Technological functions of hydrolyzed whey concentrate in ice cream

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Abstract

Introduction. The article examines the quality indicators of low-fat ice cream with a different ratio between sugar and hydrolyzed and non-hydrolyzed concentrates of demineralized whey.

Materials and methods. The degree of lactose hydrolysis was determined by iodometric and refractometric methods, the water activity in the mixtures was determined using the water activity analyzer, the rheological characteristics were determined using a rotary viscometer, the foam overrun and foam stability of the ice cream mixtures and the melting rate of ice cream were determined using modified methods, sensory indicators were determined using the descriptive-integral method. The mass fraction of protein, dry matter, overrun, resistance to melting in ice cream were determined using well-known methods.

Results and discussion. Based on the calculation of the degree of sweetness of whey concentrates, taking into account the mass fraction of total solids, the degree of lactose hydrolysis and the known values of the relative sweetness of sugar, lactose, glucose and galactose, a concentrate with a solids content 40% was chosen for use in the ice cream formulation. According to the results of the study of the quality indicators of ice cream mixtures, it was found that the hydrolyzed concentrate of demineralized whey with a mass fraction of solids 40% could replace up to 42% of sugar in the composition of ice cream, while maintaining the degree of sweetness determined for this type of ice cream in the range from 0.8 to 0.9. According to the viscosity-speed characteristics, the mixture of low-fat ice cream with a concentrate of hydrolyzed demineralized whey is classified as a system with a pronounced coagulation structure with the detection of thixotropic properties. Ice cream based on hydrolyzed whey concentrate contains 3.3% of whey proteins, which corresponds to the standard chemical composition of ice cream. The high content of lactose hydrolysis products in ice cream increases overrun, but reduces the resistance to melting of ice cream, which must be taken into account during the technological process and when choosing a consumer container.

Conclusions. The feasibility of using a hydrolyzed whey concentrate with a mass fraction of solids 40% as a sweetening and protein-containing ingredient in low-fat ice cream has been proven.

Introduction

One of the modern trends in the food industry is the production of low-calorie dessert products, including ice cream. The calorie content of ice cream is usually reduced by limiting its fat content (not higher than 5%), but its absence or low content leads to the formation of a coarse crystalline structure, a dense consistency and a decrease in the melting resistance of this product (Bass et al., 2018; Özdemir et al., 2018; Syed et al., 2018). The quality of low-fat ice cream is usually improved by using in its composition technologically effective food hydrocolloids, in particular polysaccharides and products of their chemical modification or destruction (Aljewicz et al., 2020; Goff et al., 2019). Polysaccharides actively bind water, structure mixtures, stabilize dispersed ice cream systems, but practically do not affect the nutritional value of the product. Instead, proteins, including milk proteins, as natural biopolymers perform not only technological functions in the composition of ice cream, but also additionally enrich it (Akalin et al., 2008; Polishchuk et al., 2020). Recently, in the composition of dessert products, protein-containing whey processing products are increasingly used, in particular, fermented whey as a source of proteins and carbohydrates. In whey concentrates with hydrolyzed lactose, the number of molecules dissolved in the aqueous phase increases by 1.5–1.8 times, compared to concentrates before hydrolysis, which significantly affects their sensory properties, osmotic pressure and cryoscopic temperature. Enzymatic hydrolysis of lactose also increases the sweetness of whey concentrates, which can be used as sweetening ingredients (Majore and Ciproviča, 2020). Therefore, the scientific justification of the partial replacement of sugar with hydrolyzed whey and the study of the effect of such replacement in the composition of ice cream on its physical and chemical characteristics is an actual applied research.

Ice cream of various types contains not only fresh milk and cream, but also protein-containing ingredients, protein concentrates and isolates. At the same time, milk powder and condensed milk, whey and buttermilk powder significantly increase the lactose content in ice cream. Under these conditions, excessive crystallization of lactose, which has a low solubility, becomes the reason for the appearance of a sandy consistency in ice cream during its low-temperature storage (Alvarez et al., 2005). Therefore, in order to improve the quality of ice cream by reducing the lactose content, additional binding of free water, forming and stabilizing the structure and increasing its biological value, it is more appropriate to use protein isolates and low-lactose protein concentrates (Ganga et al., 2017; Nasser et al., 2018; Polishchuk et al., 2020).

Proteins of different fractional composition, degree of purification and origin show specific technological activity in the composition of ice cream (Nastaj et al., 2019; Peng et al., 2009). Among the proteins of animal and plant origin, the ability of whey proteins to mask the absence or lack of fat and increase the overrun of ice cream (El-Zeini Hoda et al., 2016) deserves special attention, which makes it possible to ensure its high quality while reducing the calorie content and increasing the biological value of the product. However, existing methods of extracting and concentrating whey proteins are quite expensive, which is reflected in their price (Arsić et al., 2019). The cheapest source of whey proteins in ice cream is condensed and powdered whey, but it contains up to 70–75% of lactose from the total solids, which is a limiting factor during its use (Livney et al., 2007). Therefore, the enzymatic hydrolysis of lactose in whey concentrates is advisable, which not only prevents the occurrence of consistency defects during the storage of hardened ice cream, but also increases its degree of sweetness (Chauhan et al., 2010; Trubnikova et al., 2018). Partial hydrolysis of lactose can also be achieved by fermentation of ice cream mixes with lactic acid bacteria (Schmidt et al., 2016).

