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IMPROVING THE QUALITY OF FINISHING CREAMS BASED ON LOW-FAT CREAM BY OPTIMIZING STRUCTURAL AND MECHANICAL PROPERTIES

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Abstract

Reducing the mass fraction of fat in creamy finishing creams is a relevant direction for the development of healthier confectionery products. However, it is accompanied by a deterioration in rheological characteristics, a decrease in dimensional stability and an increase in syneresis. The aim of the work was to improve the quality of finishing creams based on low-fat cream by optimizing structural and mechanical properties through improving the recipe and mechanical processing modes. The effect of hydrocolloids, namely gelatin, xanthan gum, guar gum and high-methoxyl pectin, as well as milk protein ingredients, including sodium caseinate and skimmed milk powder, on viscosity, dimensional stability, syneresis and the stability of the emulsion-foam structure of the cream was studied. It was shown that reducing fat from 30 % to 12 % without stabilization leads to a significant decrease in viscosity and an increase in the tendency to whey separation. The best technological effect is provided by the combined system "gelatin + guar gum + sodium caseinate", which brings the structural parameters closer to the control sample and reduces syneresis to 1.3 % after 72 h of storage at (4±2)°C. The optimal whipping mode is set to 6 min at 1200-1400 rpm, which provides a balance between overrun and foam stability. The results can be used in confectionery production to create low-calorie creams without losing the organoleptic profile of the product.

Keywords: butter cream; low-fat cream; hydrocolloids; sodium caseinate; rheology; syneresis; dimensional stability; whipping; food emulsions; food foams.

ПОКРАЩЕННЯ ЯКОСТІ ОЗДОБЛЮВАЛЬНИХ КРЕМІВ НА ОСНОВІ ВЕРШКІВ З НИЗЬКИМ ВМІСТОМ ЖИРНОСТІ ШЛЯХОМ ОПТИМІЗАЦІЇ СТРУКТУРНИХ ТА МЕХАНІЧНИХ ВЛАСТИВОСТЕЙ

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Анотація

Зменшення масової частки жиру в вершкових оздоблювальних кремах є актуальним напрямком розробки більш здорових кондитерських виробів. Однак це супроводжується погіршенням реологічних характеристик, зниженням розмірної стабільності та збільшенням синерезису. Метою роботи було покращення якості оздоблювальних кремів на основі знежирених вершків шляхом оптимізації структурно-механічних властивостей за рахунок удосконалення рецептури та режимів механічної обробки. Досліджений вплив гідроколідів, а саме желатину, ксантанової камеді, гуарової камеді та високометоксилованого пектину, а також інгредієнтів молочного білка, включаючи казеїнат натрію та сухе знежирене молоко, на в'язкість, розмірну стабільність, синерезис та стабільність емульсійно-пінної структури вершків. Показано, що зменшення жиру з 30 % до 12 % без стабілізації призводить до значного зниження в'язкості та збільшення схильності до відділення сироватки. Найкращий технологічний ефект забезпечує комбінована система «желатин + гуарова камедь + казеїнат натрію», яка наближає структурні параметри до контрольного зразка та знижує синерезис до 1.3 % після 72 год зберігання за (4±2)°C. Оптимальний режим збивання встановлено на 6 хв за 1200-1400 об/хв, що забезпечує баланс між перебігом та стійкістю піни. Результати можуть бути використані в кондитерському виробництві для створення низькокалорійних кремів без втрати органолептичного профілю продукту.

Ключові слова: вершковий крем; знежирені вершки; гідроколіди; казеїнат натрію; реологія; синерезис; розмірна стабільність; збивання; харчові емульсії; харчові піни.

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Introduction

Finishing creams (creamy masses for filling, layering and decorating) belong to multicomponent food disperse systems, in which the processes of emulsification (formation of "fat-water"), foaming (introduction and stabilization of air bubbles) and structure formation (transition into a semi-solid viscoelastic matrix) are simultaneously implemented. Functionally, such systems should: (a) be easy to form during deposition, (b) maintain the relief and shape of the decorative elements, (c) have a pleasant creamy texture, (d) remain stable over a long period of time and despite temperature fluctuations in the "producer-logistics-consumer" chain. From the standpoint of colloidal chemistry, finishing creams are highly dispersed emulsion-foam systems with a dominant role of the interfacial surface, and their quality is determined by the rheology of the continuous phase, the parameters of the dispersed phase and the strength of the interfacial films [1-5].

