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SUBSTANTIATING TECHNOLOGICAL FACTORS FOR PREPARING FERMENTED MILK-CONTAINING PRODUCTS WITH A COMBINED COMPOSITION OF RAW MATERIALS WITH A LONG STORAGE PERIOD

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This paper substantiates and defines the technological parameters for obtaining stable emulsions when making fermented milk-containing products. The object of research was the modes of mechanical and heat treatment of mixtures with a combined composition of raw materials based on dairy and vegetable fats. The task to be solved was to obtain stable emulsions by two-stage homogenization of the cream-vegetable mixture and the heat treatment temperature of the fermented cream-vegetable mixture with a combined composition of raw materials with a fat content of 10 % and 15 %. It is shown that during the homogenization of a cream-vegetable mixture with a mass fraction of fat of 10 %, the pressure in the first stage should be 10.0–12.0 MPa, in the second – 2.5–3.0 MPa; for a cream-vegetable mixture with a mass fraction of fat of 15 %, the pressure in the first stage is 8.0–10.0 MPa, in the second – 2.5–3.0 MPa. Modes of thermomechanical processing of the fermented cream-vegetable mixture at temperatures of 65±2 and 70±2 °C to ensure the microbiological stability of the milk-containing product during storage have been substantiated. A stabilizing system based on milk proteins has been selected. It was established that in order to improve the consistency, increase heat resistance, and avoid foaming of the finished product, it is necessary to perform thermomechanical processing of the fermented cream-vegetable mixture with a fat content of 10 % and 15 % at temperatures of 70±2 °C and 65±2 °C, respectively, and mass fraction stabilizer – 0.5 % and 0.15 %, respectively. The research data do not always coincide with previously established patterns, which is due to the difference in the chemical composition of the studied food systems, as well as the methods of their preparation and use. The results of the work could be used in the technology of milk-containing products with a combined fat composition

Keywords: fat mixtures, emulsion, microstructure, homogenization, thermomechanical processing, consistency, dynamic viscosity

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1. Introduction

A promising direction for food technologies is to make products from dairy and vegetable raw materials that combine their useful properties [1]. In particular, it is advisable to use milk raw materials and milk fat substitutes (MFSs), which makes it possible not only to save milk raw materials but also obtain products of increased biological value due to a balanced fatty acid composition [2, 3]. Vegetable fats and vegetable oils for products with a combined composition of raw materials must meet the quality according to the purpose and specification. Fat mixtures are widely used for the production of spreads, ice cream mixes, protein-fat pastes, sauces, etc., and natural oils are used for the production of fermented products [4, 5].

When choosing MFSs to make fermented milk products, it is important to give preference to fat systems with a balanced fatty acid and triglyceride composition. An important role is played by the formation of protein complexes and lipids [6, 7]. They ensure the compatibility of the components of milk raw materials with vegetable fat during emulsification.

Emulsification is carried out in two ways. The first is to use mechanical energy to disperse fat droplets in a liquid, which ensures an even distribution of fat. The second is in the use of emulsifiers, which, due to their physical and chemical activity, form stable emulsions, contributing to the long-term stability of the product during storage. The choice of the appropriate emulsification method and the appropriate

MFS are important conditions for ensuring the stability of products with a combined fat phase [3, 4].

In addition, the deterioration of the quality characteristics of the product, its structure and consistency may be due to the development of undesirable microflora during long-term storage. To prevent microbiological risks, the technological operation of heat treatment ("thermalization") of the product has become widespread. This technique helps stabilize the microbiological and structural properties of products, increasing their resistance to changes during storage.

Despite significant progress in expanding the range of products through the use of a combination of dairy and vegetable fats in food systems, a number of problems remain unsolved. In particular, regarding the efficiency of emulsification of mixtures based on cream and MFS using different methods of mechanical processing, stability of emulsions after fermentation and heat treatment, structural characteristics of finished products.

In view of the above, the study of thermomechanical processing modes is necessary to establish rational modes that would allow obtaining stable emulsions for various types of fat products.

Expanding the range of milk-containing products with a combined fat phase and improving their quality is urgent and aimed at meeting the needs of consumers for this group of products.

2. Literature review and problem statement

Milk fat is one of the most important components of milk and, at the same time, it is the most variable in terms of quantity and composition. Milk fat is associated with a number of negative effects on human health. Consumer concern has led to a decrease in milk fat consumption due to high levels of saturated fat and cholesterol. In particular, cholesterol and certain fatty acids contained in it could lead to the development of cardiovascular diseases. As a result, the practice of reducing the consumption of milk fat and increasing the consumption of low-fat dairy products has become widespread [8].