In ice cream technology, hydrolyzed whey is not only used, but also appropriate hydrolysis of lactose is carried out in mixtures for the production of ice cream. Thus, the hydrolysis of 75% of lactose in ice cream mixes has a positive effect on the physicochemical parameters of the product and allows reducing the sugar content to 25% (Abbasi et al., 2015). Tsuchiya et al. (2017) also proved the feasibility of reducing the sugar content from 20 to 14% due to the use of hydrolyzed whey. Monosaccharides as lactose hydrolysis products lower the cryoscopic temperature, increase the degree of sweetness, form a softer ice cream texture, and facilitate the extrusion process (Wilson et al., 2003). At the same time, reducing the sugar content in ice cream reduces the total amount of solids in the product, which must be taken into account to prevent consistency defects (McCain et al., 2018).

The authors of this article proved that in order to achieve the maximum effect during lactose hydrolysis, it is more effective to use enzyme and starter preparations simultaneously. This method of enzymolysis of demineralized whey concentrates with a solids content 10–40% and a degree of demineralization 70% makes it possible to achieve 80–90% hydrolysis of lactose (Osmak et al., 2021). Hydrolyzed whey concentrate with an increased content of whey proteins and monosaccharides can be a promising ingredient in ice cream technology, which requires additional investigating and outlines the scientific interest of this study.

The aim of research was to determine the functions of hydrolyzed whey concentrate in low-fat ice cream.

To achieve the goal, the following tasks were chosen:

- to determine the possibility of partial replacement of sugar in the composition of ice cream with hydrolyzed whey concentrate containing 40% of total solids;
- to study the physicochemical characteristics of the ice cream mixture with hydrolyzed whey concentrate;
- to study the effect of hydrolyzed whey concentrate on ice cream quality indicators.

Materials and methods

Raw material for research

Hydrolyzed whey concentrate (solids 40%) was selected for use in the composition of ice cream, which was obtained by reconstitution of demineralized dry whey in drinking water (ash – not more than 2.5%, lactose – not less than 79%, protein – not less than 10.7% in conversion to solids).

The liquid preparation β-D-galactosidase-hydrolase with the commercial name GODO-YNL2 ("Danisko", Denmark) was used for the hydrolysis of whey concentrates, which is a producer of breeding strains of *Kluyveromyces lactis*. Under standard conditions of milk hydrolysis for 24 hours at a temperature of (4.4–7.2) °C, the recommended amount of the preparation GODO-YNL2 containing 10% β-galactosidase is 100 g per 100 liters of milk.

For the fermentation of whey concentrates, a fermenting single-strain lyophilized starter *"L. acidophilus LYO 50 DCU-S"* (Danisko, Denmark) was used at the recommended dose of 5 g per 100 liters of milk.

To stabilize the structure of low-fat ice cream, the stabilization system Cremodan SE 406 (DuPont™ Danisco®) was chosen in the amount of 0.6%, in accordance with the manufacturer's recommendations.

Production of whey concentrates and ice cream samples

Dry demineralized whey was reconstituted in drinking water at a temperature of (40–45) °C to obtain a concentrate with a mass fraction of total solids 40%. The concentrate was filtered, pasteurized at a temperature of (85–88) °C for 3–5 minutes, cooled to a temperature of (40–43) °C and fermented with the preparation GODO-YNL2 and starter based on "*L. acidophilus LYO 50 DCU-S*". In case of simultaneous application of GODO-YNL2 and a starter during the lag phase of *L. Acidophilus* development (2–4 hours), the enzyme manages to detect hydrolytic activity at an active acidity of pH ≥ 5.7, and, as a result, lactose hydrolysis reached 80–90%.

Mixtures with non-hydrolyzed whey concentrate (5 control samples) and mixtures with hydrolyzed whey concentrate (5 experimental samples) were prepared with a simultaneous decrease in the sugar content from 17 to 9% and an increase in the content of 40% whey concentrate in the amount from 0 to 30% by mass fraction of total solids.

The mixtures were filtered, pasteurized at a temperature of (85±2) °C for 5 minutes and homogenized at a pressure of (12.0±2.5) MPa using a laboratory homogenizer-disperser model 15M-8TA "Lab Homogenizer and Sub-Micron Disperser" (GAULIN CORPORATION, Massachusetts, USA). The homogenized mixtures were cooled to a temperature of (4±2) °C, kept for at least 2 hours and frozen using a periodic freezer of the FPM-3.5/380-50 "Elbrus-400" brand (Ukraine). The freezing process was carried out in 2 stages:

1. The stage of cooling to a temperature of minus 2 °C at a stirrer speed of 270 rpm;
2. The stage of freezing to a temperature of minus 4 °C at a stirrer speed of 540 rpm. The samples of soft ice cream were hardened and stored for at least 48 hours in a "Caravell A/S" freezer (Denmark) at a temperature of minus (22±1) °C.

Research methods

Degree of sweetness of whey concentrates was calculated depending on the mass fraction of total solids and the degree of lactose hydrolysis in these concentrates. The authors previously established that the simultaneous use of enzyme and starter preparations makes it possible to achieve a degree of lactose hydrolysis of 80-90%, therefore, the relative sweetness of concentrates was calculated for this range. The range from 0.8 to 0.9 was chosen as the acceptable degree of ice cream sweetness. (Osmak et al., 2021).

The relative sweetness of the non-hydrolyzed concentrate and concentrates with a degree of lactose hydrolysis of 80, 85, and 90% was calculated based on their chemical composition (content of monosaccharides and disaccharides), taking into account the known values of the relative sweetness of sugar (1), lactose (0.16), glucose (0.73), and galactose (0.32).

