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FEATURES OF ICE-CREAM FOAM STRUCTURE FORMATION

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Анотація. Проведено системний аналіз закономірностей формування і стабілізації структури морозива різного хімічного складу. Досліджено зміну збитості, розмірів повітряних включень та опору таненню морозива молочного, вершкового, пломбіру. Встановлено, що найскладніше досягти балансу між складовими компонентами для морозива з низьким вмістом жиру. Розроблено рекомендації для складання рецептур морозива з низьким вмістом жиру та нежирного.

Ключові слова: морозиво, хімічний склад, оптимізація

Аннотация. Проведен системный анализ закономерностей формирования и стабилизации структуры мороженого различного химического состава. Исследованы изменения взбитости, размеров воздушных включений и сопротивления таянию мороженого молочного, сливочного, пломбира. Установлено, что наиболее трудно достичь баланса между составляющими компонентами для мороженого с низким содержанием жира.

Ключевые слова: мороженое, химический состав, оптимизация

Introduction

Ice cream is a food-dispersed system with different aggregation instability during processing and storage. The formation of ice cream foam structure during freezing is a very complicated process, which is significantly related to ice cream chemical composition and its physical properties. Therefore, the peculiarities of structure formation and stabilization of ice cream with different fat content require additional scientific investigations.

Literature review

Ice-cream is a highly hydrated heterogeneous disperse system as the ratio between water and solid substances is very important while creating the froth structure. The water content accounts from 68 to 72 % for the low-fat ice-cream, 64 – 70 % – for that one with the middle fat content, and 58 – 62 % – for the high-fat ice-cream. The solid and ice structure appears against the essential decrease of solid substances, in particular that of fat, in the low-fat and non-fat ice-cream [1-3]. Under those conditions the overrun and the dispersion of ice-cream air phase diminish as well. As a result, there is a significant need in the further study of the regularity of ice-cream structure formation with the different content of fat

The main characteristics of the ice-cream structure formation and stabilization effectiveness are the following: overrun, mean diameter of the air bubbles and thawing resistance [4, 5]. These indicators denote organoleptic perception of the ice-cream consistence and influence a lot on the conditions of water freezing out while ice-cream hardening [6, 7].

Russian scientists O. Olenev, A. Tvorogov and others worked out recommendations to the mentioned characteristics. So, in order to get creamy- like soft ice-cream with the stable structure at the exit from the freezer, the overrun must be no less than 60 %, the mean diameter of the air bubbles must be not higher than 60 mkm and the thawing resistance of the hardened ice-cream must be not lower than 41,5 min [8].

Therefore, the quality content of compositions is determinative for the ice-cream structure formation although the requirements as for the chemical content are not systematized fully. Consequently, there is a great need in further deep investigation of ice-cream physical and chemical indices in the low-fat ice-cream by using wide and technically grounded content range of the main recipe components (fat, MSNF, sugar, stabilizer).

Materials and research methods

Cremodan SE 406 produced by the firm «Danisco» (Denmark) was chosen as a modern stabilizing system for the ice-cream with the wide range of fat content. This system contains mono-, diglycerides, guar gum, carrageenan, polysorbat in the ratio which provides maximum interaction of main components. It can be used to produce the hardened ice–cream namely low, middle and high in fat applying different methods at all types of production. Cremodan SE 406 is an integrated stabilizing system and reveals its stabilizing action at the presence of the fat of different origin. Stabilizer doesn't create the bitty cream while hydrating and it doesn't need the prior mixing with sugar, it doesn't react with the mixture temperature and it can be added at any stage of production before pasteurization and homogenization, it doesn't need maturation, it doesn't thicken the mixture, it improves the consistence and maximize the thawing resistance. The recommended content constitutes from 0,6 to 0,4 % against the fat content in the ice-cream from 4 % to 12 %. It is necessary to emphasize that the mentioned range of fat is rather low, that's why the recommendations on stabilizing system content need to be clarified.