In classical formulations, the main structural factor is the fat phase. Partially crystallized fat globules are capable of aggregation and partial coalescence, forming a framework that strengthens the walls of air bubbles and provides high viscoelasticity of the cream. That is why increasing the fat content usually facilitates the production of shape-stable creams. However, excess fat increases the energy value and contradicts the trend of its reduction in the diet, which is confirmed by modern review works on the evolution of whipped cream and cream formulations [6].

Reducing the mass fraction of fat in creams (for example, using 10-12 % cream instead of 30-35 %) causes a number of technological problems: a decrease in viscosity and yield point, deterioration of plasticity, a decrease in the ability to retain air (reduction of overrun), an increase in the drainage rate in the foam structure, the appearance of syneresis (separation of whey) and a reduction in the permissible shelf life of decorated products [6-8]. Some of these phenomena are associated with the fact that in low-fat systems the phase ratio changes and the number of fat globules that can participate in the mechanism of partial coalescence decreases [5; 9; 10].

In light of this, technological optimization of low-fat creams involves the creation of alternative structure-forming potential due to hydrocolloids, proteins and their complexes.

Hydrocolloids perform the functions of thickeners, gelling agents and stabilizers, reducing the mobility of the aqueous phase and slowing down the processes of coalescence and drainage [11-13]. Milk proteins, in particular caseinates, act as effective surfactants that stabilize the interfacial surface and can interact with polysaccharides to form complexes that increase the stability of emulsions [14-18].

In addition to the recipe, the key factor in the formation of the structure is the mechanical processing mode: the intensity and duration of whipping, temperature and the order of adding components. It is the technological parameters that control aeration, bubble size and dispersion of the fat phase. Therefore, an integrated approach that combines the optimization of the stabilization system and whipping modes is the most justified for creating low-fat finishing creams with prolonged quality.

Fat reduction in milk and cream systems has technological consequences. Reducing the fat content changes the phase ratio and structure of the dispersed system. In the case of whipped cream, partial coalescence of fat plays a key role: the presence of fat crystals on the surface of the drops contributes to the "adhesion" of the drops to each other, the formation of aggregates and the creation of a spatial network that stabilizes the foam [1-3]. Current studies show that the processes of partial coalescence, the distribution of fat crystals in the drops and the protein composition of the interfacial film can change during whipping and after reaching the end point, causing both an improvement and a deterioration in stability [19]. A 2024 study on whipped cream highlights that the search for low-fat formulations requires simultaneous control of the emulsion and foam components and is sensitive to the composition of additives [6].

Hydrocolloids as stabilizers and "fat substitutes" are widely used in the dairy industry as thickeners, gelling agents and stabilizers. Review works from 2023-2025 systematize the role of polysaccharides (xanthan, guar, pectin, carrageenan, alginates, starches, etc.) in shaping the texture and stability of low-fat products, as well as their effect on the sensation of "creaminess" in the mouth [11-13; 20]. From a technological point of view, the following are especially important for creams: (a) the ability to increase viscosity at low concentrations, (b) pseudoplasticity (easy settling upon shear and restoration of the structure after it), (c) water-

holding capacity (reduction of syneresis), (d) compatibility with milk proteins and sugar.

Xanthan gum provides high thickening efficiency and pronounced pseudoplasticity, which is useful for finishing creams that must be "soft on deposit" and "hard after molding". Guar gum is effective as a thickener and shows synergy with other polysaccharides. Pectin, in addition to thickening, is able to interact with caseinates and affect interfacial stabilization. Gelatin forms thermoreversible gels and can increase the elasticity of the cream structure, but with the wrong hydration regime it can cause inhomogeneity.

Combinations of milk proteins with polysaccharides are considered as a promising tool for stabilizing emulsions and foams. The caseinate-pectin system is actively studied as a model of a protein-polysaccharide complex: it has been shown that the order of addition, pH conditions and ionic strength can significantly affect the interfacial properties and stability of emulsions [14–16]. Studies in 2024 demonstrate that caseinate/pectin complexes are able to form more stable emulsions and can be regulated by technological influences (in particular ultrasound) to achieve the required dispersion [15]. In the context of low-fat creams, it is important that such complexes can: (a) enhance adsorption at the phase boundary, (b) increase the elasticity of the interfacial film, (c) reduce coalescence, (d) increase the viscosity of the continuous phase and the yield point [21; 22].

