Scientific and practical aspects of trehalose contain in ice cream without sucrose

A A Tvorogova¹, A V Landikhovskaya¹, N V Kazakova¹, R R Zakirova¹ and M M Pivtsaeva²

¹ All-Russian Scientific Research Institute of Refrigeration Industry - branch of V.M. Gorbaten Federal Research Center for Food Systems of Russian Academy of Science, 12, Kostyakova str., Moscow, 127422, Russia
² Torgsnab LLC, 17B-2 office 203 Verknaya Krasnoselskaya str., Moscow, 107140, Russia

E-mail: antvorogova@yandex.ru

Abstract. The article presents the results of studies on the creation of a composition, the determination of quality indicators of low fat ice cream without sucrose. The research is determined by the population’s need for healthy food and conducted with the help of modern rheological, microstructural and thermostatic research methods. To replace the traditionally used sucrose, a mixture of trehalose and fructose is provided. This provided the sweetness and dry substances characteristic of milk ice cream with a sucrose mass fraction of 15.5%. It has been established that the use of fructose and trehalose instead of sucrose does not adversely affect technologically significant product parameters. Their use leads to an increase in the effective viscosity of the mixture by 1.2 times, does not reduce the thermal stability of the finished product and increases the dispersion of ice crystals. Ice crystals with trehalose were dominated by ice crystals up to 15 microns in size after quenching. An increase in their size to 22 microns after 1 month. storage did not adversely affect the organoleptic characteristics of the product. In the control sample, ice crystals prevailing at least 35 microns in size during this period.

1. Introduction
The increase in the number of people of all ages who are overweight and obese has led to the need to restrict foods containing fat and sugar. Currently, many foods are made using extra sugars (added sugars). The main role of sugars is energy, they provide the body with the energy necessary for the functioning of all systems and organs. Excess sugars are harmful to health, in particular because of their possible transformation into fats. The proportion of incoming sugars with added sugars needs to be controlled. In ice cream and frozen desserts, sucrose, fructose and corn syrup, and honey are considered as high fructose products. Lactose, which is part of the used dairy raw materials, as well as fructose, which is present in fruits, does not apply to added sugars [1]. WHO regulates sugar intake up to 10% of daily calorie intake [2].

The mass fraction of added sugars in ice cream, mainly sucrose, can be 30-50%, in frozen desserts - up to 90%. In these products, sugars are a source of sweetness, an important component of dry matter and a component necessary for the formation of structure and consistency. Currently, there are several strategies that are followed in addressing the issue of lowering sugar levels, based on partial or
complete replacement of sucrose, or simply reducing its amount. Replacing sucrose requires the use of alternative sweeteners and dry matter substitutes. At the same time, some sweeteners are not enough, other components that can be sources of energy are also necessary, their composition depends on the formulation, legislative restrictions and taste preferences of consumers. The joint use of alternative sweeteners and other components - sucrose substitutes for dry matter is the most common approach to reducing sugar in foods [2].

All intense sweeteners are considered as nutritional supplements. Polyols, like fructose, are involved in metabolism independent of insulin [3]. But there are restrictions on the use of polyols, since polyols in huge amount consuming can cause diarrhea.

Trehalose can be an effective substitute for sucrose. The popularity of trehalose is due to its lower sweetness compared to sucrose, and a stable taste profile. In a group study, 85\% of respondents preferred the taste of trehalose compared to sucrose, and also noted that its sweetness is perceived harmoniously (more pronounced and faster) [4]. In addition, it is known that trehalose inhibits the growth of ice crystals, which is explained by the effect (decrease) in the amount of free water and an increase in the number of nucleation centers [5].

The restriction on the use of trehalose in food production in the 90s was primarily due to the high cost of trehalose, about 700 US dollars, but after the industrial development of the enzymatic process, its cost decreased to 5-6 US dollars, which made it more affordable for use [6].