Lactose content in whey concentrates and test samples of ice cream mixtures was determined by iodometric and refractometric methods (Romanchuk et al., 2018). The refractive index of transparent lactose solutions was determined refractometrically after precipitation of milk proteins with a calcium chloride solution. For complete separation of proteins, lactose solutions were previously centrifuged. The fraction of the refractive index due to the presence of residual mineral salts was conventionally taken as a constant value, and the fraction of the refractive index due to the presence of lactose as a variable value. The accuracy of the determination was calibrated using the iodometric method.

The degree of lactose hydrolysis was taken as the ratio of lactose content in hydrolyzed samples to its initial content, expressed as a percentage (Osmak et al., 2021).

Definition of foam overrun. Experimental ice cream mixes, after cooling to a temperature of (2–6) °C, were whipped using a mixer with a special nozzle for 5, 10 and 15 minutes with breaks of 5 minutes according to the method of Lim et al. (2008a). Foam overrun was determined as the ratio of the volume of the whipped mixture to its initial volume, expressed as a percentage. A foam overrun value of at least 200% was considered satisfactory.

The foam stability of experimental samples of ice cream mixtures was determined according to the modified method of Philips L., according to which a container with a hole at the bottom was used for the foam to flow after whipping (Lim et al., 2008b). The foam stability indicator was taken as the time during which 50% of the initial volume of the mixture, which was used for whipping, is formed as a result of foam destruction.

The viscosity characteristics of ice cream mixtures with non-hydrolyzed and hydrolyzed whey concentrates (mass fraction of total solids – 40%) were determined on a rotary viscometer with a "cylinder-cylinder" measuring system by taking deformation kinetics curves. Measurements were made at a temperature of 20°C. Shear stress τ (Pa) was measured at twelve values of the shear rate gradient (γ) in the range from 3 to 1312.2 s^{-1} during forward and reverse motion. The maximum effective viscosity of the practically undamaged structure ($\gamma = 3\ s^{-1}$), the minimum effective viscosity of the marginally destroyed structure ($\gamma = 1312.2\ s^{-1}$) and the effective viscosity of the restored structure ($\gamma = 3\ s^{-1}$) were recorded. The degree of restoration of the structure of ice cream mixtures (thixotropic ability) was determined as a percentage by the difference in the values of the effective viscosity of the practically intact structure at the beginning and at the end of the measurement at a shear rate gradient ($\gamma = 3\ s^{-1}$) (Mykhalevych et al., 2022).

Determination of the mass fraction of total solids in ice cream samples was carried out by the arbitration method, the principle of which consists in drying the sample, diluted with distilled water and mixed with sand, at a temperature of 102°C to a constant mass, followed by weighing to determine the mass of the residue.

Determination of the mass fraction of protein in ice cream was carried out by the Kjeldahl method.

The water activity in ice cream mixes was determined on a water activity analyzer "HygroLab 2" (Rotronic, Switzerland) at a temperature of 20°C in the measurement range of 0–1 Aw (0–100% rh) (Kuzmyk et al., 2021).

The overrun of ice cream was determined by the weight method based on the difference in the weight of samples of the same volume of mixture and ice cream, expressed as a percentage (Sofjan and Hartel, 2004). Satisfactory was considered a value of at least 80%.

The resistance to melting was determined by the accumulation time of 10 cm^3 of liquid (melt) flowing out of a sample of ice cream, which was cut in the form of a cylinder with a diameter of 30 mm and a height of 50 mm from ice cream that had an initial temperature of minus 15°C and this sample was placed in a chamber with an adjustable temperature at (20±1)°C. Values not less than 41 min were considered satisfactory resistance to melting.

The melting rate was determined according to the method of Goff and Hartel (2003). Ice cream samples were stored at minus (22±1) °C, selected and placed on a special grid for melting at room temperature (19±1) °C. The weight of the melted ice cream was recorded after one hour every 10 minutes for 2 hours. The melting rate (M, %) was calculated according to the formula:

M = (mass of melted ice cream) / (mass of ice cream until melting) × 100

Sensory evaluation of ice cream with whey concentrates. To conduct a sensory assessment of two samples of ice cream containing non-hydrolyzed or hydrolyzed whey concentrates at the level of 75% and sugar at the level of 11 and 9%, respectively, a descriptive method of sensory analysis was used (Cherevychna et al., 2019), which was modified by the authors of the article. The arithmetic mean of individual indicators was calculated according to the formula:

$$\bar{X} = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n}} ,$$

where $\sum_{i=1}^{n} x_i^2$ is the sum of experts' evaluations according to each of the five criteria (taste and aftertaste, smell, appearance, consistency, color) of one ice cream sample;

n is the number of experts.

The standard deviation for each unit indicator was determined by the formula:

$$S = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n} - \overline{x^2}} ,$$

where $\sum_{i=1}^{n} x_i^2$ is the sum of squares of experts' assessments, points;

$\overline{x^2}$ is the square of the average value of the indicator's evaluations, points.

The complex indicator Q was calculated according to the formula:

$$Q = \sum_{i=1}^{n} \bar{x}_i ,$$

where $\bar{x}_i$ is average score of a single quality criterion, points.

The coefficient of coincidence was calculated according to the formula:

$$W = \frac{\sum_{i=1}^{n} (x_{i1} - x_{i2})^2}{n} ,$$

where x_{i1} is value of quality assessments of a series of ice cream samples at the first stage of assessment;

x_{i2} is value of quality assessments of a series of ice cream samples at the second stage of assessment;

n is the number of experts.