The multifactorial regression analysis of how the chemical content of the ice-cream influence on its quality indices has been made by taking into the consideration the following content of the main components:

– dairy fat – in the range from 0 to 20 %. Also, at certain stages of the research the following differentiation of fat content was taken into account: 0 – 7,5 % for low-fat ice-cream; 8 – 11,5 % for middle-fat ice-cream; 12,0 – 20,0 % for high-fat ice-cream;

– sugar in the range from 12 to 20 %;

– MSNF - from 6 to 14 %;

– stabilizer (stabilizing system) – from 0,2 to 1,0 %.

The ground on the chosen component content range is the following. Fat content ranging from 0 to 7,5 %, 8 –11,5 % and 12 – 20 % is regulated by the state standards according to which the ice–cream can be referred to low-fat, middle-fat and high-fat [9]. The determined content of other components includes both technologically recommended quantity and some deviations from them. Thus, the sugar content in the ice-cream could be in a range from 14 to 18 % to provide saturated sweet taste, the recommended MSNF content makes from 8 – 12 % and stabilizer content is from 0,4 to 0,8 %.

Experimental ice-cream samples were manufactured on the freezer which operates recurrently, named FPM-3, 5/380-50 «Elbrus-400» (Ukraine). The volume of one mixture pouring into the screw conveyer chamber accounts 4 $dm^{3.}$ The duration of mixture cooling was 2 min while that of its freezing lasted 3 min. The mixture temperature at the entrance to the freezer was kept 2 – 6 ºС, whereas soft ice-cream needed the temperature range from –4...–6 °С.

The ice-cream overrun was determined by weight method. The air bubble sizes were determined by the microscopic method with the extension 10x15. Micro photos which had been got by the digital camera were worked out using the computer programs. Thawing resistance of the hardened ice-cream was determined no less than after being kept for 24 hours at the temperature –24 ºС. Hardened ice-cream samples have been formed as cylinders with the height of 50 mm and diameter 35mm, they have been placed on the grid to be kept to mature at the temperature (22±2) ºС for 2 hours and after that it was written down the time of water accumulation till 10 cm^3 which had been dripped out of the ice-cream.

The multifactorial mathematical models which describe properly the overrun changes, the mean diameter of air bubbles and thawing resistance of the ice-cream under the variability of 4 independent factors have been got by using the mathematical packet MathCAD 15 [10].

Results and their discussion

Through handling the research results, equations which describe mathematical models for the ice-cream at the wide range of fat content (0-20 %) were found. They can be introduced in the coded form like:

$$Y_1= 36,3513+3,0346\,X_1+ +0,9049\,X_2-2,0887\,X_3+29,09\,X_4 \quad (1)$$

$$Y_2= 111,5089-4,8875\,X_1-0,0979\,X_2-$$

$$-0{,}0514\,X_3-20{,}1155\,X_4 \qquad (2)$$

$$Y_3= -92{,}08+5{,}608\,X_1+1{,}746\,X_2+2{,}672\,X_3+36{,}52\,X_4 \qquad (3)$$

where: Y_1 – overrun %;

Y_2 – mean diameter if the air bubbles, mkm;

Y_3- thawing resistance, min;

X_1 – MSNF content, %;

X_2 – fat content, %;

X_3 – sugar content, %;

X_4 – stabilizer content, %.

The adequacy of the model was checked using the coefficient of determination R^2_{Y1}=95,8 %, R^2_{Y2}=94,0 %, R^2_{Y3}=98,7 %, which a particular evidence of the high quality characteristic of the link in the coefficient system. Moreover, it was carried out verification by using F-test (F – Fisher's criterion) and t-Student's apportionment to assess the reliability of the coefficient correlation.

For a complex study and optimization of the ice-cream chemical composition with the help of the mathematical packet MathCAD 15 there were created two-dimensional regression models which properly describe the overrun changes and the mean diameter of the air bubbles under the variability of two independent factors («MSNF/ stabilizing system», «fat/sugar»). The adequacy for these models was verified under the root-mean-square variations of the calculated data from experimental which are lower than one.