Currently, there are developments on the replacement of sucrose in the formulations of ice cream and frozen desserts [7]. In [8], the joint use of a mixture of erythritol, inulin, and fructose (in the ratio of 4, 7, and 2.15%) was studied in the production of a frozen dessert based on coconut milk. The scholars managed to obtain a product with a low glycemic index, 64\% lower than that of the control with a sucrose mass fraction of 12\%. According to the authors, this product had high organoleptic characteristics.

The study [9] is devoted to studying the replacement of 50\% and 100\% sucrose in ice cream with components such as honey, trehalose, and erythritol. It is noted that honey affects the viscosity and duration of freezing of the product, and trehalose and erythritol must be used together with other sweeteners to achieve the necessary hardness and resistance to melting.

The insufficient number of works related to the complete replacement of sucrose in ice cream, in particular, with a low content of milk fat (not higher than 3\%), creates the prerequisites for creating the appropriate composition. It should be borne in mind that when reducing the mass fraction of fat in the product to 3\%, it is important to form a structure characteristic of ice cream with a high mass fraction of fat [10]. In addition, the replacement of sucrose with other mono- and disaccharides affects the taste and condition of the product structure.

The objectives of the study are to develop the composition of ice cream with a low fat content using a composition of trehalose and fructose and to study its quality indicators.

2. Materials and methods

The object of the study is ice cream containing 3\% of a mass fraction of fat, with the complete replacement of sucrose with trehalose and fructose, with a total solids content of 32.5\%. Milk ice cream with a sucrose mass fraction of 15.5\% was chosen as a control. Ice cream was produced at the experimental bench of the ice cream laboratory of the All-Russian Scientific Research Institute of Refrigeration Industry. Trehalose and polydextrose manufactured in China were provided by Torgsnab LLC.

2.1. Determination of thermal stability

The method is based on the determination of the mass fraction in ice cream melted under the influence of temperature (20 ± 0.5) °C.

The thermal stability was determined using a thermostat TCO-1/80 СΠУ (Russia) and electronic scales with an accuracy of weighing ± 1 g.
2.2. Determination of the dispersion of ice crystals in ice cream

The method is based on the technique described by scholars [11]. The described method was modified, considering the reagents and laboratory conditions.

The study on the state of ice crystals in ice cream was conducted with the help of an Olympus CX41RF microscope (Japan) with an integrated camera and programmed control. The calculation of the obtained elements was performed using ImageScope software (Russia). All measurements were performed in triplicate [10].

2.3. Dynamic Viscosity Definitions

The method is based on measuring the resistance of a liquid (mixture for ice cream) to the spindle rotation caused by the generated torque. Dynamic viscosity was calculated based on the value of torque and a coefficient depending on the speed of rotation and the characteristics of the spindle.

The studies were carried out using the Brookfield DV-II + Pro reotest (USA) with Rheocalc V3.1-1 software, on the SC4-31 spindle with a 10 cm$^3$ cuvette. Studies were performed at a constant temperature (4 ± 1) °C.

The measurement was carried out as follows: a previously prepared sample of a mixture with a volume of 10 cm$^3$ was placed in a cuvette. The effective viscosity was measured in the speed range from 0 s$^{-1}$ to 1 s$^{-1}$, the duration of the measurement of effective viscosity at each speed was 10 s. Each measurement was carried out in at least two replicates.

3. Results

At the first stage of research, the composition of ice cream was developed. Ice cream with a mass fraction of fat of 3% is taken as a basis, which makes it possible to declare it as a product with a low fat content. The total solids content is increased to the level of ice cream by adding polydextrose. This choice is due to the low calorie content of polydextrose. The mixture of trehalose and fructose in the formulation provides the sweetness characteristic of milk ice cream with a mass fraction of sucrose of 15.5%, thereby replacing it both in sweetness and in dry matter in a ratio of 1:1.