The integral assessment was carried out on a 100-point scale, which had the following quality gradation: 0–24 – extremely low, 25–39 – low, 40–54 – below average, 55–69 – average, 70–84 – above average, 85- 95 is high, 96–100 is extremely high.

Each of the five quality criteria was graded according to descriptors specific to this type of ice cream, taking into account the recommendations of the international standard ISO 13299:2016.

Statistical processing. Data were expressed as the mean with standard deviation of triplicate measurements. Statistical analysis was performed using the program Statistika 10. Differences were considered reliable at validity α = 0.95.

Results and discussion

Study of the possibility of replacing sugar with hydrolyzed concentrates of demineralized whey

In order to study the degree of sweetness of hydrolyzed concentrates of demineralized whey with a mass fraction of total solids of 10–40% and with a degree of hydrolysis of 80–90%, their relative sweetness was calculated (Table 1).

Table 1

Degree of sweetness of whey concentrates with different degrees of lactose hydrolysis

Mass fraction of solids in whey concentrate, %	Degree of lactose hydrolysis, %			
	0	80	85	90
10	0.0123	0.0345	0.0359	0.0373
20	0.0246	0.0690	0.0718	0.0745
30	0.0369	0.1035	0.1076	0.1118
40	0.0492	0.1380	0.1435	0.1491

Due to the increase in the content of monosaccharides, as products of lactose enzymolysis, a correlation between the degree of hydrolysis and the degree of sweetness of whey concentrates was noticed (Table 1).

A concentrate with solids content 40% was chosen for further research. This concentrate is the closest in terms of this indicator to the chemical composition of full-fat ice cream and is effective for increasing the solids content of low-fat ice cream to prevent texture defects such as sandiness, coarse crystalline structure, and watery taste (Akalin et al., 2008), because they are caused by an excess of free water. As for the choice of the degree of hydrolysis, within the achieved limits of the efficiency of this process (from 80 to 90%), a slight difference in the degree of sweetness for the hydrolyzed samples is obvious, which will not significantly affect the general recommendations for the development of ice cream formulations with fermented whey concentrates. Therefore, a concentrate with an average degree of lactose hydrolysis (85%) was chosen.

At the next stage, mixtures with non-hydrolyzed whey concentrate (5 control samples) and mixtures with hydrolyzed whey concentrate (5 experimental samples) were prepared with a simultaneous decrease in the sugar content from 17 to 9% and an increase in the content of demineralized whey concentrate in the amount from 0 to 30% mass fraction of solids.

Sucrose in the composition of ice cream plays the functions of a sweetener and a source of solids, ensures the proper formation of the structure of the frozen dessert and affects its physicochemical parameters – overrun and resistance to melting (Atallah et al., 2022; Hinkova et al., 2015). Replacing sucrose with other ingredients, such as monosaccharides, dietary fiber and others, does not always have a positive effect on the quality of the finished product (Ozdemir et al., 2008; Mitchell et al., 2008).

The foam overrun and foam resistance of ice cream mixtures with partial replacement of sugar with whey concentrates were investigated (Figure 1 and 2). The obtained results were to some extent correlated with the data of scientists who studied the quality indicators of ice cream, in particular, whey ice cream (Lim et al., 2008a; 2008b; Pei et al., 2010).