Foams in food systems are degraded by drainage (liquid run-off), bubble coalescence, and Ostwald ripening. A review of the physics of foam systems emphasizes the role of continuous phase rheology: increasing viscosity and the appearance of a yield point can significantly reduce the rate of drainage and increase foam stability [23]. For creams, this means that stabilizers must increase the viscoelasticity of the films between the bubbles and create a matrix that retains water.

Thus, the literature analysis indicates that the optimization of low-fat finishing creams should be based on the combination of protein and polysaccharide stabilizers and the precise selection of technological whipping modes.

The aim of this study is to improve the quality of finishing creams based on low-fat cream by optimizing their structural and mechanical properties through improved formulation and mechanical processing parameters.

Experimental part

Raw materials and ingredients. The main raw material used was normalized drinking cream with a fat mass fraction of 12 %, obtained by separating pasteurized cow's milk. The control sample was prepared according to the classic recipe for butter cream with a fat mass fraction of 30 %. To modify the structural and mechanical properties of the low-fat cream system, the following hydrocolloids were used: food gelatin at 0.8 %, xanthan gum at 0.15 %, guar gum at 0.20 %, and high-methoxyl pectin at 0.50% of the total formulation weight. Skimmed milk powder was added at 4.0 %, while sodium caseinate, used as a protein emulsifier and interfacial stabilizer, was introduced at 1.0 % of the total formulation weight. These concentrations were selected on the basis of preliminary technological trials and literature data on the ability of hydrocolloids and protein-polysaccharide systems to increase the viscosity of the continuous phase, improve water retention and stabilize emulsion-foam food systems [14–16]. The sweetening component was granulated sugar; aroma and taste were adjusted with vanillin or food flavouring.

The choice of cream with a fat mass fraction of 12 % as the baseline experimental level was technologically justified by the need to model a low-fat finishing cream with a substantially reduced fat phase compared with the traditional 30 % fat control. At this fat level, the contribution of partially coalesced fat globules to foam stabilization is markedly reduced, which makes it possible to clearly evaluate the structure-forming effect of hydrocolloids and milk proteins. At the same time, 12 % cream remains a technologically realistic dairy base that can be whipped and incorporated into confectionery cream formulations without complete loss of the characteristic creamy sensory profile. Therefore, this fat level was selected as a compromise between nutritional fat reduction and the preservation of technological applicability in finishing cream production.

Experimental design. The study was conducted in three stages: (I) selection of stabilization systems and comparison of their effectiveness in creams with a fat mass fraction of 12 %; (II) establishment of the influence of whipping duration on structure formation for the most effective stabilization system; and (III) assessment of cream stability during storage at (4±2) °C for 72 h. Four experimental low-fat cream samples were prepared: sample No. 1 contained gelatin at 0.8 %; sample No. 2 contained xanthan gum at 0.15 %; sample No. 3

contained guar gum at 0.20 % and high-methoxyl pectin at 0.50 %; sample No. 4 contained gelatin at 0.8 %, guar gum at 0.20 % and sodium caseinate at 1.0 %. The control sample was prepared using 30 % fat cream without additional stabilizers.

Sample preparation. The cream was cooled to 6–8 °C before whipping. Dry hydrocolloids and protein ingredients were first mixed with granulated sugar in order to improve their dispersion and prevent agglomeration. Gelatin was hydrated in cold water for 30 min and then dissolved at 45–50 °C, followed by cooling to the whipping temperature. Xanthan gum, guar gum and pectin were dispersed in part of the aqueous phase under intensive stirring for 10–15 min until a homogeneous hydrated system was obtained. Sodium caseinate and skimmed milk powder were dissolved separately in the aqueous phase at 35–40 °C and then cooled to 6–8 °C before being added to the cream base. The prepared cream mixtures were kept for 20 min at 6–8 °C to complete hydration and temperature equilibration. Whipping was performed using a planetary mixer at 1200–1400 rpm. The whipping duration was varied from 2 to 10 min depending on the experimental stage.

