

В якості поліпшувача структури збитих десертів розроблено та запропоновано харчову добавку “Магнетофуд” – нанопорошок з розміром частинок (70–80) нм. “Магнетофуд” може як самостійно формувати структурно-механічні властивості збитих мас, так і впливати на гелеутворювач, вступаючи з ним в хімічні і електростатичні взаємодії. Тому, харчова добавка “Магнетофуд” може впливати одразу на декілька технологічних властивостей у харчовій дисперсній системі: бути стабілізатором, загусником, піно- та драглеутворювачем. За рахунок Fe (II), нанорозмірів та розвиненої активної поверхні “Магнетофуд” має сорбційні, комплексоутворюючі, емульгуючі, вологоутримуючі, жирутримуючі, вологозв’язуючі, стабілізуючі, структуроутворюючі властивості. Це дозволяє рекомендувати “Магнетофуд” як добавку комплексної дії для формування структури збитих десертів та підвищення якості збитої десертної продукції. Встановлено, що введення харчової добавки “Магнетофуд” у дослідні зразки ягідно-фруктових мусів та самбуків у кількості 0,10 %, 0,15 %, 0,20 % від маси рецептурної суміші поліпшує структурно-механічні властивості збитих десертів. При використанні добавки “Магнетофуд” зменшується густина на (29 ± 1) кг/м³ – для мусів, на (26 ± 1) кг/м³ – для самбуків й тривалість збивання на ~15 % у порівнянні з контролем. Доведено, що введення добавки “Магнетофуд” сприяє збільшенню пластичної міцності в 1,23 рази; пористості на $(14,3 \pm 0,7)$ % – для мусів і на $(12,7 \pm 0,6)$ % – для самбуків; стабільності піни на $(22,5 \pm 1,1)$ % в порівнянні з контролем. Також збільшується піноутворююча здатність на (40 ± 2) % – для мусів і на (55 ± 3) % – для самбуків; ефективна в’язкість на $(4,4 \pm 0,2)$ % – для мусів і на $(4,1 \pm 0,2)$ % – для самбуків в порівнянні з контролем. Встановлено раціональний вміст харчової добавки “Магнетофуд” – 0,15 % до рецептурного складу.

Одержані експериментальні дані можуть бути використані при розробленні технологій збитої десертної продукції

Ключові слова: харчова добавка “Магнетофуд”, збиті десерти, стабілізуючі і структуроутворюючі властивості

FORMING THE STRUCTURE OF WHIPPED DESSERTS WHEN INTRODUCING THE FOOD ADDITIVE "MAGNETOFOOD" TO THEIR FORMULATION

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1. Introduction

At present, among a wide range of food products in special demand by consumers are whipped dessert products: mousses, fruit-and-egg white jellies, smoothies, etc. [1].

Development of technologies for whipped dessert products that contain voids in the form of gas bubbles is considered in the West today to be the most relevant because of the inexhaustible and a low-cost resource of “emptiness” [2, 3].

However, the demand for whipped dessert products has not been fully satisfied. Obviously, this relates to that whipped desserts have short shelf-life, complex and laborious production technology that predetermines inconsistent quality and hinders the expansion of their range [1, 4].

The rapid growth in demand for whipped dessert products necessitates the improvement of their structural-mechanical, functional and technological properties, as well as prolonging their shelf life.

One should take into consideration that the structural and mechanical properties of whipped desserts (foam-forming capacity, foam stability, dispersity, porosity, and foam density) characterize the quality of whipped desserts and are taken into account by consumer when choosing from a wide range of products.

To form the stable foamy structure of whipped desserts, their formulations must be supplemented with substances that have the surface-active properties: food emulsifiers, foam-forming agents, and foam stabilizers [1, 3]. An analysis of the food market reveals that at present the formation and stabilization of whipped dessert products utilize both food additives and raw materials of animal and plant origin. Currently, there are not enough new substances that are used for foaming and stabilizing foam structures of whipped desserts. This relates to the difficulty of finding new kinds of structure-forming agents and stabilizers that possess the required properties; a significant share of costly ingredients, etc. [1, 3, 5, 6].

To form and stabilize the foamy structure of the protein-carbohydrate system of whipped desserts, specifically berry-fruit mousses and fruit-and-egg white jellies, it is possible to propose the food additive “Magnetofood”. “Magnetofood” is a food additive, which is an ultra-thin powder of ferrum oxides $\text{FeO}\cdot\text{Fe}_2\text{O}_3$, with particles the size of ~ 80 nm. The capability of nanoparticles from “Magnetofood” to form the structure and create spatial structures with proteins, carbohydrates is determined, basically, by the electrostatic – dipole-dipole (van der Waals) and ion-dipole interactions. The formation of supramolecular ensembles with biopolymers also involves the donor-acceptor (co-ordination) interactions. They occur between the surface of nanoparticles and the molecules of proteins, carbohydrates in the food systems that are adsorbed. At the surface of a nanoparticle (NP) from the additive “Magnetofood” (Fe_3O_4) are the oppositely polarized sections ($^{+\delta}\text{Fe}$) and ($^{-\delta}\text{O}$). The structure-forming ions in the food additive “Magnetofood” are the ferrum cations Fe^{2+} and Fe^{3+} . The high tension of the electric field generated by the ions of ferrum from the nanoparticles of the additive enhances the polarization of molecules in the compounds of food systems, which contributes to their additional ordering outside the surface of the particles, as well as adsorption [7–9].

Nanoparticles in the food additive “Magnetofood” have the high energy and chemical potential and the bio-affinity to biopolymers, specifically proteins, carbohydrates, and are characterized by new functional and technological properties: structure-forming, stabilizing, emulsifying, water-binding, water-retaining. Thus, the food additive “Magnetofood” can affect the processes of structure formation and foaming during production of whipped desserts, as well as the quality indicators of finished products. However, these data are missing and thus additional research is needed. Therefore, it is a relevant task to study the influence of the food additive “Magnetofood” on the structural and mechanical properties of whipped dessert products, specifically berry-fruit mousses and fruit-and-egg white jellies.

2. Literature review and problem statement

The technology of whipped dessert products, specifically mousses and fruit-and-egg white jellies, involves a large number of food additives. Some of them are the chemically pure substances, while some raw materials are of animal and plant

origin. This affects the quality and cost of the finished dessert. Numerous studies have been conducted recently aimed at finding new foam- and structure-forming agents and stabilizing components with low cost. They could improve the functional and technological, structural-mechanical, physical-chemical, and organoleptic indicators of whipped dessert products. In addition, there has been an active search to partially or completely replace traditional foam- and structure-forming agents, in particular, gelatin, egg and dairy products. For example, gelatin is a foam- and structure-forming agent of protein nature, whose disadvantages include a specific smell and taste, low melting point and the considerable time required for the formation of gel. The main disadvantages of egg protein are associated with the risk of microbial infection, high allergenicity, as well as the insufficient stability and multiplicity of produced foam [6, 10, 11].