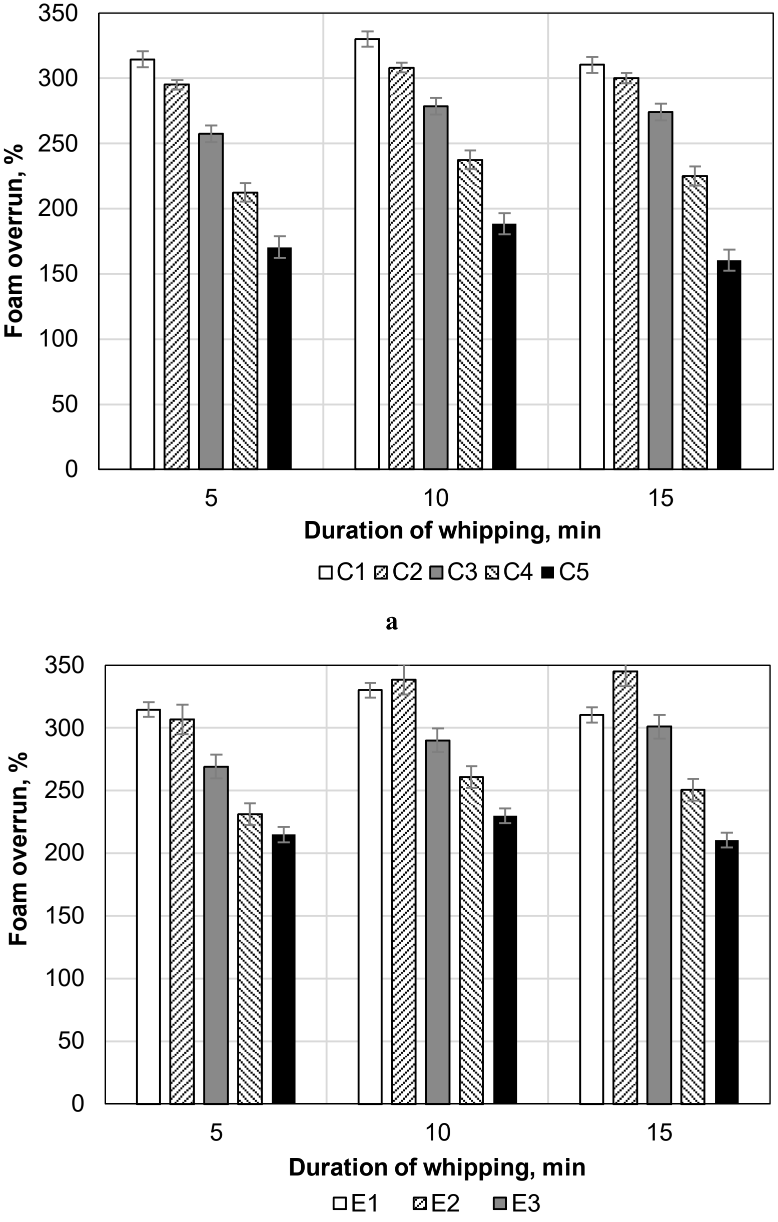
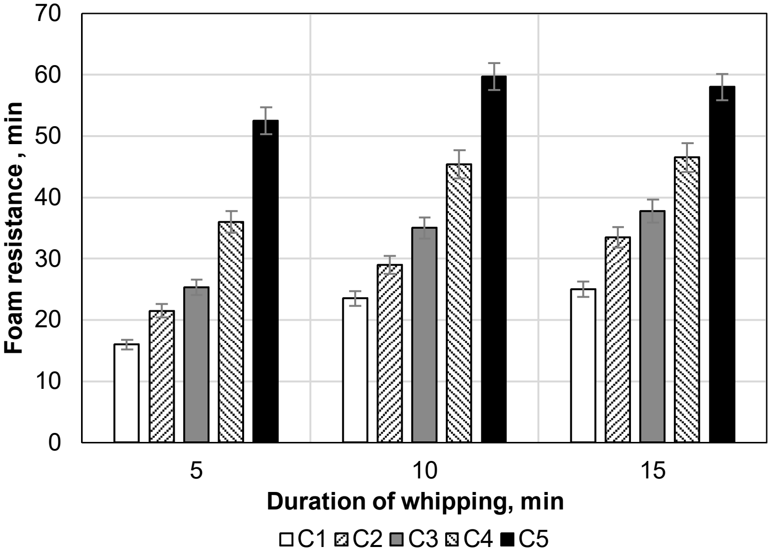
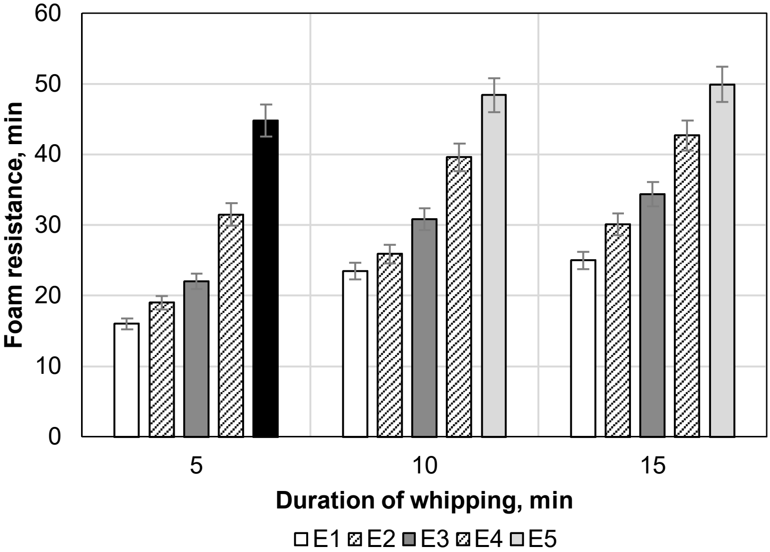


Figure 1. Foam overrun of ice cream mixtures with whey concentrates:
a – non-hydrolyzed,
b – hydrolyzed: C1 and E1, 17% sugar, 0% concentrate;
C2 and E2, 15% sugar, 18.75% concentrate;
C3 and E3, 13% sugar, 37.5% concentrate;
C4 and E4, 11% sugar, 56.25% concentrate;
C5 and E5, 9% sugar, 75% concentrate.



a



b

Figure 2. Foam resistance of ice cream mixtures with whey concentrates:
a – non-hydrolyzed,
b – hydrolyzed:
C1 and E1, 17% sugar, 0% concentrate;
C2 and E2, 15% sugar, 18.75% concentrate;
C3 and E3, 13% sugar, 37.5% concentrate;
C4 and E4, 11% sugar, 56.25% concentrate;
C5 and E5, 9% sugar, 75% concentrate.