General recommendations for nutrition involved reducing the consumption of saturated fats and replacing them with polyunsaturated and monounsaturated fatty acids [9]. However, this ignores the substantial evidence that the health effects of saturated fat vary depending on the specific fatty acid and food source [10].

The search for new opportunities to reduce the content or partially replace milk fat with vegetable fats prompts manufacturers to change the composition of products. Such a technological technique is combining milk fat with mixtures of vegetable fats and obtaining stable emulsions with the help of various types of equipment.

To obtain emulsions with a mass fraction of fat from 30 to 50 %, blended oil balanced in terms of fatty acid composition is selected. Emulsions were obtained using an oleophilic emulsifier and sodium caseinate in different ratios. Emulsions with high sedimentation resistance are recommended as fat concentrates for use in the composition of new types of fat-containing products [6]. However, the effectiveness of using concentrates in the production of lower-fat products has not been reported.

It was shown in [11] that ultrasound treatment produces better monodisperse emulsions, which demonstrated greater stability to coalescence than those obtained during homogenization under high pressure. However, under certain regimes of specific energy, the authors obtained emulsions with the same size distribution and encapsulation yield [11]. The use of such methods for obtaining emulsions has proven to be effective but their industrial application is limited.

In general, the functional direction of designing milk-containing products with a combined composition of raw materials based on milk and vegetable fat is to reduce the content of saturated fatty acids and fortify them with unsaturated fatty acids. When choosing fats and oils, organoleptic properties, chemical and physical functionality, economic factors, and consumer perception of specific ingredients are taken into account. At the same time, the choice of ingredients used in such food products is dictated by the specificity of the target product.

In most cases, fermented dairy products with a combined composition of the fat phase are presented as mixed or double emulsion structures. One of the methods for obtaining milk-based emulsions using vegetable fats is homogenization. It was established that homogenization reduces the size of milk fat globules in milk, increases their number and surface area, and also changes the properties of the membranes of fat globules, which are a complex combination of lipids and proteins [12]. Such components of milk emulsion as casein and whey proteins, being adsorbed on the surface of fat globules, affect new interfaces and provide stability against coalescence [13, 14]. The acceptability of mixtures in terms of taste and aftertaste properties is related to the viscosity perceived in the mouth. Smaller average droplet sizes are characterized by the highest overall acceptability [15].

It should be noted that heat treatment ("thermalization") of fermented milk mixtures is one of the effective technological methods for improving the microbiological indicators of the product [16]. Thermalization efficiency is influenced by the temperature of the heat treatment, the acidity of the product (pH), the content of fat, protein, carbohydrates, the type of stabilizer used, etc. It was shown that during heat treatment of milk-containing mixtures with a casein content of more than 3 %, a grainy consistency could be formed, and in this case, it is necessary to use vegetable hydrocolloids. According to other data, it was established that the thermalization of fermented milk products with a fat content of 20 % and acidity in the range of 4.6–4.7 pH units could be carried out without the use of stabilizers.

Thermalization of fermented milk curds is used during the production of milk products with an extended shelf life. However, some issues of the application of heat treatment in the technologies of products with a combined fat phase remain insufficiently studied. In particular, with regard to the effect of different processing temperatures of mixtures on the structure and texture of the final product, in the fat phase of which the ratio of milk fat to MFS is 50:50. Such studies will make it possible to determine rational thermalization modes of fermented milk-containing mixtures with a combined fat phase. According to their organoleptic properties, structure and consistency, the final products must correspond to their intended purpose. The range of milk-containing products is constantly expanding. The preservation of the quality indicators of the product will depend on the properties of the emulsion components, the type and amount of the introduced emulsifier, and the technique of carrying out the process.

3. The aim and objectives of the study

The purpose of our work is to establish rational technological modes for obtaining stable emulsions based on mixtures with a combined fat phase. This will make it possible to produce on their basis fermented milk-containing products with a long shelf life with appropriate organoleptic and structural-mechanical properties.

To achieve the goal, the following tasks were set:

– to investigate the effect of different modes and techniques of mechanical processing on the characteristics of cream-vegetable emulsions;

– to investigate the influence of the dose of stabilizer and the thermalization temperature of the fermented cream-vegetable mixture on the organoleptic and structural-mechanical properties of the fermented milk-containing product.

4. The study materials and methods

The object of our research was the modes of mechanical and heat treatment of mixtures with a combined composition of raw materials based on dairy and vegetable fats. In order to obtain stable food emulsions with a mass fraction of total fat of 10 % and 15 %, the efficiency of dispersion of cream-vegetable mixtures was investigated using different processing methods used under industrial conditions. The subjects of research were cream-vegetable mixtures with a fat content of 10 % and 15 %, in which the ratio between milk fat and MFS was 50:50.