Methods of analysis. The mass fraction of moisture was determined by drying to constant mass according to DSTU ISO 5537:2022 [24]. Titratable acidity was determined by the titrimetric method according to DSTU ISO 6091:2010 [25]. Apparent viscosity was measured using a Brookfield-type rotational viscometer at 6 ± 1 °C after 10 min of sample temperature equilibration. Measurements were performed at a constant spindle speed, and the results were expressed in Pa·s as the mean value of three parallel determinations. Dimensional stability was evaluated by depositing equal portions of cream in the form of standard relief elements and determining the percentage of shape retention after 60 min at 20 ± 2 °C. Overrun was calculated from the change in sample volume before and after whipping using the formula: overrun (%) = $[(V_2 - V_1) / V_1] \times 100$, where V_1 is the initial volume of the cream mixture and V_2 is the volume after whipping. Foam stability was determined as the percentage of retained foam volume after holding the whipped sample for 60 min at 20 ± 2 °C. Syneresis was determined after storage at (4 ± 2) °C by separating the released liquid and expressing it as a percentage of the initial sample mass. Microstructural observations were performed by light microscopy at $100 \times$

magnification to assess the visual distribution of fat droplets, air bubbles and aqueous channels in the cream matrix [9; 17; 26–29].

Organoleptic evaluation was carried out on a five-point scale based on appearance, consistency, taste and aroma.

Statistical analysis. Each determination was performed in triplicate ($n = 3$). Results are presented as mean \pm standard deviation (mean \pm SD). Parametric criteria (t-test/ANOVA) were used to compare groups at $p \leq 0.05$. Data processing was performed in Microsoft Excel/statistical packages.

Additional approaches to the interpretation of rheological data. To describe the flow of dispersed food systems, it is advisable to use viscoplastic flow models (e.g., Bingham or Herschel–Bulkley), which allow estimating the yield stress τ_0 , the consistency coefficient K , and the flow index n . This requires viscosity measurements at several shear rates (or at several spindle speeds). The obtained parameters are technologically informative: τ_0 correlates with dimensional stability and the ability to retain relief, while n reflects the degree of pseudoplasticity, which is important for the settling process [23; 26–28]. Within the framework of this study, the dynamic viscosity index was used for comparative assessment, but the presented approach is recommended for expanding the experiment in further work.

Results and their discussion

A decrease in the mass fraction of fat in creams leads to a decrease in the specific fraction of the dispersed phase and a weakening of the foam stabilization mechanisms associated with partial coalescence of fat. This is reflected in a decrease in viscosity, deterioration of plasticity and an increase in syneresis [4; 6–8]. Therefore, at the first stage, a series of experimental samples of cream with a fat content of 12 % with different stabilization systems was formed and their influence on rheological parameters was compared.

Comparative data are summarized in Table 1. Mono-ingredient systems (gelatin or xanthan gum) partially restore viscosity and dimensional stability, but do not provide a sufficient reduction in syneresis. The most balanced indicators were obtained for the combined system (gelatin + guar gum + sodium caseinate), which indicates the synergy of the protein stabilizer and polysaccharide structure-forming agents. Such synergy is consistent with modern ideas about

the role of protein-polysaccharide complexes in the stabilization of emulsions [14–16; 21; 22].

Table 1

The influence of stabilization systems on the quality of low-fat creams (fat mass fraction 12%, n=3)

Sample	Stabilization system	Viscosity, Pa·s (mean±SD)	Dimensional stability, % (mean±SD)	Syneresis, % (mean±SD)
Control (30% fat)	No additives	5.26±0.08	93.2±1.3	0.03±0.05
Nº1	Gelatin	3.85±0.13	80.5±2.5	4.33±0.41
Nº2	Xanthan gum	4.19±0.15	84.1±1.3	2.57±0.25
Nº3	Guar gum + pectin	4.58±0.09	89.0±1.1	1.54±0.04
Nº4	Combined (gelatin + guar + caseinate)	4.71±0.20	91.7±0.9	0.76±0.05

The data in Table 1 show that the combined stabilization system No. 4 provided the closest structural and mechanical characteristics to the control sample. For additional visualization, Fig. 1 presents the viscosity of the cream samples, since this indicator is the key technological parameter determining deposition behaviour and resistance

to deformation. Sample No. 4 reached a viscosity of 4.71±0.20 Pa·s, which was only 5.8 % lower than that of the control sample with 30 % fat. This confirms that the combination of gelatin, guar gum and sodium caseinate compensates for the technological losses caused by reducing the fat mass fraction from 30 % to 12 %.