The foam overrun of mixtures with non-hydrolyzed whey concentrate during the first 10 min increased with a subsequent slight decrease, except for sample C5 with the highest degree of replacement of sucrose with whey concentrate, which caused a sharp decrease in the foam overrun (Figure 1, 2). Samples of ice cream mixtures with hydrolyzed whey concentrate showed increased foam overrun during 15 min of whipping, except for samples E4 and E5, for which foam overrun decreased slightly after 10 min of whipping. Syed et al. (2018) reported that the recommended content of sugar in ice cream is 14–16% within the permissible range of 12–20%. The use of a smaller or larger dose of sugar in ice cream with an increased content of solids can lead to a deterioration in quality indicators. However, the study of ice cream mixtures in this work indicates that using 11% sucrose and 30% solids of non-hydrolyzed concentrate, as well as 9% sucrose and 30% solids of hydrolyzed concentrate, makes it possible to obtain a foam overrun that is higher than the established satisfactory level (200%). Goff (2018) reported about cases of variation in the sucrose content in different types of ice cream, which are in the range of 9–28%, which confirms the impracticality of further reduction of sucrose in ice cream with hydrolyzed whey concentrate. The whey ingredients are also known to increase the foam overrun and foam stability of ice cream mixes. Thus, Lim et al. (2008a) reported that processed whey protein concentrate helps to achieve optimal foam resistance and foam overrun in low-fat ice cream mixes (37.94% of total solids), however, in our study, foam resistance was lower, while foam overrun was higher, which is related with varied content of total solids in samples (from 18 to 41.61%) and adsorptive action of monosaccharides in samples with hydrolyzed whey concentrate, which ensures uniform distribution of free moisture and its retention. İbanoğlu and Karataş (2001) found that high-pressure treatment of whey protein concentrates allows achieving the maximum values of foaming resistance of their aqueous solutions, so probably even low-pressure treatment of the mixture during homogenization has a positive effect on this value.

The difference between the indicators of foam overrun and foam resistance for samples with non-hydrolyzed (C1–C5) and hydrolyzed (E1–E5) whey concentrates could also be explained by the lower viscosity of food systems with lactose hydrolysis products (Schmidt et al., 2016). This makes it possible to increase the total solids content without significantly changing the quality indicators of the ice cream.

To achieve the recommended degree of sweetness of ice cream (0.8–0.9) with non-hydrolyzed whey concentrate, the maximum possible replacement of sugar is to reduce its content from 15.5 to 11% while adding up to 30% of concentrate solids. As for ice cream with hydrolyzed concentrate, the maximum possible reduction in sugar content is more significant and reaches 9% in the case of adding up to 30% solids of the concentrate. Thus, the reduction in the need for sugar in ice cream with non-hydrolyzed whey concentrate can reach 29% (based on its total content), and with hydrolyzed concentrate – 42%.

In the case of the use of hydrolyzed concentrate, this indicator significantly exceeds the results of research by other scientists (Sofjan et al., 2004), who achieved only 25% sugar replacement. Even non-hydrolyzed concentrate due to its high lactose content is able to replace partially sugar, although the addition of lactose in such an amount in the composition of ice cream can lead to consistency defects. At the same time, the mass fraction of total solids in ice cream does not significantly decrease (McCain et al., 2018), which is a positive point, especially for low-fat ice cream with low amount of total solids.

Physicochemical properties of mixtures and ice cream with hydrolyzed and non-hydrolyzed whey concentrates

At the second stage, two samples of ice cream with non-hydrolyzed and hydrolyzed whey concentrates with maximum sugar replacement were selected (Table 2), according to the results of the previous series of experiments. Physicochemical indicators of mixtures and ice cream with whey concentrates are given in Table 3.

Table 2

Ice cream formulations with whey concentrates

Components	**Weight of components, kg/1000 kg of product**	
	Ice cream with non-hydrolyzed concentrate	**Ice cream with hydrolyzed concentrate**
Demineralized whey concentrate (40% total solids, of which protein is at least 4.4%)	750.0	750.0
White crystalline sugar	110.0	90.0
Stabilization system Cremodan SE 406	6.0	6.0
Vanillin	0.1	0.1
Water	133.9	153.9
Total	1000.0	1000.0

Table 3

Physicochemical indicators of mixtures and ice cream with whey concentrates

Physicochemical indicators	**Ice cream with non-hydrolyzed concentrate**	**Ice cream with hydrolyzed concentrate**
Total solids, %	41.61±0.41	39.61±0.40
including:		
– lactose	23.70±0.02	3.55±0.01
– protein	3.3±0.02	3.3±0.01
Water activity	0.955±0.015	0.911±0.017
Overrun, %	62.7±1.4	71.9±1.2
Resistance to melting, min	43.7±1.0	35.1±0.5

Ice cream with non-hydrolyzed and hydrolyzed concentrates differs in total solids by 2% (Table 3), which is due to a decrease in the need for sugar in the presence of monosaccharides. At the same time, the lactose content in the sample with unfermented concentrate is unacceptably high (23.7%), which can negatively affect the quality of the product during storage (Dekker et al., 2019), so the use of hydrolyzed whey concentrate is acceptable in ice cream. Usually, ice cream is a high-lactose product, because the average content of MSNF in it at the level of 10% ensures the presence of up to 5.2-5.5% lactose (Mykhalevych et al., 2022). Unlike ice cream with a traditional composition, ice cream based on hydrolyzed whey concentrate contains 6.7 times less lactose while being enriched with biologically complete protein. This is an important advantage of this author's development, which allows preventing excessive crystallization of lactose in ice cream (patent 4374861A US "Lactose-reduced ice cream and process for the production thereof").

Usually, the mass fraction of proteins in milk-based ice cream in the composition of MSNF ranges from 2.0 to 3.7% (Patel et al., 2006; Polishchuk et al., 2020), however, for amateur types of ice cream, in particular whey, this indicator may be lower at the level of 1.28-1.41% (Polishchuk et al., 2021; Young, 2007).

In both ice cream recipes, the content of high-value whey proteins is 3.3%, which fully corresponds to the standart protein content in ice cream for the formation of typical sensory and physicochemical indicators of this product.