Experimental samples of the cream-vegetable mixture with a mass fraction of fat of 10 % and 15 % were prepared in the following way. Normalized milk in terms of fat content was heated to a temperature of 65±2 °C. The substitute for milk fat was first added to skim milk heated to a temperature of 65±2 °C and then into normalized milk. The resulting mixture was dispersed in two ways: using a rotary-vortex emulsifier (first method) and a homogenizer (second method).

Mixtures were processed in a rotor-vortex emulsifier of the Ya5-OEV brand at a rotor speed of 3000 rpm, and the duration of processing was 90 seconds. Using a homogenizer, dispersion of the mixtures was carried out at a pressure ranging from 6 MPa to 14 MPa. In the case of homogenization using a single-stage technique, the pressure was 6.0; 8.0; 10.0; 12.0; 14.0 MPa. In the two-stage technique, in the first stage, the pressure parameters were the same as in the one-stage technique, in the second – in the range from 1.5 to 3.5 MPa with an interval of 0.5 MPa.

The study of microstructure of the cream-vegetable emulsion with different fat content was carried out by taking microphotographs using a biological binocular microscope of research class, XSP-XY (China), equipped with a Canon PowerShot G6 camera (Japan). Photographs were taken at 200x and 400x magnification with field of view diameters of 0.97 mm and 0.48 mm, respectively (approximately 1 mm and 0.5 mm). Processing of the obtained photomicrographs was carried out using the Adobe Photoshop CS6 software of the OM-P object-micrometer scale and subsequent application of dimensional grids combined with the appropriate divisions of the scale.

To determine the stability of the resulting emulsions, they were transferred to a transparent measuring cylinder and left at rest for 24 hours at a temperature of 20±2 °C. After settling, during the specified period, the volumes of the formed phases were registered.

The stability of the emulsion was determined by the percentage ratio of the volume of the emulsified phase to the total volume of the sample. The smaller the volume of the stratified phase, the more stable the emulsion.

Formula (1) was used to quantitatively assess emulsion stability:

$$S=(V_{a.e}/V_{b.e})*100, \quad (1)$$

where S is emulsion stability, %;

$V_{a.e}$ – volume of the emulsified phase after settling, cm^3;

$V_{b.e}$ – total volume of the emulsion before settling, cm^3.

Emulsions that remain stable with minimal delamination are considered more stable, and those that exhibit significant delamination are considered less stable. This method makes it possible to quickly evaluate the stability of emulsions and their ability to resist delamination under the influence of time or external factors.

The emulsification efficiency was calculated as the ratio of the volume of the stable emulsion to the total volume of the mixture, expressed as a percentage. This relationship could be represented by formula (2):

$$E=(V_{a.e}/V_{b.e})*100, \quad (2)$$

where E is the emulsification efficiency, %;

$V_{a.e}$ – volume of stable emulsion after a certain period of observation, cm^3;

$V_{b.e}$ – total volume of the mixture before emulsification, cm^3.

This procedure makes it possible to determine the degree of emulsion stability, taking into account the volume of liquid that remains emulsified after the time during which a part of the mixture could separate.

Heat treatment of the studied fermented mixtures was carried out on an emulsifier of the Ya5-OEV brand. In this case, as a stabilizer, we used the stabilization system "Multistab C3-05" based on locust bean gum, carrageenan, guar gum, and milk proteins, which was introduced after previously dissolving in a small amount of skim milk.

The effective viscosity was determined on a rotary viscometer ATAGO-895 VISCO (Japan) using S/S_2 measuring cylinder devices, and viscosity indicators were recorded from an electronic display. The measuring cylinder (rotor) S_2 was chosen in such a way that the gradient layer extended over the entire thickness of the product layer placed in the annular gap of the viscometer measuring device. For each experiment, a new portion of the product was taken and, after reaching the set temperature, it was thermostated for 20 minutes.

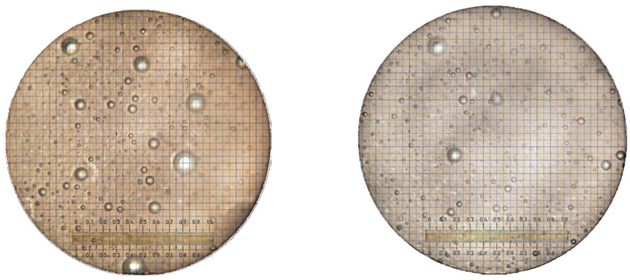
All studies were performed five times for three identical samples of milk-containing products. Tukey-Kramer multiple comparison was used to compare mean values, considering that significant differences were observed at $p<0.05$. The results of the experimental data were processed by the method of mathematical statistics using the STATISTICA 12.0 software.