To improve the properties of foam structures in whipped desserts, researchers increasingly recommend using various foam-forming agents of protein nature. In particular, whey protein gels, in order to stabilize foam [12]; hydrophobic proteins – as new functional ingredients that possess the high foam-forming and stabilizing capacities [13]. In addition, complex protein micelles of surfactant with casein atom are used. They produce the high stabilizing and structuring effect [14]. High foam-forming, emulsifying, and stabilizing effect is demonstrated by protein complexes of casein and whey proteins with polysaccharides (cellulose, ethyl cellulose, hydrophobic-modified starch granules) [15]. Complexes of fish gelatin (FG) with alginate (AL) contribute to the improvement of foaming and foam stability of whipped desserts [16]. However, the issue on improvement the dispersity of foam structures remains unresolved.

To enhance the stability of food foams of protein nature, stabilizers are typically introduced – the additives of polysaccharide nature. Using these substances makes it possible to obtain a foamy structure with the predefined functional and technological properties. Thus, to improve plastic strength, as well as the consistency and texture of whipped desserts, a variety of hydrogels are used. The properties of thickeners, stabilizers, and structure-forming agents are demonstrated by gum tar, guar gum, caraway gum, xanthan gum [17], xanthan, carrageenan and its sodium, potassium, ammonium salts, including furcellaran and others [18–20]. However, these structure-forming components are rather costly.

Some scientists suggest the combined systems of structure-forming agents for adjusting the structural-mechanical properties of foam structures, in particular a combination of gelatin and pectin, with sulfated polysaccharides; gelatin – k-carrageenan, gelatin-LM pectin [18]. To improve the foam-forming capacity and to increase the stability of egg protein, some researchers suggest polyvalent cations, including aluminum, copper, iron, zinc, due to their capability to interact with the ovotransferrin of protein [21, 22]. Successfully used are trisodium phosphate, pyrophosphate, hexametaphosphate and other sodium phosphates to enhance the foam-forming capacity of egg protein [23]. However, the problem on stability of foamy structure has not been solved up to now.

In order to enhance the capability of foaming by egg protein, it is supplemented with a variety of vegetable and fruit-berry purees, such as purée from feijoa, kiwi, Jerusalem artichoke, etc. [24, 25]. However, stability of the foamy structure was not enough while the foam-forming capacity of the system decreased at a simultaneous significant decrease in its viscosity.

Now, in order to increase the stability of foam structures, they widely use binary mixtures of biopolymers composed of protein and one polysaccharide (β -lactoglobulin+Arabian gum, β -lactoglobulin+pullulan, whey protein isolate+Arabian gum, egg protein albumin+pectin, etc.) [26, 27]. Recently used are the protein-containing structure-forming additives derived from cereals (oats, barley, soybean) [28, 29], as well as structure-forming agents and stabilizers of plant origin: medicinal and aromatic herbs in the form of powders or extracts, vegetable and fruit and berry powders [30]. However, they do not provide for sufficient porosity and dispersity.

To adjust the structurally-mechanical properties of foam structures, technologists have started using biological stabilizers [31] and nano-additives (particles of modified silica) [32].

An analysis of information sources [1, 10–32] reveals the lack of data about technologies of whipped desserts using nanopowdered mineral additives that have foam- and structure-forming stabilizing properties; improve the structural-mechanical properties of foam structures, quality indicators, and prolong shelf life of whipped desserts. We have designed and proposed the food additive “Magnetofood” as an improving additive to food systems. In food systems, “Magnetofood” demonstrates the antioxidant, sorption, bacteriostatic, complex-forming, emulsifying, moisture-retaining, moisture-binding, stabilizing, and structure-forming properties [7–9].

Given this, it is of scientific and practical interest to study the structural and mechanical properties of whipped desserts, specifically mousses and fruit-and-egg white jellies when introducing the food additive “Magnetofood” to their formulation.

Thus, despite the numerous studies in the field of technology for whipped dessert products, there are the unresolved issues related to the formation of structure of whipped desserts. The reason for this is the insufficient number of structure-forming agents and their high cost. Using domestic mineral structure-forming agents that have low cost, specifically the food additive “Magnetofood”, appears promising. The functional and technological properties of the food additive “Magnetofood” allow us to argue that it is expedient to conduct a study that addresses the formation of structure of whipped desserts under the influence of nanoparticles from the additive “Magnetofood”.

3. The aim and objectives of the study

The aim of this study is to improve the structure of whipped desserts by introducing the food additive “Magnetofood” to the formulation composition.

To accomplish the aim, the following tasks have been set:

– to study the effect of the food additive “Magnetofood” on the foam-forming capacity and foam stability of

the examined samples of mousses and fruit-and-egg white jellies;

– to investigate the impact of the food additive “Magnetofood” on strength and effective viscosity, dispersity, porosity, and density of the examined samples of mousses and fruit-and-egg white jellies;

– to establish a rational mass share of the food additive “Magnetofood” in the formulations of the berry-fruit mousse “Malynka” and the fruit-and-egg white jelly “Yahydka”.

4. Materials and methods to study the food additive “Magnetofood”

4.1. Examined material and equipment used in the experiment

We have examined the effect of the food additive “Magnetofood” on foam-forming capacity, foam stability, dispersity, porosity, foam density of berry-fruit mousses and fruit-and-egg white jellies.

The object of study: technology of berry-fruit mousses and fruit-and-egg white jellies using the additive “Magnetofood”.

The subjects of research: model samples of berry-fruit mousses and fruit-and-egg white jellies containing the additive “Magnetofood”; control basic formulations of mousse “Cranberry” No. 898 and fruit-and-egg white jelly “Apple or Plum” No. 904 [33], given in Table 1. It should be noted that the selection of control samples was based on standard documentation, and the formulation composition of the developed aerated desserts was elaborated according to the functional and technological properties of foam systems: foam-forming capacity, foam stability, dispersity, porosity, density, effective viscosity.