In the production of ice cream with trehalose, you can use natural fruit fillers in the form of mashed potatoes or juices [12], as well as natural extracts from green tea [13].

3.1. The quality indicators of the mixture and ice cream

The dynamic viscosity of a mixture of an ice cream sample with trehalose with a shear gradient of 0.83 s$^{-1}$ was 307 mPa · s; in the control sample, this indicator was 219 mPa · s.

![Figure 1](image_url)

**Figure 1.** Dependence of the mass fraction of melt in samples on the holding time

Sucrose-free ice cream was unloaded from the freezer at a temperature of minus 6.2 °C determined by calculation. After achieving this temperature more than 50% moisture in the product was frozen. This is necessary for the formation of a structure in the product without organoleptically noticeable ice
crystals. In the control sample, the mass fraction of frozen water was achieved at a temperature of minus 5.5 °C. The overrun of ice cream with trehalose was at the level of 87%, the overrun of the control sample was 108%.

Figure 1 shows the thermal stability data of the samples.

3.2. Dispersion of ice crystals in ice cream without sucrose
The dispersion of ice crystals and their size distribution are presented in Figure 2. Microphotographs of ice crystals in ice cream with trehalose and a control sample are shown in Figure 3.

Figure 2. Crystal size distribution during storage

Figure 3. Microphotographs of ice crystals after 1 month: a - ice cream with trehalose, b - control
3.3. Organoleptic assessment

Tasters emphasized that ice cream with trehalose has a creamy structure, a pleasant sweet profile and small ice crystals, organoleptically imperceptible.

4. The discussion of the results

The effect of the complete replacement of sucrose with trehalose and fructose on the quality indicators of ice cream was studied.

The use of trehalose leads to an increase in the viscosity of the product by 1.4 times, compared with the control sample with the same mass fraction of the introduced stabilization system (Figure 1). It should be noted that increasing the viscosity of the product is also possible due to an increase in the mass fraction of solids. At the same time, the introduction of polydextrose in the formulation increased the mass fraction of fat in ice cream.

It was noted that with partial replacement of sucrose with fructose, it is necessary to lower the temperature of unloading ice cream from the freezer by 0.7 °C, due to an increase in the proportion of low molecular weight sugars when replacing part of sucrose (disaccharide) with fructose (monosaccharide), which correlates with the data obtained in the work [9].

It was found that in the production of ice cream without sucrose only slightly (1.24 times) decreased the ability of the mixture to saturate with air, determined by the “overrun” indicator. Differences in thermal stability, determined by the mass fraction of melt after 60 minutes. curing at a temperature of 20 °C after 60 minutes from the beginning of temperature control have not been established, which indicates only a slight effect on this indicator of the replacement of some sugars by others.

The main advantage of using trehalose in ice cream with a fat mass fraction of 3% was noted when studying the dispersion of ice crystals. The distribution curves (Fig. 2) show that in ice cream with trehalose the quantitative fraction of ice crystals up to 15 μm in size prevails after quenching and after 1 month. Storage average crystal size increased to 22 microns. Which is probably caused by the coalescence of crystals located at a distance of less than 10 microns (energy barrier), due to their high dispersion. However, and after 1-month storage dispersion of the sample without sucrose was higher than in the control sample. In the control sample after 1-month storage, the predominant number of ice crystals was characterized by a size of at least 35 microns. The difference in the dispersion of ice crystals is visually noticed in microphotographs (Figure 3).

5. Conclusion

The composition of ice cream with a low fat content without sucrose is theoretically and experimentally justified. The expediency of using natural sucrose substitutes for dry matter and sweetness – fructose and trehalose. It was found that the replacement of sucrose in ice cream with fructose and trehalose leads to an increase (1.4 times) in the dynamic viscosity of the mixture, does not significantly affect the thermal stability of samples during 60 minutes of temperature control, and leads to the formation of smaller (almost 2 times) ice crystals.

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