5. Results of investigating the influence of technological factors on the properties of cream-vegetable mixtures

5. 1. Results of investigating the influence of mechanical processing on the characteristics of cream-vegetable emulsions

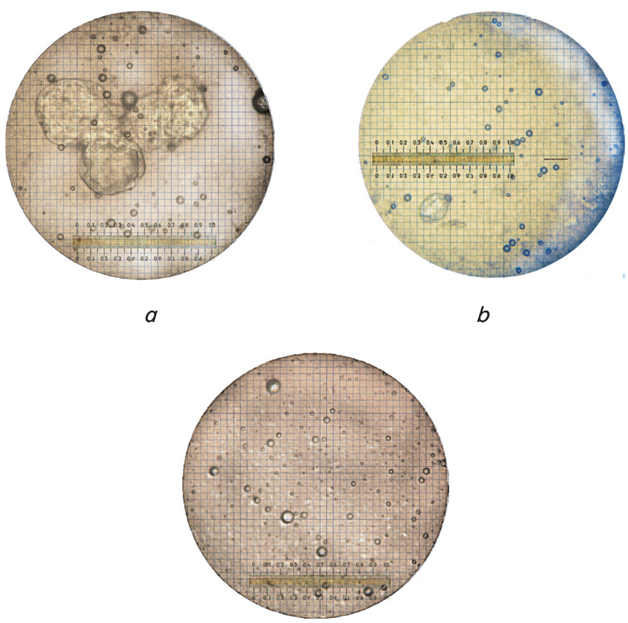
In order to compare the effectiveness of techniques for processing the cream-vegetable mixture using a homogenizer and a rotary-vortex emulsifier, a study was conducted visually based on the presence of clusters of fat globules on microphotographs.

Photomicrographs of experimental samples of cream-vegetable emulsion with a mass fraction of fat of 10 % and 15 % obtained with the help of an emulsifier are shown in Fig. 1, with the help of a homogenizer – in Fig. 2, 3, respectively.



a *b*

Fig. 1. Photomicrographs of a cream-vegetable emulsion obtained during processing in a rotary-vortex emulsifier, with a fat content: *a* – 10 %; *b* – 15 %

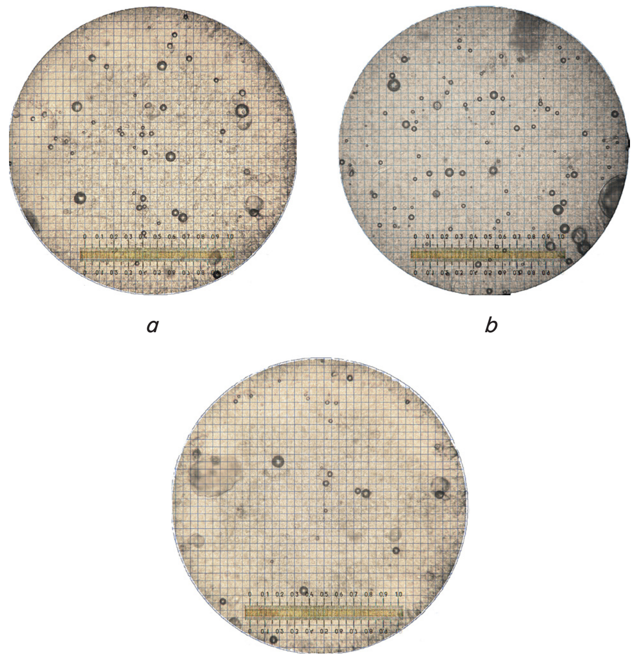


a *b* *c*

Fig. 2. Photomicrographs of a cream-vegetable emulsion with a fat content of 10 % obtained at different homogenizer pressures: *a* – 6.0 MPa; *b* – 8.0 MPa; *c* – 10 MPa

In order to study the homogenization modes that are usually used under industrial conditions, the processing of a cream-vegetable mixture with different fat content in a homogenizer was investigated in two ways: one-stage and two-stage. Test samples with a mass fraction of fat of 10 % and 15 % were subjected to homogenization using a single-stage technique, the pressure was in the range from 6.0 MPa to 14.0 MPa, and a two-stage technique – in the first stage, the pressure was the same as in the one-stage technique, in the second – within 1.5–2.0; 2.0–2.5; 2.5–3.0; 3.0–3.5 MPa.