Table 1

Formulations of berry-fruit: mousse “Cranberry” and fruit-and-egg white jelly “Apple or Plum” (control) and mousse “Malynka” and fruit-and-egg white jelly “Yahydka” with different mass fraction

Name of raw material	Consumption of raw materials per 100 g of finished product, g (gross weight)							
	samples of mousse “Malynka”				samples of fruit-and-egg white jelly “Yahydka”			
	No. 1 control	No. 2	No. 3	No. 4	No. 5 control	No. 6	No. 7	No. 8
Raspberry	–	13.15	13.15	13.15	–	–	–	–
Strawberry	–	–	–	–	–	39.75	39.75	39.75
Black current	–	3.29	3.29	3.29	–	9.94	9.94	9.94
Cranberry	26.3	2.63	2.63	2.63	–	–	–	–
* Apple	–	7.23	7.23	7.23	79.5	21.86	21.86	21.86
* Plum	–	–	–	–	72.2	7.95	7.95	7.95
Powder sugar	20.0	20	20	20	20.0	20.0	20.0	20.0
Eggs (whites)	–	–	–	–	4.8 (2 eggs)	4.8 (2 eggs)	4.8 (2 eggs)	4.8 (2 eggs)
Gelatin	2.7	2.6	2.55	2.5	1.5	1.4	1.35	1.3
Water	65.0	65.0	65.0	65.0	42.0	42.0	42.0	42.0
Food additive “Magnetofood”	–	0.10	0.15	0.20	–	0.10	0.15	0.20

Note: * – the formulation composition of the fruit-and-egg white jelly “Apple or Plum” (control) contains: either 79.5 g of apple or 72.2 g of plum. The formulation composition of the fruit-and-egg white jelly “Yahydka” (samples 6–8) contains: both apple and plum. In addition, it should be noted that the loss of mass by the finished product occurs through the evaporation of water at thermal treatment (specifically swelling and dissolution of gelatin when obtaining the semi-finished product “Solution of gelatin with the food additive “Magnetofood”)

We prepared the samples of mousse and fruit-and-egg white jellies according to the conventional technology of mousses and fruit-and-egg white jellies according to the classic formulation [33], given in Table 1.

The examined materials, equipment, as well as techniques used in the experiment, are described in more detail in paper [34].

We evaluated the research results and processed them statistically using modern methods of calculating the statistical reliability of measurement results ($n=5, p \leq 0.05$) employing the software packages Microsoft Office Excel 2010, Statistic 6.0, and MathCAD 14.

5. Results of studying the indicators for whipped desserts

5.1. Investigating the influence of the food additive “Magnetofood” on foam-forming capacity and foam stability of the examined samples of mousses and fruit-and-egg white jellies

In assessing the quality of desserts, it is necessary to establish their structural-mechanical properties, which in many respects affects a positive perception of a food product by consumer. For mousses and fruit-and-egg white jellies, basic structural-mechanical properties are consistency and texture. Consistency is the degree of density. Texture is in turn a physical-structural property of a product, perceived by the organs of vision and touch, leading to a certain feeling when a person consumes it (biting, chewing, swallowing) [35, 36].

Therefore, to determine technological parameters and production modes for the berry-fruit whipped desserts: mousse “Malynka” and fruit-and-egg white jelly “Yahydka”, we investigated the effect of the food additive “Magnetofood” on density and foam stability of the examined samples of mousses and fruit-and-egg white jellies.

Fig. 1 shows the foam-forming capacity of the examined samples of berry-fruit whipped desserts: mousses and fruit-and-egg white jellies, respectively, when introducing the food additive “Magnetofood” to the formulation compared with control.

One can see from Fig. 1, *a, b*, which shows the dependence of duration of whipping on foam-forming capacity of the examined samples of whipped desserts, introducing the additive “Magnetofood” in the amount of (0.10–0.15) % of the formulation composition improves the foam-forming capacity of whipped desserts, on average, by (40 ± 2) % for mousses and by (55 ± 3) % for fruit-and-egg white jellies.

We investigated foam stability (FS) of the examined samples of berry-fruit whipped desserts when introducing the food additive “Magnetofood”, shown in Fig. 2.

The results obtained (Fig. 2, *a, b*) indicate the high stability of the examined samples of whipped desserts with gelatin (mousses) and with a composition of gelatin and egg protein (fruit-and-egg white jellies) and with the use of the food additive “Magnetofood”. This relates to that the surface-active nanoparticles from the additives “Magnetofood” contribute to the density of berry-fruit desserts and stabilize their foamy structure. The effect is accomplished by forming a stable spatial frame as a result of magnetofood-protein-carbohydrate complex formation (using molecular and intermolecular bonds). In addition, it is accomplished by redistributing moisture based on the kind of bonds and changes in the spatial bonding of water in the system (owing to the high water-binding and water-retaining capacity of particles from the additive “Magnetofood”) [8, 9].

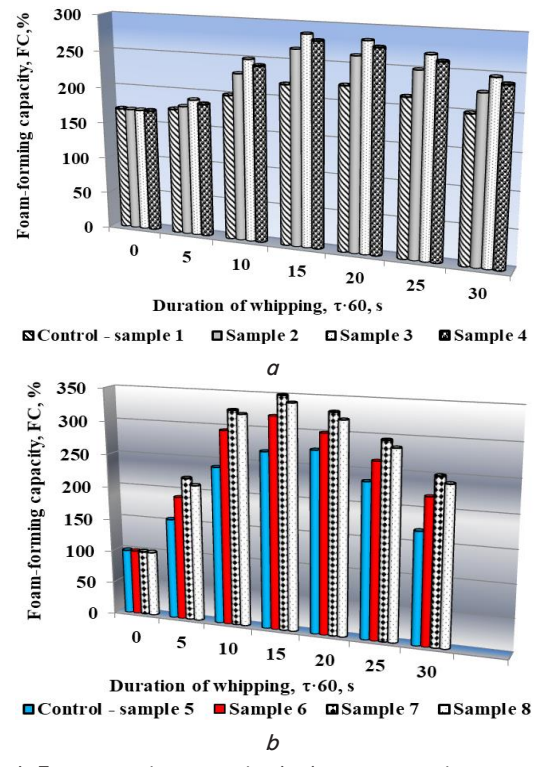


Fig. 1. Foam-forming capacity (pp) of the examined samples of berry-fruit whipped desserts, when introducing the food additive “Magnetofood” to the formulation, compared with control: *a* – for mousse (foam-forming agent – 5 % solution of gelatin); *b* – for fruit-and-egg white jelly (binary foam-forming agent – 5 % solution of gelatin:egg white =3:1)

