highest gumminess value observed in the AI sample and the lowest value in the MI sample were found to be significant ($p < 0.05$). The gumminess values obtained in this study were within the range (46.62–134.52) reported by PON et al. [22] for ice cream samples produced with the addition of stevia sugar.

As seen in Tab. 7, the highest chewiness value among the ice creams produced within the scope of the study was determined in the AI sample and the lowest in the MI sample ($p < 0.05$). At this point, it is seen that these two ice cream samples also have the highest and lowest gumminess values. In fact, it has been reported that gumminess and chewiness values have a directly proportional relationship [33]. In a different study, the chewiness value of ice creams in which bacterial cellulose was used as a stabilizer was determined to be 26.64 g [34].

Sensory properties

The sensory evaluation results of the ice cream samples are shown in Tab. 8. Each value represents the median of the data provided by 10 panellists with duplicate testing (N = 20). The Kruskal-Wallis test was used to evaluate data that did not show normal distribution. The sensory property scores of the samples were either the same or close to each other ($p > 0.05$). Since it was aimed to obtain an appearance close to plain type ice cream, all three ice cream types were found to be close to the desired sensory white colour ($p > 0.05$). In the sensory softness-hardness evaluation of the ice cream samples, high scores were given to those with the ideal consumption hardness and low scores were given to those with softness or hardness defects. Among the evaluated samples, SI and AI groups were found to be closer to the ideal consumption hardness ($p > 0.05$).

The lowest scores for features such as rough structure and icy structure, which are considered

Tab. 8. Sensory evaluation of the ice cream samples containing 8 % added sugar.

Sensory properties	Ice cream samples		
	SI	AI	MI
Colour and appearance	9.0 ^{a}	9.0 ^{a}	9.0 ^{a}
Softness-Hardness	8.0 ^{a}	7.5 ^{a}	6.5 ^{a}
Rough structure	9.0 ^{a}	8.5 ^{a}	9.0 ^{a}
Icy structure	9.0 ^{a}	8.0 ^{a}	10.0 ^{a}
Gummy structure	5.0 ^{a}	5.0 ^{a}	5.5 ^{a}
Melt in mouth	7.0 ^{a}	7.5 ^{a}	7.5 ^{a}
Coldness intensity	7.5 ^{a}	7.5 ^{a}	8.5 ^{a}
Sweetness level	7.5 ^{a}	8.5 ^{a}	7.5 ^{a}
General appreciation	7.0 ^{a}	8.0 ^{a}	8.0 ^{a}

Each value represents the median of the data (N = 20) using a 9-point hedonic scale (where 1 represents 'dislike extremely' (or poor quality/strong defect, depending on the attribute) and 9 represents 'like extremely' (or no defect/excellent quality).
The means shown with same superscript letters in the same row are not different from each other ($p > 0.05$).
SI – ice cream with saccharose, AI – ice cream with agave syrup, MI – ice cream with maple syrup.

as structural defects in ice cream, indicate that the ice cream has this structural defect. In terms of rough structure feature, the SI and MI groups had higher median values, in other words, they were found to be more flawless ($p > 0.05$). Similarly, the MI were the most flawless samples in terms of icy structure feature ($p > 0.05$).

In the comparison of sensory gumminess properties of the SI, AI and MI samples, the highest score represents the ideal level of gumminess. Among the ice cream samples, the gumminess score of MI was found to be slightly higher ($p > 0.05$). Of the samples, the natural sweetener containing samples (AI and MI) received higher scores in terms of melting quality in the mouth and it was determined that they melted in the ideal consumption time. In the sensory evaluations, the panellists perceived the AI and SI samples colder in the mouth than the MI sample ($p > 0.05$). The highest scores in terms of sweetness show the ideal sweetness level of the samples. The sweetness of sample AI had the highest median value ($p > 0.05$). According to the 9-point hedonic scale, all the ice cream samples were positively rated in terms of overall appreciation, with the SI sample receiving a score of 7 ('like moderately') and both AI and MI samples receiving a score of 8 ('like very much'), indicating a higher level of sensory acceptance for AI and MI ($p > 0.05$). This level of sensory acceptance is noteworthy, as previous studies on low-fat and low-sugar ice cream formulations containing agave fructans reported lower overall liking scores (5.7–6.5) on the same scale [16]. However, the MI sample had a more characteristic taste out of these two samples and therefore may not appeal to everyone, while AI samples had a taste closer to the SI samples.

CONCLUSIONS

In this study, ice cream with an acceptable low sweetener amount was produced. For this purpose, saccharose, agave and maple syrups as natural sweetener were used in the production of ice cream samples coded as SI, AI and MI, respectively. A level of 8 % added sugar in the final product was identified as the minimum acceptable proportion for all three sweeteners evaluated in the study. Using this sweetener amount, SI, AI and MI ice cream samples were subsequently reproduced, and their various properties were compared. As a result, the use of maple and agave syrups showed that they can be used as alternative sweetener to saccharose due to the positive effect they have on the functional properties, some physical qualities, and sensory properties of ice cream. However, the agave syrup-added samples had more successful scores in terms of appearance, sweetness, and general appreciation. They were successful also in terms of perceived defects in ice cream such as rough texture, icy texture, and melting too quickly in the mouth ($p > 0.05$).

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