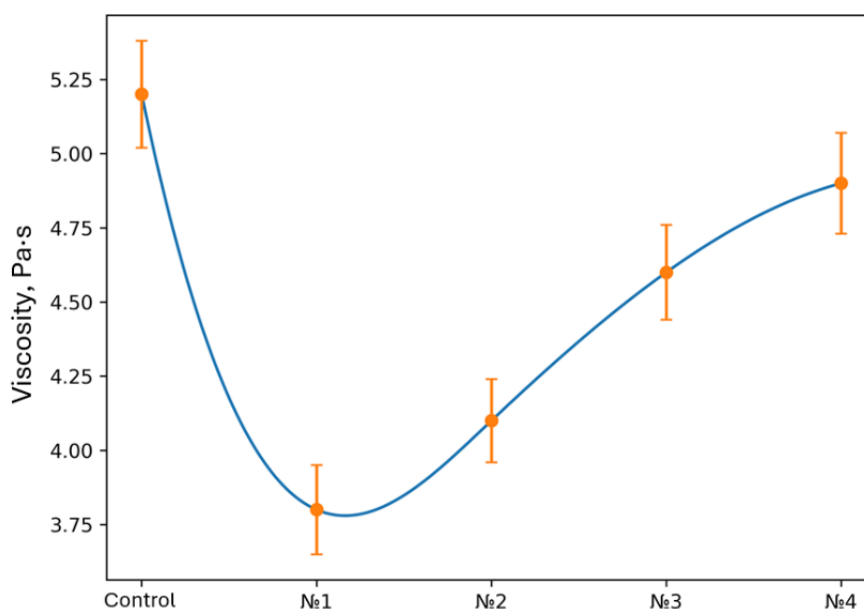


Fig. 1. Viscosity of cream samples depending on the stabilization system

Mechanistically, the effect of the combined system is explained by the fact that sodium caseinate adsorbs at the “fat–water” interface and forms a stable interfacial film, while gelatin and guar gum increase the viscosity of the continuous phase and can form a spatial matrix that reduces the drainage rate in the foam structure. As a result, the viscoelasticity of the system increases, coalescence is suppressed, and syneresis is reduced [14–16; 23].

Mechanical processing (whipping) is a critical stage in the production of finishing creams, as it determines the degree of fat dispersion, the intensity of air saturation (overrun), the size of bubbles and the quality of interfacial films.

Excessive intensity or duration of whipping may lead to destruction of the protein-polysaccharide matrix, coalescence of fat globules and sedimentation of the foam, which is manifested by thinning and loss of decorative properties.

The study was conducted on sample No. 4 with the optimal stabilization system. At a fixed whipping speed of 1200–1400 rpm, the duration of whipping was varied within 2–10 min. The viscosity, overrun and foam stability indicators are summarized in Table 2, while Fig. 2 additionally visualizes foam stability as the most sensitive indicator of the balance between aeration and structural resistance.

Dependence of rheological and foaming parameters on the duration of whipping (sample №4, n=3)				
Beating duration, min	Viscosity, Pa·s (mean±SD)	Overrun, % (mean±SD)	Foam stability, % (mean±SD)	Consistency description
2	3.70±0.11	17.7±0.2	72.2±0.6	Under-beaten
4	4.45±0.16	32.2±0.9	85.1±1.4	Homogeneous, fluffy
6	4.88±0.10	38.3±0.4	92.6±1.4	Optimal
8	4.65±0.15	39.3±0.9	88.8±1.2	Start of reprocessing
10	4.24±0.08	35.7±1.5	82.1±0.7	Signs of thinning