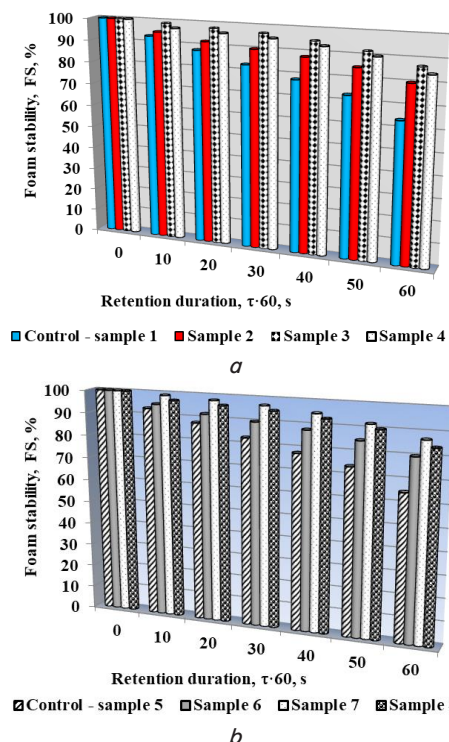


Fig. 2. Foam stability (FS) of the examined samples of berry-fruit whipped desserts when introducing the food additive “Magnetofood” to the formulation: *a* – for mousse (foam-forming agent – 5 % solution of gelatin); *b* – for fruit-and-egg white jelly (binary foam-forming agent – 5 % solution of gelatin:egg white =3:1)

Thus, one can say that it is expedient, when designing new whipped products, to use food compositions based on a berry-fruit puree with the addition of the food additive “Magnetofood”, which makes it possible to obtain rich foam, gentle mass, and provides for its stability.

5.2. Studying the influence of the food additive “Magnetofood” on structural-mechanical properties of whipped desserts

Studying the structural-mechanical indicators, in particular plastic strength (Fig. 3) and effective viscosity (Fig. 4, 5), of whipped desserts, containing nanoparticles from the food additive “Magnetofood”, over the rated storing period (24 hours), also confirms this hypothesis and data from previous studies into the density and stability of foam systems of whipped desserts using a nano additive.

Experimental research (Fig. 3, *a, b*) has proven that the use of the food additive “Magnetofood” strengthens the structure of the foam systems of mousse “Malynka” and fruit-and-egg white jelly “Yahydka” – by 1.23 times as compared with control samples.

Fig. 4, 5 show results from studying the effective viscosity of samples of mousse (Fig. 4) and fruit-and-egg white jellies (Fig. 5). The study was carried out in the range of shear rates from 1.8 s^{-1} to 25.0 s^{-1} . Shelf life of the examined samples: 1 h, 12 h, 24 h, at a temperature of $(2-4)^\circ\text{C}$.

An analysis of data from Fig. 4 shows that when stored over 24 hours, the viscosity of mousse samples (at a shear rate of 1.8 s^{-1}) increases by $(4.4 \pm 0.2) \%$ – in the samples with the addition of “Magnetofood”, and by $(2.7 \pm 0.1) \%$ – in the control sample (without the additive “Magnetofood”).

Experimental data from Fig. 5 show that, when stored for 24 hours, viscosity of the samples of fruit-and-egg white jellies (at a shear rate of 1.8 s^{-1}) increases by $(4.1 \pm 0.2) \%$ – in samples with the addition of “Magnetofood” and by $(2.5 \pm 0.1) \%$ – in the control sample (without the addition of “Magnetofood”).

Taking into consideration that during the storage of the examined samples of mousse and fruit-and-egg white jelly we have created conditions to prevent the evaporation of moisture, the increase in viscosity can be explained as follows. The samples of whipped berry-fruit desserts during storage under the influence of the nanoparticles from the food additive “Magnetofood”, owing to molecular and intermolecular bonds (magnetofood-protein-carbohydrate complex-formation) undergo the formation, stabilization, and a gradual strengthening of the spatial frame [9].

An important aspect of foods with a foamy structure is the dispersity of the foam, which provides for the required stability of food texture over time. In accordance with theoretical positions, the smaller the particles, the greater the dispersity. Foam-like systems, which include whipped desserts, are characterized by the size and concentration of the air fraction. We have studied and identified the size and number of air bubbles. We have determined the normalized distribution function of air bubbles for the diameter and specific share of bubbles of each size. Results from a microscopic study are shown in Fig. 6.

The microphotographs show (Fig. 6) that in these microstructures the air bubbles are identified in the form of ideally spherical shapes distributed for volume. Moreover, introducing the food additive “Magnetofood” contributes to the formation of smaller air bubbles and their more uniform distribution throughout the entire volume of the whipped mass (samples 3 and 7, Fig. 6, *b, d*) compared with control (samples 1 and 5, Fig. 6, *a* and *c*). We determined the size and number of air bubbles. We quantified the surface areas of air bubbles relative to the surface of the examined system. Results of air bubbles distribution for diameter are shown in Fig. 7 and given in Table 2.

Fig. 7 shows that the maximum number of air bubbles has a diameter of $d=(0.2 \pm 0.01) \text{ mm}$ and is: 27 pieces for mousse “Malynka” and 21 pieces for fruit-and-egg white jelly “Yahydka” (out of 45 pieces). Specific density of the particles is 25·106 pieces for mousse “Malynka” and 19·98 pieces for fruit-and-egg white jelly “Yahydka” per 1 m^2 of the examined plane. One can also see that the introduction of the food additive “Magnetofood” contributes to a narrower distribution of air bubbles for diameter compared with control samples.

Data from Table 2 show that whipped desserts with the use of the food additive “Magnetofood” have a greater dispersity compared with control samples.

Studying the dispersity has established (Table 2) that the foamy structure of whipped desserts with the addition of the food additive “Magnetofood” has the medium size of air bubbles (a diameter of 0.1–0.3 mm), and the specific number of bubbles per 1 mm^2 of the examined plane changes toward the smaller bubbles (Fig. 6 and Fig. 7).

That is, we can conclude that whipped desserts (mousse “Malynka” and fruit-and-egg white jelly “Yahydka”) with the addition of the food additive “Magnetofood”, while having a greater dispersity, is more resistant to destruction.

Other important indicators that characterize the structure of whipped desserts are density and porosity (Table 3).