The characteristics of the resulting emulsions with different fat content are given in Tables 1, 2.



a *b* *c*

Fig. 3. Photomicrographs of a cream-vegetable emulsion with a fat content of 15 % obtained at different homogenizer pressures: *a* – 6.0 MPa; *b* – 8.0 MPa; *c* – 10 MPa

Table 1

Characteristics of cream-vegetable emulsions with a mass fraction of fat of 10 % for different homogenization techniques

Sample No.	Homogeni zation pressure, MPa	Homogeni-zation efficiency, %	Average diameter of fat globules, μm	The presence of accumulations of fat globules (visually)
1	P=6.0	55	2.4	yes
2	P=8.0	66	1.8	yes
3	P=10.0	68	1.0	no
4	P=12.0	68	0.9	no
5	P=14.0	68	0.8	no
6	P_1=6.0; P_2=1.5–2.0	66	2.4	yes
7	P_1=6.0; P_1=2.0–2.5	68	2.4	yes
8	P_1=6.0; P_2=2.5–3.0	72	2.4	no
9	P_1=6.0; P_2=3.0–3.5	72	2.4	no
10	P_1=8.0; P_2=1.5–2.0	68	1.8	yes
11	P_1=8.0; P_2=2.0–2.5	70	1.8	yes
12	P_1=8.0; P_2=2.5–3.0	74	1.8	no
13	P_1=8.0; P_2=3.0–3.5	74	1.8	no
14	P_1=10.0; P_2=1.5–2.0	70	1.2	yes
15	P_1=10.0; P_2=2.0–2.5	72	1.2	yes
16	P_1=10.0; P_2=2.5–3.0	76	1.2	no
17	P_1=10.0; P_2=3.0–3.5	76	1.2	no
18	P_1=12.0; P_2=1.5–2.0	70	1.0	yes
19	P_1=12.0; P_2=2.0–2.5	72	1.0	yes
20	P_1=12.0; P_2=2.5–3.0	77	1.0	no
21	P_1=12.0; P_2=3.0–3.5	77	1.0	no
22	P_1=14.0; P_2=1.5–2.0	72	0.8	yes
23	P_1=14.0; P_2=2.0–2.5	74	0.8	yes
24	P_1=14.0; P_2=2.5–3.0	78	0.8	no
25	P_1=14.0; P_2=3.0–3.5	78	0.8	no

Table 2

Qualitative indicators of a cream-vegetable mixture with a mass fraction of fat of 15 % for different homogenization techniques

Sample No.	Homogenization pressure, MPa	Homogenization efficiency, %	Average diameter of fat globules, μm	The presence of accumulations of fat globules (visually)
1	P=6.0	49	2.2	yes
2	P=8.0	61	2.2	yes
3	P=10.0	62	1.0	no
4	P=12.0	63	0.9	no
5	P–14.0	64	0.8	no
6	P_1=6.0; P_2=1.5–2.0	62	2.2	yes
7	P_1=6.0; P_2=2.0–2.5	65	2.2	yes
8	P_1=6.0; P_2=2.5–3.0	73	2.2	no
9	P_1=6.0; P_2=3.0–3.5	73	2.2	no
10	P_1=8.0; P_2=1.5–2.0	72	1.2	yes
11	P_1=8.0; P_2=2.0–2.5	73	1.2	yes
12	P_1=8.0; P_2=2.5–3.0	77	1.2	no
13	P_1=8.0; P_2=3.0–3.5	77	1.2	no
14	P_1=10.0; P_2=1.5–2.0	72	1.1	yes
15	P_1=10.0; P_2=2.0–2.5	74	1.1	yes
16	P_1=10.0; P_2=2.5–3.0	78	1.1	no
17	P_1=10.0; P_2=3.0–3.5	78	1.1	no
18	P_1=12.0; P_2=1.5–2.0	72	1.0	yes
19	P_1=12.0; P_2=2.0–2.5	74	1.0	yes
20	P_1=12.0; P_2=2.5–3.0	78	1.0	no
21	P_1=12.0; P_2=3.0–3.5	78	1.0	no
22	P_1=14.0; P_2 –1.5–2.0	72	0.8	yes
23	P_1=14.0; P_2=2.0–2.5	74	0.8	yes
24	P_1=14.0; P_2=2.5–3.0	79	0.8	no
25	P_1=14.0; P_2=3.0–3.5	79	0.8	no

As could be seen from Tables 1, 2, with single-stage homogenization within the pressure range from 6.0 MPa to 14 MPa, the average size of fat globules was 1.5 μm, but at the same time, in all the tested variants, the accumulation of fat globules was visually observed. With a two-stage homogenization technique at a pressure of 2.5–3.0 MPa and 3.0–3.5 MPa, accumulation of fat globules was no longer observed in the second stage.