The surface response and the lines of the constant overrun meanings, the mean diameter of the air bubbles and thawing resistance for the classic low-fat ice-cream (with the mass fat portion 3,5 %), for the classic middle-fat ice-cream (10 %) and for the classic high-fat ice-cream (15 %) with the sugar content 15 % and the content of MSNF and stabilizer are covered in the figure 1.

The figure 1 shows that MSNF and stabilizer have a substantial influence on the ice-cream overrun. In this case the overrun nature of the middle-fat ice-cream and high-fat ice-cream remains almost the same contrary to that one of the low-fat ice-cream. The areas of the optimal value of the main characteristics of the foamy structure are essentially narrowed for the low-fat ice-cream at the chosen range of concentration and MSNF, and stabilizer.

For the low-fat ice-cream the fat increase of mixtures till 7,5 % resulted in the overrun improving. When the fat content accounted approximately 4,0 – 4,5 %, there was noticed a tendency of a slight decrease in the mixture response to the air saturation,

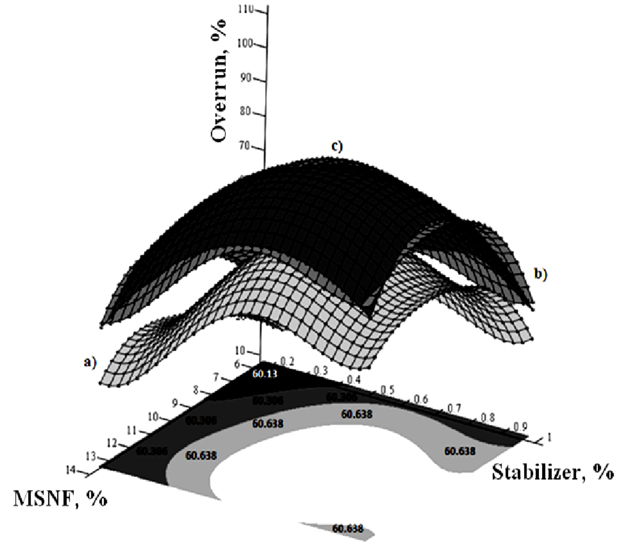

Fig. 1 – Patterns of the classic ice-cream overrun – low-fat ice-cream (a), middle-fat ice-cream (б) and high-fat ice-cream (в) under the changing content of MSNF and stabilizer

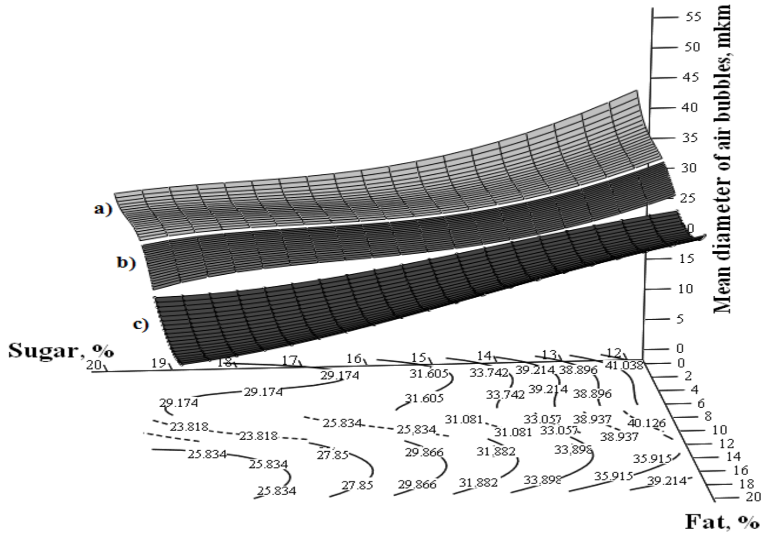

Fig. 2 – Overrun patterns of the low-fat ice-cream (a), middle-fat ice-cream (б) and high-fat ice-cream (в) under the changing content of sugar

which disappeared with the further fat increase. The biggest overrun (93 і 102 %) was typical for the low-fat ice-cream with fat content ranging 5and 7,5 %, sugar content – 12 % and stabilizer – 0,6 %. For the ice-cream with fat content of 2,5 % and non-fat ice-cream, the overrun made 82 and 70 % when the sugar content was 12 % and stabilizer – 0,6 – 0,8 %. For the effective air apportionment in the thin environment of the low-fat ice-cream, it's necessary that the MSNF content be no less than 10 % under the rather wide variation of the other component quantity.