Table 2

Distribution of air in fraction in the examined samples of mousses and fruit-and-egg white jellies

Model system	Distribution of bubbles (%) for size 10^{-3} m						Total, %
	0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	1.0–1.1	
Mousse “Cranberry” (control)	36.3	24.2	39.5	0.0	0.0	0.0	100.0
Mousse “Malynka” (sample 3)	26.2	69.0	4.8	0.0	0.0	0.0	100.0
Fruit-and-egg white jelly “Apple”	13.0	15.6	12.1	9.0	20.2	30.1	100
Fruit-and-egg white jelly “Yahydka” (sample 7)	9.3	45.7	15.4	17.6	12.0	0.0	100

Table 3

Density and porosity of the examined samples of whipped dessert: mousses and fruit-and-egg white jellies ($n=3, p \leq 0.05$)

Indicator name	Examined samples of whipped desserts							
	Examined samples of mousse				Examined samples of fruit-and-egg white jelly			
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Density, kg/m^3	610±2	585±2	580±2	578±2	630±2	595±2	590±2	588±2
Porosity, %	44±0.5	57±0.5	59±0.5	60±0.5	41±0.5	53±0.5	55±0.5	56±0.5

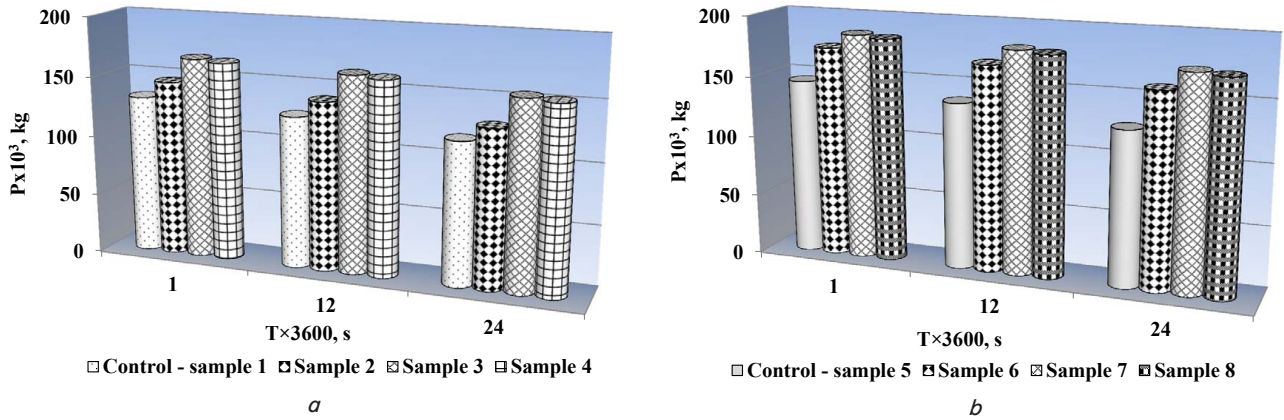


Fig. 3. Strength diagrams of the examined samples of whipped desserts, when introducing the food additive “Magnetofood” to the system, over the rated storage duration at a temperature of (2–4) °C: *a* – for mousse (foam-forming agent – 5 % solution of gelatin); *b* – for fruit-and-egg white jelly (binary foam-forming agent – 5 % solution of gelatin:egg white =3:1)

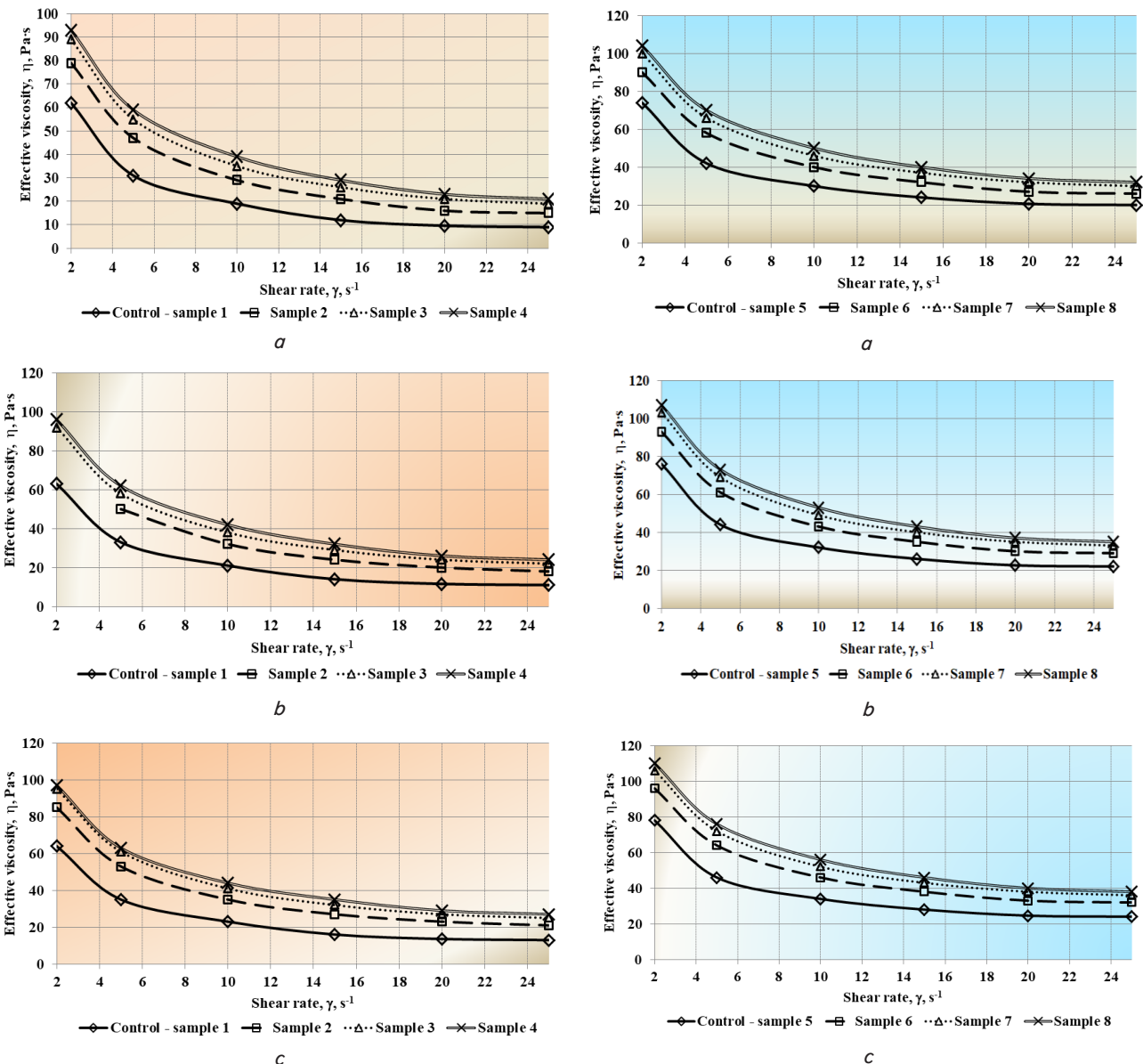


Fig. 4. Effective viscosity in the range of shear rate (1.8–25.0) s^{-1} of the examined samples of mousse “Malynka” that were stored at a temperature of (2–4) °C over: *a* – 1 hour; *b* – 12 hours; *c* – 24 hours

Fig. 5. Effective viscosity in the range of shear rate (1.8–25.0) s^{-1} of the examined samples of fruit-and-egg white jelly “Yahydka” that were stored at a temperature of (2–4) °C over: *a* – 1 hour; *b* – 12 hours; *c* – 24 hours