5. 2. Results of investigating the effect of temperature and stabilizer dose on the characteristics of fermented mixtures

In order to obtain fermented cream-vegetable mixtures with stable quality during storage, the application of the "Multistab C3-05" stabilization system was tested. The use of a stabilizer prevents agglomeration of particles of the fermented cream-vegetable mixture under the influence of thermomechanical load during thermalization.

Test samples were obtained under two-stage homogenization regimes: for a cream-vegetable mixture with a mass fraction of fat of 10 %, the pressure at the first stage was 10.0–12.0 MPa, at the second – 2.5–3.0 MPa. For a mixture with a mass fraction of fat of 15 %, the pressure at the first stage was 8.0–10.0 MPa, at the second stage it was 2.5–3.0 MPa. The obtained cream-vegetable emulsion was fermented with a leavening preparation of lactic acid bacteria based on thermophilic and mesophilic strains. The stabilizer "Multistab C3-05" was added to fermented cream-vegetable mixtures in the amount of 0.15 % and 0.5 %. Then the studied samples were subjected to thermomechanical treatment at the following temperatures: 65±2, 70±2, and 80±2 °C. Samples of the fermented cream-vegetable mixture obtained after thermalization were evaluated according to organoleptic indicators, acidity, and dynamic viscosity.

Organoleptic characteristics and viscosity indicators of thermalized fermented mixtures with a mass fraction of fat of 10 % and 15 % for different stabilizer content and processing temperature of the fermented mixture are given in Tables 3, 4, respectively.

Analysis of the data given in Tables 3, 4 reveals that with an increase in the amount of added stabilizer, fat content, and processing temperature, the dynamic viscosity indicators increase.

Table 3

Organoleptic indicators of fermented mixtures with a mass fraction of fat of 10 % and 15 % depending on the stabilizer content and processing temperature

Mass fraction of fat of the fermented mixture	Mass fraction of the structure stabilizer	Characteristics of the fermented mixture			
		Before processing	At processing temperature, °C		
			65±2	70±2	80±2
10 %	0.15	The consistency is homogeneous, moderately thick, without the presence of bubbles	The consistency is homogeneous, liquid, foamy, with a lot of bubbles on the surface and inside the product	The consistency is homogeneous, liquid, foamy, with a lot of bubbles on the surface and inside the product	The consistency is heterogeneous, mealy, liquid, foamy, with a lot of bubbles on the surface and inside the product
	0.50		The consistency is homogeneous, moderately thick, with bubbles on the surface of the product	The consistency is homogeneous, moderately thick, with single bubbles on the surface of the product	The consistency is foamy, with single bubbles and inside the product
15 %	0.15	The consistency is homogeneous, moderately thick, without the presence of bubbles	The consistency is homogeneous, moderately thick, with bubbles on the surface of the product	The consistency is homogeneous, moderately thick, with single bubbles on the surface of the product	The consistency is foamy, with a lot of bubbles on the surface and inside the product
	0.50		The consistency is homogeneous, thick, with single bubbles on the surface of the product	The consistency is homogeneous, dense	The consistency is heterogeneous, foamy with single bubbles on the surface of the product

Table 4

Viscosity of fermented mixtures with a fat content of 10 % and 15 % depending on the stabilizer content and processing temperature

Mass fraction of fat of the fermented mixture	Mass fraction of the «Multistab C3-05» stabilizer, %	Dynamic viscosity, Pa·s			
		before processing	at processing temperature, °C		
			65±2	70±2	80±2
10 %	0.15	0.489	0.508	0.521	0.498
	0.50	1.485	1.889	2.22	1.467
15 %	0.15	1.455	1.872	2.35	1.439
	0.50	2.651	3.212	3.712	2.673

6. Discussion of results of investigating the influence of technological factors on the parameters of cream-vegetable fat mixtures

In order to obtain a high-quality milk-containing product, in which the milk fat is partially (50 %) replaced by a mixture of vegetable fats (MFS), it is necessary to obtain an emulsion based on a multicomponent system consisting of water, fat, proteins, carbohydrates, as well as flavoring additives. For these purposes, under industrial conditions, emulsification in emulsifiers and homogenizers of various designs or mechanical processing by repeated circulation of the mixture with a closed system "centrifugal pump-bath" is mainly used [6]. The emulsion consists of two immiscible phases (fat and water), one of which (fat) is dispersed in the form of balls in the water phase. The size, number, and homogeneity of the distribution of these fat globules determine the stability of the emulsion [15]. Visual analysis makes it possible quickly and without the use of complex equipment to evaluate the effectiveness of the emulsification process. Using a microscope or other imaging techniques, the distribution and size of fat globules could be determined.