The comparative analysis of the overrun under the fat changing is covered on the figure 2 for three main ice-cream types at the range of the rationed fat content at the sugar content of 15 % and stabilizing system of 0,5 %.

It's worth emphasizing that at the range of fat content from 0 до 20 % the highest overrun is typical for the ice-cream with the fat content of approximately 12,0 – 13,0 %. The further fat content rise decreases slightly the overrun, perhaps, due to the loosening of the air bubble structure because of the significant concentration of dispersed nonpolar particles on their polar surface.

In the other words, the loosened fat content rise in the mixtures reduces the initial balanced stableness which results from the same polar background. At times the pointed fat content in the mixtures is reached, in the no frozen water phase there takes place the solution concentration of the sucrose, lactose and salt which results in the mixture thickening and structuring as well as in the reduce of its overrun capability.

The rise of stabilizer and sugar content reduces the air bubble sizes as well, however to a less extent. Sugar as a whole reduces the overrun in each set of experiments, however, it can be recommended at the range from14 to 16 % under the different ratio of main component content.

Thawing resistance of the low-fat ice-cream (3,5 % of fat), middle-fat ice-cream (10 % of fat) and high-fat ice-cream (15 % of fat) under the changing content of MSNF and stabilizer is covered in the figure 3.

When the ice-cream warms, the ice melts and at a time the foam structure destroys. Even after the ice melting, fat ice-cream is able not to lose the volume until the air bubbles stabilized with fat agglomerate are destroyed. Now the low resistance to thawing becomes completely clear under the low fat content or its full absence.

According to the figure 3 to reach marginally necessary thawing resistance of low fat ice-cream is only possible if the MSNF and stabilizer content is rather high – at the range not lower than 10 and 0,6 % respectevely.

For the middle-fat ice-cream it is possible to set a marginally necessary content of MSNF and stabilizer at the range not lower than 8 and 0,4 %.

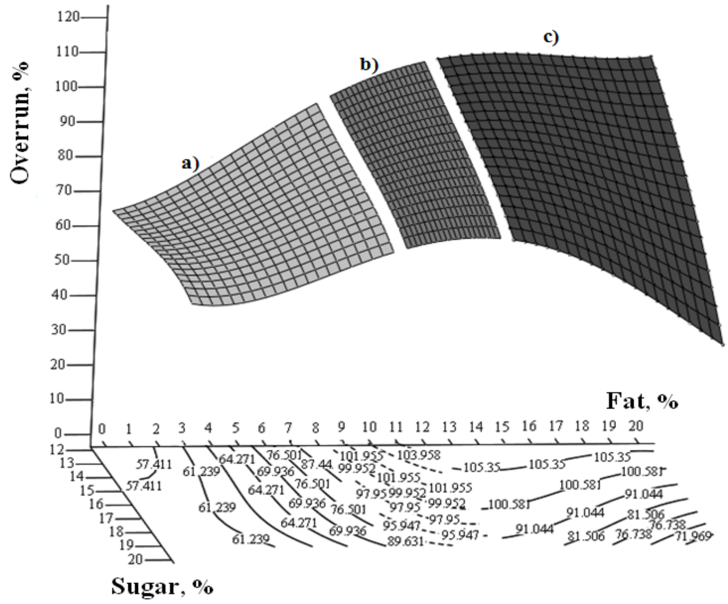

Fig. 3 – Thawing resistance of the classic ice-cream– low-fat ice-cream (a), middle-fat ice-cream (б) and high-fat ice-cream (в) under the changing content of MSNF and stabilizer