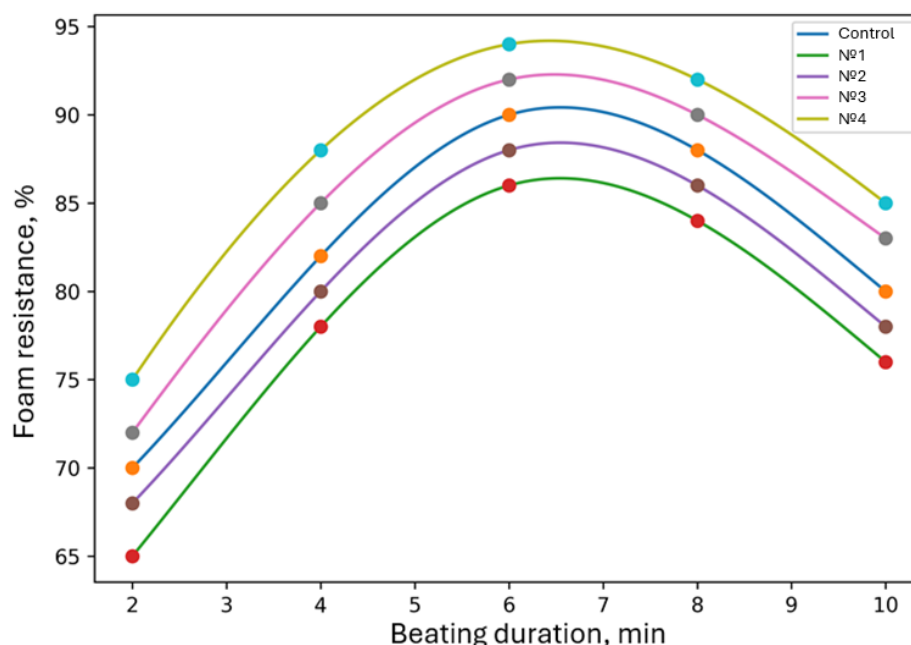


Fig. 2. Effect of whipping duration on foam stability

At 2 min, the cream has insufficient aeration, reduced viscosity and foam stability, which is consistent with the mechanism of incomplete formation of the interfacial structure. At 4–6 min, an increase in overrun and viscosity is observed, as well as maximization of foam stability. The optimal interval is 6 min, when the highest foam stability is achieved with sufficient viscosity and a homogeneous consistency.

A further increase in duration to 8–10 min tends to reduce the viscosity and foam stability, which can be interpreted as the beginning of overprocessing: some of the air bubbles coalesce, redistribution of the aqueous phase occurs, and protein-polysaccharide structures undergo mechanical destruction. Similar conclusions are consistent with literature data on the sensitivity of food foams to the rheology of the continuous phase and technological parameters of whipping [23].

The stability of finishing creams during storage is critical for preserving the decorative properties of the products. The main undesirable phenomena are syneresis, shrinkage, loss of elasticity and “smearing” of the relief. In low-fat systems, the risk of syneresis increases due to the relative increase in the proportion of the aqueous phase and the decrease in the structure-forming role of fat [6–8].

Syneresis was evaluated for the control and experimental samples during 72 h of storage at $(4 \pm 2)^\circ\text{C}$ (Table 3). The results show that single-component stabilization systems, namely gelatin or xanthan gum, did not provide sufficient moisture retention: whey release was observed after 24 h and progressed over time. The combined system No. 4 demonstrated the best stability and provided minimal whey release even after 72 h of storage.

Dynamics of syneresis during storage at (4±2)°C (n=3)				
Sample	Fat content, %	Syneresis 24 h, % (mean±SD)	Syneresis 48 h, % (mean±SD)	Syneresis 72 h, % (mean±SD)
Control (30% fat)	30	0.02±0.03	0.05±0.06	0.05±0.05
Nº1 (gelatin)	12	2.45±0.13	4.10±0.40	6.32±0.88
Nº2 (xanthan)	12	1.83±0.02	3.41±0.36	4.71±0.22
Nº3 (guar + pectin)	12	1.13±0.06	2.10±0.04	3.03±0.21
Nº4 (combination)	12	0.38±0.02	0.71±0.07	1.25±0.09

The dynamics of syneresis presented in Table 3 demonstrates that samples No. 3 and No. 4 had substantially lower whey separation during storage compared with single-component stabilization systems. The best result was obtained for sample No. 4, in which syneresis after 72 h was only 1.25±0.09 %. This confirms the advantage of combined structure-forming systems based on the interaction of hydrocolloids and milk proteins. The obtained results are consistent with modern studies indicating that protein-polysaccharide interactions can increase the elasticity of interfacial films, improve water retention and reduce liquid migration in emulsion-foam food systems [4; 9; 14–16; 23].

From a practical point of view, this means that confectionery manufacturers can extend the

technological window for using cream and reduce the risk of finished products being rejected due to the instability of the decor.

For technological practice, it is important to understand the relationship between rheological parameters and cream stability. In low-fat systems, an increase in the viscosity of the continuous phase usually correlates with a decrease in the drainage rate in the foam structure and a decrease in syneresis [23]. Fig. 3 presents the relationship between viscosity and syneresis after 72 h of storage. This figure is retained as an analytical visualization because it does not duplicate a single table directly, but summarizes the relationship between two technological indicators.