It was established that the processing of a cream-vegetable mixture with a fat content of 10 % and 15 % in a rotary-vortex emulsifier resulted in the formation of an emulsion with the size of fat globules in the range of 1.2–1.5 μm with accumulation (Fig. 1).

In cream-vegetable mixtures processed in a homogenizer under a pressure of 6.0 MPa, the size of fat globules was 2.0–2.4 μm with a fat content of 10 % (Fig. 2, *a*) and about 2.2 μm with a fat content of 15 % (Fig. 3, *a*). Accumulation was observed in both samples (Fig. 2, 3, *a*). At a pressure of 8.0 MPa, the size of fat globules was 1.6–1.8 μm and 1.2–1.6 μm for mixtures with a fat content of 10 % and 15 %, respectively (Fig. 2, 3, *b*). At the same time, accumulation was also observed for both samples (Fig. 2, 3, *b*). At pressures of 10.0 MPa, 12.0 MPa, and 14.0 MPa, the size of fat globules was less than 1.0 μm without accumulation for both samples of the mixture (Fig. 2, 3, *c*).

It is evident that the smallest sizes of fat globules, in the absence of their accumulation, were noted in the case of processing of cream-vegetable emulsions with the help of a homogenizer at a pressure ranging from 10 to 14 MPa. At the same time, it should be noted that in both versions of the mixtures – with a mass fraction of total fat of 10 % and 15 %, the diameter of the balls varied in the same size range, namely less than 1.0 μm.

Thus, dispersing the cream-vegetable mixture in a homogenizer leads to obtaining a cream-vegetable emulsion with a high degree of dispersion without accumulation of fat balls.

Analyzing the data in Tables 1, 2 reveals that the presence of clusters or agglomerates of fat balls indicates a violation of the homogeneity of the emulsion. Instead of an even distribution, the fat globules gather in aggregates, which is a sign of emulsion instability. This may be the result of insufficient emulsification or a coalescence process where small fat globules coalesce into larger ones. The formation of such clusters could lead to further delamination of the emulsion and loss of such desirable properties as homogeneity of texture or proper taste. Emulsions with accumulations of fat globules are less stable and, as a rule, have a shorter shelf life. In this case, the visual definition of these clusters makes it possible to predict a possible violation of the product structure, for example, delamination.

Our research allows us to conclude that the evaluation of emulsification efficiency based on the analysis of the obtained microphotographs of cream-vegetable emulsions is much more accurate and objective compared to the traditional technique of settling, which is used to evaluate homogenization. Photomicrographs allow a detailed study of the structure of the emulsion at the microscopic level, providing an accurate representation of the level of dispersion of fat droplets, their size, shape, and uniformity of distribution in the mixture. This makes it possible to detect even minor defects in the emulsification process that may remain unnoticed during settling. The settling method, in turn, although it is simple and widely used, does not provide such detail and accuracy in assessment. It only gives a general idea of the stability of the mixture as it is based on the observation of the delamination of the components over time, which does not always reflect the real state of the homogenization or emulsification process. Therefore, the use of photomicrography as a tool to analyze emulsification performance provides a deeper understanding of the structural integrity of the emulsion, which is important to ensure the high quality of the final product.

Therefore, the rational modes of homogenization are the two-stage homogenization technique: for a cream-vegetable mixture with a mass fraction of fat of 10 %, the pressure in the first stage should be 10.0–12.0 MPa, in the second – 2.5–3.0 MPa; for a product with a mass fraction of fat of 15 %, the pressure at the first stage is 8.0–10.0 MPa, at the second stage – 2.5–3.0 MPa. These homogenization modes could be recommended during the production of a wide range of milk-containing products based on cream-vegetable mixtures with a fat content of 10 % and 15 %, in which the ratio of replacement of milk fat with vegetable fat is 50:50.

The technology of milk-containing combined products with a long shelf life using thermalization of the fermented mixture ensures the inactivation of enzymes and microorganisms of fermentative and non-fermentative origin. As a result, the process of development of microorganisms stops. The product obtained in this way is characterized by a stable level of acidity, high sanitary and microbiological indicators, which provide it with a long shelf life [17]. Obtaining a cream-vegetable emulsion and thermalization of the fermented mixture are the main stages of production of a fermented milk-containing product, which affect the formation of physicochemical and microbiological indicators of the finished product [16, 17].