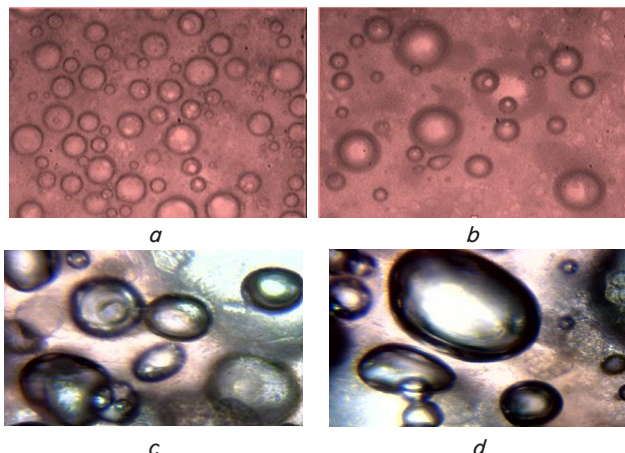


Fig. 6. Microphotographs of the examined samples of whipped desserts: *a* – sample 3 (mousse “Malynka”) – with the additive “Magnetofood”; *b* – sample 1 – mousse without the additive “Magnetofood”; *c* – sample 7 (fruit-and-egg white jelly “Yahydka”) – with the additive “Magnetofood”; *d* – sample 5 – fruit-and-egg white jelly without the additive “Magnetofood”

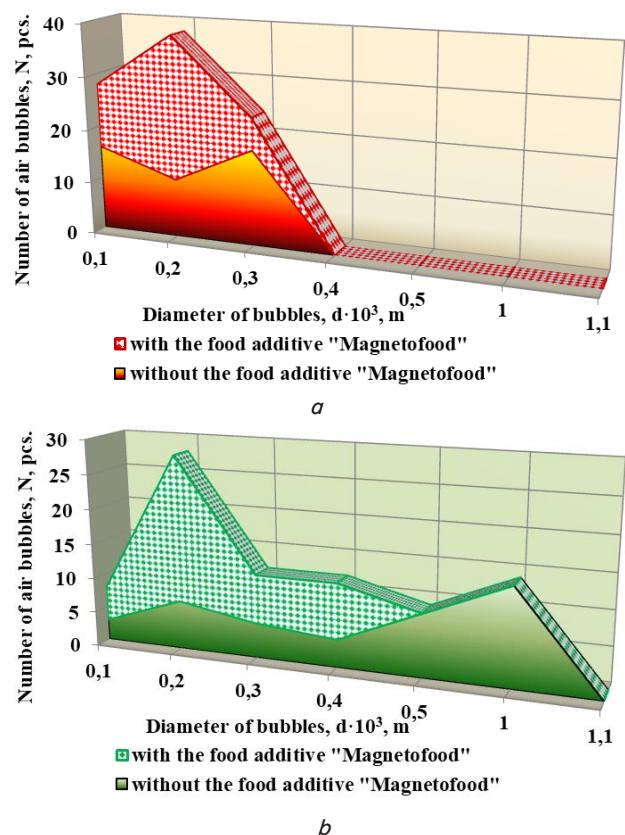


Fig. 7. Distribution of air bubbles for diameter in the examined samples of whipped desserts: *a* – sample 3 (mousse “Malynka”) with the additive “Magnetofood”) and control – sample 1 (mousse “Malynka”) without the additive “Magnetofood”); *b* – sample 7 (fruit-and-egg white jelly “Yahydka”) with the additive “Magnetofood”) and control – sample 5 (fruit-and-egg white jelly “Yahydka”) without the additive “Magnetofood”)

An analysis of experimental data (Table 3) reveals that the introduction of the food additive “Magnetofood” in the amount of (0.10; 0.15; 0.20) % of the formulation composition helps reduce the magnitude of density for the

samples of whipped desserts by $(29 \pm 1) \text{ kg/m}^3$ for mousse, by $(26 \pm 2) \text{ kg/m}^3$ for fruit-and-egg white jelly when compared with control samples. In addition, it increases porosity of the whipped desserts by $(14.3 \pm 0.7) \%$ for mousse, by $(12.7 \pm 0.6) \%$ for fruit-and-egg white jelly when compared with control samples.

5.3. Establishing the rational mass fraction of the food additive “Magnetofood” in formulations for berry-fruit mousses and fruit-and-egg white jellies

Based on the conducted experimental study, we have found the rational amount of the food additive “Magnetofood”, which is 0.15 % by weight of the formulation composition.

Fig. 8 shows the diagrams of formulation composition of mousse “Malynka” and fruit-and-egg white jelly “Yahydka”.

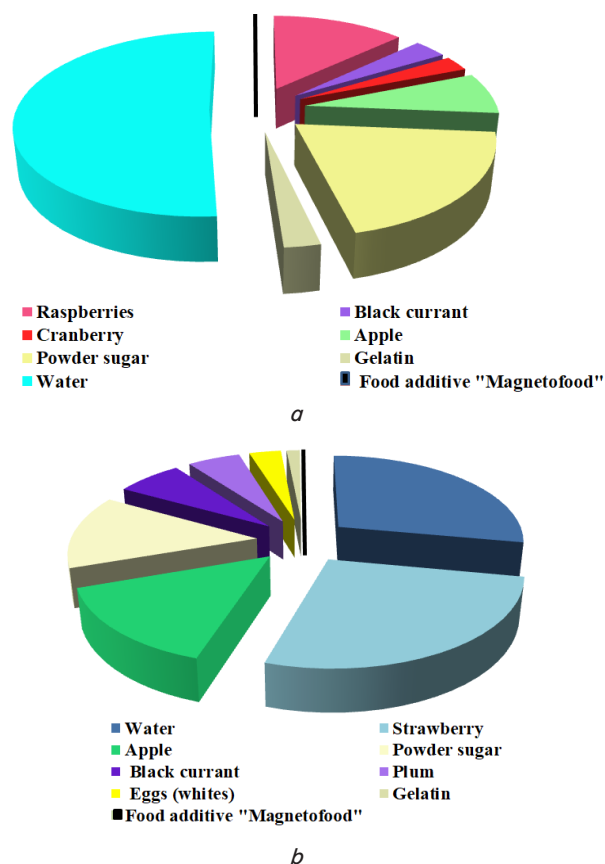


Fig. 8. Diagrams of formulation composition of berry-fruit whipped desserts with the rational amount of the food additive “Magnetofood” – 0.15 % of the formulation mixture: *a* – mousse “Malynka”; *b* – fruit-and-egg white jelly “Yahydka” “Magnetofood”

Our study has proven and substantiated forming the structural-mechanical properties of whipped desserts when introducing the food additive “Magnetofood” to their formulation.