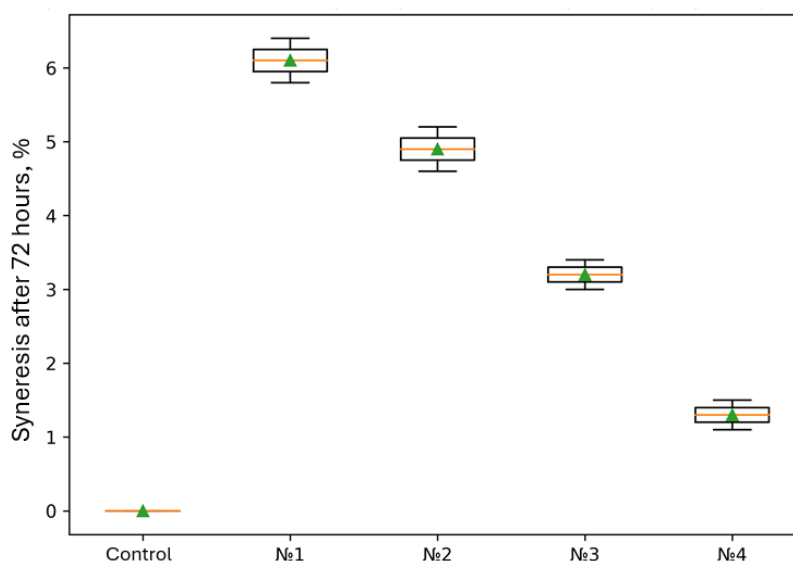


Fig. 3. Dependence of syneresis after 72 h of storage on the viscosity of cream samples

At the same time, excessive viscosity increase can complicate whipping and reduce overrun due to limited air dispersion. Therefore, optimization should consider the trade-off between aeration ability and foam stability. Sample No. 4 demonstrates the most balanced properties: sufficient viscosity for stability and at the same time the ability to form a fluffy structure at 6 min of whipping.

Light microscopy observations confirmed qualitative differences between the control, single-stabilizer samples and the combined

stabilization system. In samples No. 1 and No. 2, larger air inclusions and visually uneven distribution of the dispersed phase were observed, which corresponded to higher syneresis values during storage. In sample No. 4, the cream matrix was more homogeneous, with a more uniform distribution of air bubbles and fewer visually detectable aqueous channels. These observations support the experimentally established reduction in syneresis and improvement in dimensional stability for the combined system.

At the same time, the present study provides only qualitative microscopic observations. Therefore, the proposed stabilization mechanism should be interpreted as a technologically substantiated explanation rather than a fully quantified microstructural model. Based on the obtained rheological and storage stability data, as well as literature evidence on protein-polysaccharide complexes [14–16], it may be assumed that the key factors in sample No. 4 were: (1) improved interfacial stabilization due to sodium caseinate; (2) increased viscosity and water-binding capacity due to gelatin and guar gum; and (3) formation of a cooperative protein-polysaccharide network limiting coalescence and water migration. Further studies should include quantitative image analysis of bubble and fat droplet size distribution.

Conclusions

Based on the experimental data obtained, a set of technological approaches to improving the quality of low-fat finishing creams was substantiated. It was established that reducing the mass fraction of fat in creams to 12 % without the use of stabilization systems leads to a deterioration in rheological properties and an increase in syneresis, which significantly limits the possibility of their use as finishing.

It was shown that the use of combined stabilization systems, in which the protein component (sodium caseinate or skimmed milk powder) provides stabilization of the interphase

surface, and hydrocolloids form the matrix of the continuous phase, allows significantly improving the structural and mechanical characteristics of creams. The most effective composition was found to be the combined stabilization system containing gelatin at 0.8 %, guar gum at 0.20 % and sodium caseinate at 1.0 % of the total formulation weight. This system provided viscosity and dimensional stability values close to those of the control sample and reduced whey release to 1.25 ± 0.09 % after 72 h of storage at (4 ± 2) °C.

It has been proven that the quality of the cream significantly depends on the mechanical processing modes: the optimal combination of overrun, foam stability and viscosity indicators is achieved under the condition of complete preliminary hydration of the stabilizers, maintaining the whipping temperature of 6–8 °C and the duration of whipping for about 6 min at a speed of 1200–1400 rpm, while further intensification of the process causes signs of overprocessing.

A summary of the results confirms the advisability of adopting a comprehensive approach to optimizing low-fat finishing creams, combining the rational selection of combined protein-polysaccharide stabilizing systems with the optimization of process parameters, which play a key role in ensuring the stability of the product's decorative properties, especially over a long shelf life.

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