It was established that for all studied samples, the content of the structure stabilizer under the studied temperature regimes of processing fermented mixtures with a fat content of 10 % and 15 % did not affect the change in the acidity index compared to the initial value. The titrated acidity remained in the range of 80 °T and 76 °T, respectively, active – in the range of 4.8–4.2 pH units.

It has been shown that with an increase in the amount of added stabilizer, fat content and processing temperature, the dynamic viscosity indicators increase. Thus, in comparison with the initial values for the amount of stabilizer of 0.15 % and 0.5 % in samples of fermented mixtures with a content of 10 %, the viscosity increased by 1.1–1.3 times with an increase in the thermalization temperature up to 70 °C, in samples of fermented mixtures with a content of 15 %, the viscosity was slightly higher – 1.4–1.6 times.

The increase in dynamic viscosity with an increase in the amount of stabilizer and fat content with an increase in the processing temperature is justified by changes in the structure and properties of the dairy system. With an increase in the concentration of the stabilizer, the bonds between molecules in the liquid phase are strengthened, forming a denser and more stable network, which increases viscosity. Increasing the fat content of the mixture creates additional structure, as fat droplets could act as obstacles to fluid movement, which also increases flow resistance. With an increase in temperature, the processing of the milk-vegetable mixture could contribute to a better distribution of the stabilizer and change the structure of the fat and protein components, which additionally affects the viscosity.

It should be noted that with increasing values of dynamic viscosity, the consistency acquires a moderate density and becomes thick in a mixture with a fat content of 10 % and more compacted in a mixture with a fat content of 15 %. This is due to the fact that fat is one of the key components that affects the structural properties of the product. A higher fat content contributes to the formation of a thicker consistency since the fat globules create a denser network in the liquid phase of the mixture. At the same time, the mobility of water in the system decreases and the dynamic viscosity increases. At a fat content of 10 %, the consistency becomes moderately dense, which creates a creamy texture that is acceptable for most types of fermented products. However, in a mixture with a fat content of 15 %, the density increases even more because a more stable fat-protein matrix is formed, which compacts the structure and makes it even denser.

When processing the cream-vegetable mixture at a temperature of 80±2 °C, changes occur in the structure of proteins and fat components, which leads to a decrease in viscosity indicators compared to the initial values in all samples of the fermented mixture. High temperature could cause protein denaturation, which reduces their ability to hold water and reduces the overall viscosity of the mixture. In addition, intense heating could lead to an excessive reduction in the size of the fat droplets, which contributes to the deterioration of the consistency, making it less uniform or excessively runny. These changes directly affect the organoleptic evaluation of the product as consumers expect from such mixtures a creamy, uniform consistency with a pleasant texture. Thus, the temperature regime of 80±2 °C is excessive for obtaining fermented products with such properties. Therefore, in order to preserve the proper parameters of the final product, it is advisable to use milder processing modes.

Thus, in order to ensure the proper quality of milk-containing products, which are produced on the basis of the thermalized fermented cream-vegetable mixture, it is necessary to carry out thermomechanical processing of the mixture with a fat content of 10 % and 15 % at the temperatures of thermalization of 70±2 °C and 65±2 °C, respectively, and mass fraction of the stabilizer – 0.5 % and 0.15 %, respectively.

It is quite obvious that in the event of a change in the component composition of products due to an increase in the mass fractions of protein and fat, it is necessary to adjust the thermomechanical processing regimes to achieve the target consistency indicators inherent in certain types of products.

7. Conclusions

1. We have established mechanical processing modes for the cream-vegetable mixture. It is shown that in order to obtain an emulsion without accumulation of fat globules with a high degree of dispersity, it is necessary to carry out two-stage homogenization. Namely, for a cream-vegetable mixture with a mass fraction of fat of 10 %, the pressure in the first stage should be 10.0–12.0 MPa, in the second – 2.5–3.0 MPa; for a cream-vegetable mixture with a mass fraction of fat of 15 %, the pressure at the first stage is 8.0–10.0 MPa, at the second stage – 2.5–3.0 MPa.

2. We have defined thermalization modes for the fermented cream-vegetable mixture to make fermented milk-containing products; the stabilization system "Multistab C3-05" has been selected. To improve the consistency and avoid foaming of the finished product, the processing temperature of the fermented mixture with a fat content of 10 % should be 70±2 °C, for the mixture with a fat content of 15 %, it should be 65±2 °C. The mass fraction of the stabilizer is 0.5 % and 0.15 %, respectively.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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