6. Discussion of results of studying the influence of the food additive “Magnetofood” on the structural-mechanical properties of whipped desserts

The reported experimental data (Fig. 1, *a, b*) allow us to state that the highest foam-forming capacity (FC) is demonstrated by the samples of whipped desserts (mouss-

es and fruit-and-egg white jellies) containing the food additive “Magnetofood” in the amount of 0.15 % of the formulation mixture, whose FC is (290 ± 5) % – for mousse “Malyinka” and (350 ± 6) % for fruit-and-egg white jelly “Yahydka” at the duration of whipping of (17 ± 1) minutes. In the control samples, the highest value for FC is (224 ± 4) % for mousse, and (275 ± 5) % – for fruit-and-egg white jelly at the duration of whipping of 20 minutes. That is, introducing the food additive “Magnetofood” reduces the duration of whipping by 3 minutes. Other examined samples of whipped desserts containing the food additive “Magnetofood” in the amount of (0.10 and 0.20) % of the formulation composition demonstrate slightly lower values for indicators (respectively, (267 ± 5) % and (279 ± 5) % – for mousse “Malyinka” and (320 ± 6) % and (340 ± 5) % for fruit-and-egg white jelly “Apple”); the minimum values for indicators are demonstrated by control samples, which are (224 ± 4) % for mousse “Cranberry” and (275 ± 5) % for fruit-and-egg white jelly “Apple or Plum”.

An analysis of influence of the food additive “Magnetofood” in the amount of (0.10; 0.15; 0.20) % of the formulation composition on the foam stability (FS) of whipped desserts (Fig. 2) reveals that almost all samples provide for the 100 % stability of foam over 5 minutes. The best indicator is demonstrated by the samples of whipped desserts containing the food additive “Magnetofood” in the amount of 0.15 % of the formulation mixture. In this case, FS of these samples decreases: by (13.0 ± 0.6) % – for mousse “Malyinka” and by (11.0 ± 0.5) % – for fruit-and-egg white jelly “Yahydka” at storage duration of 60 minutes. Other examined samples of whipped desserts containing the food additive “Magnetofood” in the amount of (0.10 and 0.20) % demonstrate a somewhat worse decrease in the values for indicators: a decrease in FS over 60 minutes of storage is, accordingly, (20.0 ± 0.9) % and (16.0 ± 0.6) % – for mousse “Malyinka” and (18.0 ± 0.8) % and (13.0 ± 0.5) % – for fruit-and-egg white jelly “Apple”). The maximum decrease in the values for FS is demonstrated by control samples, which are (36 ± 2) % – for mousse “Cranberry” and (35 ± 2) % for fruit-and-egg white jelly “Apple or Plum”. Thus, applying the food additive “Magnetofood” increases the density of mousses and fruit-and-egg white jellies (Fig. 1) and stability of whipped desserts (Fig. 2). The research results prove that the hypothesis on stabilizing the structure of whipped desserts by using the food additive “Magnetofood” is predetermined by its moisture-retaining properties. In addition, nanoparticles from the additive “Magnetofood” with a large specific surface act as surface-active centers [8, 9]. However, introducing the food additive “Magnetofood” at around 0.2 % and above to the system inhibits the rise of foam and accelerates coalescence (viscosity and density of the system increases while density of the berry-fruit base decreases).

An analysis of influence of the food additive “Magnetofood” in the amount of (0.10; 0.15; 0.20) % of the formulation composition on strength of the examined samples of mousses and fruit-and-egg white jellies (Fig. 3) reveals the following. When storing whipped desserts at a temperature of $(2-4)$ °C for (1; 12; 24) hours, mechanical strength of their structure slightly increases, on average: by 1.21; 1.23; 1.24 times in mousse “Malyinka”, and by 1.25; 1.29; 1.33 times in fruit-and-egg white jelly “Yahydka” when compared with control. The results of our research are the basis for reducing the content of gelatin in the formulation mixture of whipped desserts: in mousse “Malyinka”, com-

pared with control, 2.55 % instead of 2.7 %; in fruit-and-egg white jelly “Yahydka”, compared with control, 1.35 % instead of 1.5 %.

Rheological curves of the examined samples of mousses and fruit-and-egg white jellies (Fig. 4, 5) testify to their pseudoplasticity, as an increase in the gradient of shear rate decreases their viscosity. At low shear rates, whipped desserts have fluidity and a capability to recover. An increase in deformation rate in the range $(1.8-8.1)$ s⁻¹ leads to a decrease in viscosity, probably due to the deformation of globular air bubbles into ellipsoid ones [1, 18]. At a shear rate exceeding 8.1 s⁻¹ the intensity of the decrease in viscosity of whipped desserts is relatively small. That is, viscosity almost ceases to depend on shear rate. These areas are characterized by a gradually growing number of collapsed air bubbles. Horizontal sections of the curves correspond to the viscosity of the examined samples of whipped desserts with a completely ruined structure [1]. It should be noted that introducing the food additive “Magnetofood” to the formulation composition in the amount of (0.10; 0.15; 0.20) % if the formulation mixture contributes to an increase in effective viscosity of the samples of berry-fruit mousses and fruit-and-egg white jellies on average by (32 ± 2) Pa·s both for mousse and fruit-and-egg white jelly. The increase in viscosity is due to the structuring action of nanoparticles from the additive “Magnetofood” [8]. This leads to the aggregation of gelatin, the result being a growing stability of foam films. Enhancing the gelatinizing capacity of gelatin makes it possible to increase viscosity in the Gibbs-Plateau channels, which slows down the process of syneresis [1, 18]. In addition, under the influence of the “Magnetofood” nanoparticles the egg white is structured (in the composition of fruit-and-egg white jelly), increasing the stability of a whipped berry-fruit dessert to mechanical impact [9].