One of the further directions for improving the composition of ice cream based on hydrolyzed whey concentrates may be additional enrichment of this product with proteins of various origins. Thus, it is known that protein enrichment of ice cream to a content of 7–8% is rational, as it improves the texture of the product and significantly reduces the size of ice crystals (Patel et al., 2006). At the same time, a higher protein content leads to a decrease in the overrun of ice cream due to the too high viscosity of the mixtures (Roy et al., 2022). Therefore, in order to assign ice cream to the category of products with a high protein content, in accordance with the requirements of EU Regulation No. 1924/2006 it is advisable to enrich this product with proteins of various origins.

As for the effect of hydrolyzed whey concentrates on the osmotic pressure of the aqueous phase of ice cream, a slightly lower activity of the water of the mixture with the hydrolyzed concentrate was found, compared to the activity of the water of the mixture with the non-hydrolyzed concentrate in the presence of monosaccharides as lactose hydrolysis products. The mixture with hydrolyzed whey concentrate is not a food system with intermediate moisture (Aw = 0.6–0.84) (Saha et al., 2020), but the high content of monosaccharides in it significantly affects the processes of forming the physicochemical parameters of ice cream as a polydisperse food system (Arslaner et al., 2019). In particular, the overrun of ice cream with hydrolyzed concentrate increases, but the resistance to melting decreases, compared to ice cream with non-hydrolyzed whey concentrate. It is clear that such changes are due to the presence of lactose hydrolysis products, which reduce the cryoscopic temperature and, accordingly, the dimensional stability of ice cream (Özdemir et al., 2008). Therefore, ice cream with monosaccharides, which has a soft consistency, must be packaged in a rigid consumer container.

In order to identify the possible influence of whey concentrate on the consistency and structure of ice cream, the rate of melting of experimental samples after their storage at minus (18±2) °C for up to 14 days was investigated (Figure 3). For both samples, the melting rate of ice cream decreases with the extension of storage time up to 2 weeks. At the same time, for a sample of ice cream with non-hydrolyzed whey concentrate, this indicator is lower, compared to a sample with hydrolyzed concentrate, due to a more significant decrease in the content of sugar as a cryoprotectant (Maity et al., 2018). In addition, the cryoscopic temperature is indirectly affected by lactose (Mullan, 2015), the hydrolysis of which leads to a decrease in melting resistance (Matak et al., 2003). On the other hand, the influence of monosaccharides on the stability of the ice cream structure during storage is not critical and does not lead to a significant deterioration in the quality of the finished product, as described (Arslaner et al., 2019; Whelan et al., 2008). This effect can be attributed to the sufficient content of whey proteins, which bind excess moisture and prevent the ice cream from quick melting (Young et al., 2007).

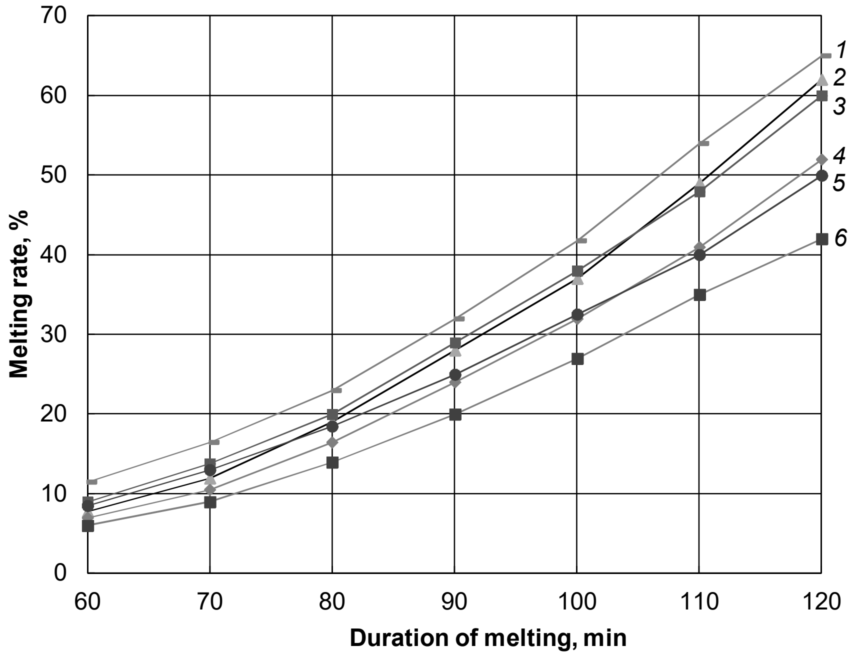


Figure 3. Melting rate of ice cream with non-hydrolyzed (NHC) and hydrolyzed (HC) whey concentrates after 24 hours of production (24 h), one week (1 w) and 2 weeks (2 w) of storage:
1, HC after 24 h;
2, NHC after 24 h;
3, HC after 1 w;
4, NHC after 1 w;
5, HC after 2 w;
6, NHC after 2 w.

At the next stage, the viscosity-speed characteristics of mixtures and ice cream with demineralized whey concentrates were investigated, which are listed in Table 4.