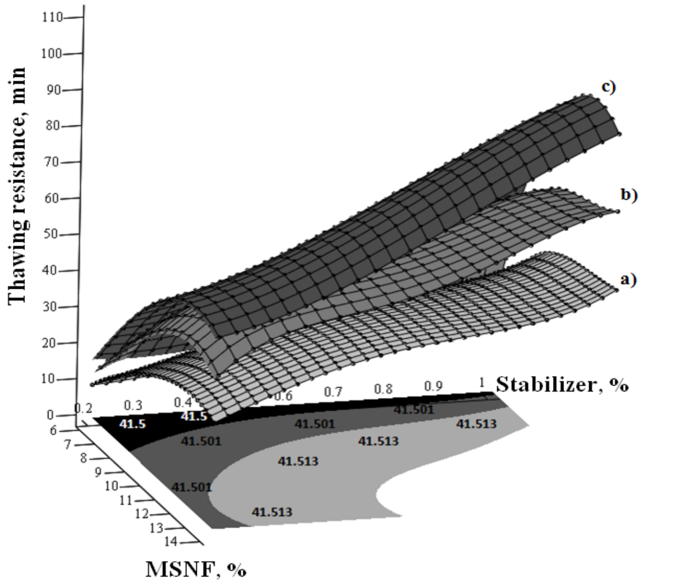

Fig. 4 – Mean diameter of air bubbles in the ice-cream with a wide range of fat content– low-fat ice-cream (a), middle-fat ice-cream (б) and high-fat ice-cream (в) under the changing content of sugar

The high-fat ice-cream is the most resistant to thawing. The MSNF and stabilizer content in it can be slightly reduced without considerable loss of its ability to keep the plasma inside the portion.

The 4[th] figure illustrates the change of the mean diameter of air bubbles in the ice-cream with the variable content of fat and sugar while stabilizing system content is 0,5 %.

According to the figure 4, the fat content has a considerable impact on the degree of air dispersity in the ice-cream while the sugar availability at the fixed range influences on this index indirectly, probably due to the increase of water phase viscosity. Therefore, low-fat ice-cream is inferior to both middle-fat ice-cream and high-fat ice-cream by all quality indications.

In general, physical and chemical indices of the ice-cream in terms of the influence of the separate components can be rated in order of their decrease like this: thawing resistance, overrun, mean diameter of air bubbles. That's why, the saturation process of the ice-cream with the air and terms of its preservation must be paid significant attention and must demand thorough control of production engineers.

Based on the results of the analyses of the main characteristics of low-fat ice-cream which was manufactured with the different content of main components, the authors have elaborated the following recommendations to make up the recipes:

– mass portion of milk solids nonfat for the ice-cream with fat content ranging 0 – 7,5 % must make no less than 10 %;

– for the low-fat ice-cream, the recommended sugar content is no less than 16 %, while stabilizing system must be 0,8-1,0 %;

– for the ice-cream with fatness of 2,5 % and 10 % milk solids nonfat, the minimum sugar content must be no less than 14 % and stabilizer 0,8 – 0,9 %. If to increase the MSNF content till 12 – 14 % and sugar till 16 %, the need in stabilizer decreases till 0,6 – 0,8 %;

– for the 5 %-fat ice-cream with MSNF content ranging 10 – 12 % and sugar 14 – 16 %, the stabilizer must be no less than 0,6 – 0,7 %;

– for the 7,5 %-fat ice-cream with MSNF content ranging 10 – 12 % and sugar 12 – 16 %, the stabilizer must be no less than 0,5 – 0,6 %.

Thus, the multifactorial regression models which have high value in factor assessment can be used to make the forecast of the ice-cream chemical composition of the rated fatness under the changes of one or more recipe components.

Conclusion

The formation and stabilizing system of the ice-cream with low content of fat is conducted at the rather narrow range of the main components compared to the middle-fat and high-fat ice-creams. In this respect the authors elaborated the recommendations concerning making up recipes of ice-creams of this group.

Physical and chemical indices of the ice-cream taking into consideration the chemical composition influence can be rated in the decreasing sequence: thawing resistance, overrun, mean diameter of air bubbles

The elaborated engineering and mathematical data can be applied under production conditions to calculate the ice-cream recipe of the fixed fatness.

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