A microscopic analysis of the examined samples of mousses and fruit-and-egg white jellies (Fig. 6) shows that introducing the food additive “Magnetofood” in the amount of (0.10; 0.15; 0.20) % of the formulation composition increases the dispersity of whipped desserts. That also promotes a narrower distribution of air bubbles for diameter compared with control samples (Fig. 7 and Table 2). Thus, mousse “Malyinka” that contains the additive “Magnetofood” in the amount of 0.15 % by weight of the formulation mixture includes 26.2 % of bubbles the size of up to 0.1 mm; 69.0 % – (0.1–0.2) mm; 4.8 % – (0.2–0.3) mm. The bubbles in a given whipped dessert account for 36.7 % of the total volume, which corresponds to the area of 1.59 mm² of the total 4.3 mm². When compared, the control sample – mousse “Cranberry” – has a somewhat smaller dispersity. Thus, the total area, occupied by the bubbles, is 1.85 mm², which is 42.9 %; out of them, 36.3 % account for bubbles the size of up to 0.1 mm, 24.2 % – 0.1–0.2 mm, 39.5 % – 0.2–0.3 mm. The fruit-and-egg white jelly demonstrates similar dynamics. The composition of fruit-and-egg white jelly “Yahydka” that contains the additive “Magnetofood” in the amount of 0.15 % by the weight of the formulation mixture includes 9.3 % of bubbles the size of up to 0.1 mm; 45.7 % – (0.1–0.2) mm; 15.4 % – (0.2–0.3) mm; 17.6 % – (0.3–0.4) mm; 12.0 % – (0.4–0.5) mm. The bubbles in a given whipped dessert take up 39.4 % of the total volume. This corresponds to the area of 1.69 mm² of the total 4.3 mm². When compared, the control sample – fruit-and-egg white jelly “Apple” – has a somewhat smaller dispersity. Thus, the total area, occupied by the bubbles, is 1.89 mm², equal to 43.9 %; out of them, 13.0 %

bubbles are the size of up to 0.1 mm, 15.6 % – (0.1–0.2) mm; 12.1 % – (0.2–0.3) mm; 9.0 % – (0.3–0.4) mm; 20.2 % – (0.4–0.5) mm; 30.1 % – (1.0–1.1) mm. This manifests itself more vividly in the samples of fruit-and-egg white jellies using egg protein and gelatin, rather than just gelatin only (mousses). In mousse “Cranberry” (control), the fraction of bubbles the size of (0–0.2) mm makes up (60.5±3.1) % of the examined plane. Whereas for mousse “Malynka” with the addition of the food additive “Magnetofood” in the rational amount of 0.15 % by weight of the formulation mixture, this makes up (95.2±4.7) % of the examined plane. In fruit-and-egg white jelly “Apple” (control), the fraction of bubbles the size of (1.0–1.1) mm makes up (30.1±1.5) % of the examined plane. Whereas for fruit-and-egg white jelly “Yahydka” we observed the distribution of air fraction for size within (0.1–0.5) mm.

Summarizing the data on stability of the samples of whipped desserts and distribution of air bubbles for diameter, one can note that the functionality of the food additive “Magnetofood” affects in this case primarily the reduction in surface tension. Destruction of the foamy structure of mousses and fruit-and-egg white jellies is due to the processes of air diffusion, fluid flowing from the walls of the bubbles (fluid viscosity), and enlargement of bubbles through mergers. A rather narrow peak at $r=(0.2\pm 0.01)$ mm for examined samples of mousse “Malynka” and fruit-and-egg white jelly “Yahydka” with the addition of “Magnetofood” points to a uniform density of berry-fruit desserts. However, given the higher viscosity and lower magnitude for the surface tension, foam stability in these examined samples with the food additive “Magnetofood” is higher.

Thus, introducing the food additive “Magnetofood” in the amount of 0.15 % by weight of the formulation mixture stabilizes the foamy structure of whipped desserts, including over the terms of storage established by standards.

It follows from the experimental data (Table 3) that the introduction of the food additive “Magnetofood” in the amount of (0.10; 0.15; 0.20) % of the formulation composition contributes to:

- a decrease in the magnitude of density of the samples of whipped desserts compared with control samples: by (29±1) kg/m³ for mousses, by (26±1) kg/m³ for fruit-and-egg white jellies. That can be explained as follows: the surface-active nanoparticles from “Magnetofood” have complex-forming and structure-forming properties. Therefore, they contribute to branching the basic chains of macromolecules of protein-containing ingredients (specifically, gelatin, egg protein) in dispersive medium. In this case, by slowing down the process of fluid outflow and by thinning the walls of the air bubbles. The result is that the density of the examined samples of whipped desserts is reduced compared with control samples;

- an increase in the porosity of whipped desserts compared with control samples: by (14.3±0.7) % for mousses, by (12.7±0.6) % for fruit-and-egg white jellies. This gives desserts a light and delicate whipped structure. This relates to the formation and stabilization of the spatial frame as a result of magnetofood-protein-carbohydrate complex

formation (using molecular and intermolecular bonds). As well as by high water-binding and water-retaining capacity of nanoparticles from the additive “Magnetofood”. All this contributes to the redistribution of moisture for the forms of bonds and changes in the spatial binding of water in the system [8, 9].

Our study into dispersity, density, and porosity of mousse “Malynka” and fruit-and-egg white jelly “Malynka” using the food additive “Magnetofood” has demonstrated that the examined whipped desserts possess high dispersity and density. That prevents the rapid destruction at a larger number of pores. In addition, the greater porosity provides whipped desserts with foamy and delicate consistency.

We have also established experimentally that the rational amount of the food additive “Magnetofood” is 0.15 % of the formulation composition, which is demonstrated in detail at the diagrams of whipped desserts’ formulations: mousse “Malynka” and fruit-and-egg white jelly “Yahydka” (Fig. 8).

The results obtained give grounds to recommend the food additive “Magnetofood” as a stabilizer, structure-forming agent and improver for food aerated structures.

7. Conclusions

1. It was established that the addition of the food additive “Magnetofood” in the amount of (0.10; 0.15; 0.20) % of the formulation composition:

- improves the foam-forming capacity on average: by (40±2) % for mousses and by (55±3) % for fruit-and-egg white jellies compared with control;
- reduces the whipping duration of desserts by 3 minutes compared with control;
- increases the foam stability of whipped desserts by (22.5±1.1) % compared with control.

2. It has been proven that introducing the food additive “Magnetofood” in the amount of (0.10; 0.15; 0.20) % of the formulation composition improves the structural-mechanical properties of whipped desserts compared with control samples:

- it increases effective viscosity by (4.4±0.2) % for mousses and by (4.1±0.1) % for fruit-and-egg white jellies;
- it improves the mechanical strength of whipped desserts by 1.23 times;
- it increases the dispersity of whipped desserts and the fraction of air bubbles the size of (0–0.2) mm by (29.5±0.9) %;

- it improves porosity by (14.3±0.7) % for mousses and by (12.7±0.6) % for fruit-and-egg white jellies;
- it reduces density by (29±1) kg/m³ for mousses and by (26±1) kg/m³ for fruit-and-egg white jellies.

3. We have established the rational content of the food additive “Magnetofood” in the formulation composition, which is 0.15 %.

The results obtained give grounds to recommend the food additive “Magnetofood” as a stabilizer, structure-forming agent, and improver for whipped desserts.

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