Table 4
Viscosity-speed characteristics of ice cream mixtures with demineralized whey concentrates

Ice cream mixture	Effective viscosity (mPa·s) under variable shear rate gradient (γ)			The time of ultimate destruction of the structure (γ= 1312 s^{-1}), min	The degree of structure recovery, %
	γ= 3 s^{-1} (straight course)	γ= 1312 s^{-1}	γ= 3 s^{-1} (reverse course)		
with non-hydrolyzed concentrate	652.2±15.6	26.0±1.1	403.2±11.8	6.6±0.2	61.8
with hydrolyzed concentrate	601.0±11.8	20.0±1.0	350.3±10.5	5.5±0.2	58.2

The effective viscosity of low-fat ice cream mixtures, based on whey concentrates, is close to the values of this indicator, characteristic of ice cream mixes with a high fat content (Syed et al., 2018). The increased content of whey proteins and solids contributes to the additional structuring of mixtures that contain the Cremodan SE 406 stabilization system. This eliminates the lack of fat as a structuring agent in the composition of ice cream. As for the comparison of the values of the effective viscosity of both mixtures, a slight decrease in the structuring ability of the mixture with the hydrolyzed concentrate should be noted. This is because disaccharides have a greater effect on the viscosity of solutions in the presence of proteins, compared to monosaccharides. Scientists explain this effect by generally accepted mechanisms of interaction between sugar and protein molecules in water solutions (He et al., 2011). The increased effective viscosity of mixtures, based on whey concentrates, compared to the viscosity of milk low-fat ice cream mixtures, to some extent neutralizes the negative effect of monosaccharides on the melting resistance of the hardened product (Table 3). At the same time, the too low effective viscosity of low-fat and non-fat mixtures of standard composition does not ensure proper stabilization of the formed dispersed ice cream systems (He et al., 2011). The effective viscosity of the restored structure of mixtures with whey concentrates reveals a pronounced thixotropic ability in the presence of an increased content of whey proteins. Such mixtures can be attributed to systems with a pronounced coagulation structure, with the detection of thixotropic properties.

Sensory evaluation of ice cream with demineralized whey concentrates

A sensory evaluation of ice cream with a concentrate of non-hydrolyzed and hydrolyzed whey was carried out using the descriptive-integral method (Table 5).

The comparative analysis of the integral assessment of sensory indicators, along with other positive characteristics, listed in the Table 3, gives reason to recommend ice cream based on hydrolyzed demineralized whey for the development of original recipes. Mahmood and Mahmood (2017) reported that ice cream samples with hydrolyzed lactose at the level of 28–56% did not have a significant difference in the degree of sweetness from ice cream with non-hydrolyzed lactose, increasing the degree of lactose hydrolysis to 85% already has a noticeable effect on the degree of sweetness ice cream. Other researchers have reported the sensation of smaller ice crystals in frozen hydrolyzed desserts compared to non-hydrolyzed ones (Skryplonek et al., 2017), however, El-Nagar et al. (2002) found unsatisfactory sensory characteristics of low-fat frozen yogurt due to the presence of coarse crystalline structure and consistency. Another advantage of ice cream with hydrolyzed whey concentrate is its plastic and delicate consistency due to the presence of monosaccharides – glucose and galactose, the influence of which on the consistency of ice cream and frozen desserts was noted by other scientists (Skryplonek et al., 2017).

Prospects for further research consist in conducting a comparative analysis of the effectiveness of the use of hydrolyzed demineralized whey concentrates with different solids content in low-fat and non-fat ice cream, as well as in additional enrichment of ice cream with proteins of various origins.

Table 5

Sensory evaluation of ice cream with whey concentrates

Descriptor	**Overall score, points**	
	Ice cream with non-hydrolyzed concentrate	Ice cream with hydrolyzed concentrate
Criterion 1. Appearance		
Finely dispersed air bubbles	5.0	5.0
Homogeneity of mass	5.0	5.0
Foam overrun	4.4	5.0
Small ice crystals	4.0	4.5
Form stability	4.6	4.1
Criterion 2. Smell and odor		
Sweet	5.0	5.0
Sour milk	3.8	4.1
Lactic	4.8	4.9
Whey	5.0	5.0
Absence of extraneous odors	5.0	5.0
Criterion 3. Color		
Yellow	3.5	3.8
Dark yellow	4.8	5.0
Deep yellow	5.0	5.0
Homogeneous	5.0	5.0
Attractive	3.9	4.4
Criterion 4. Consistency		
Overrun	4.1	4.5
A mass that does not melt quickly	3.9	3.0
Without sandiness	3.2	4.6
Homogeneous	4.0	4.7
Small ice crystals	4.6	4.9
Criterion 5. Taste and aftertaste		
Sour milk	3.8	3.3
Whey	5.0	4.8
Lactic	4.9	5.0
Sweet	5.0	5.0
Without a sweet aftertaste	3.6	5.0
Integral evaluation	**88.72**	**92.48**

Conclusions

1. The concentrate of demineralized hydrolyzed whey with total solids content 40% can replace up to 42% of sugar in the composition of ice cream, while maintaining the degree of sweetness determined for this type of ice cream in the range from 0.8 to 0.9.
2. According to the viscosity-speed characteristics, the mixture of low-fat ice cream with the concentrate of demineralized hydrolyzed whey can be attributed to systems with a pronounced coagulation structure with the detection of thixotropic properties. The

effective viscosity of the mixture is close to the values of this indicator, characteristic of ice cream mixtures with a high fat content. Ice cream mixes with hydrolyzed whey concentrate have a higher foam overrun and stability due to lower viscosity, which allows maximum replacement of sugar with whey concentrate solids.

3. Ice cream based on hydrolyzed concentrate contains 3.3% protein, which corresponds to the standard chemical composition of ice cream. The high content of lactose hydrolysis products in ice cream increases overrun, melting rate, improves consistency, but reduces the resistance to melting of ice cream, which must be taken into account during the technological process and when choosing a consumer container.

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