

THE EFFECTS OF THICKENERS UPON THE VISCOUS PROPERTIES OF SOUR CREAM WITH A LOW FAT CONTENT

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ABSTRACT

Background. Fermented cream is a common and widely used dairy product throughout the world. The structure of sour cream with a low (10 to 15%) fat content is determined by the acid gel of milk proteins, while that of sour cream with a high ($\geq 30\%$) fat content is determined by the gel formed by fat globules coated with protein. Sour cream with a fat content of about 20% has an intermediate gel structure, which is not characterized with high viscosity. To increase the viscosity of the product, as well as to prevent the separation of whey during storage, thickeners and stabilizers (gelatin, various types of starch, etc.) are added. As these decrease the sensorial characteristics of products, new thickeners (elamin, citrus pectin, flax seed flour, banana puree, and fromase milk-clotting enzyme preparation) are used instead.

Materials and methods. Sour cream was made by separating whole cow's milk, normalization, homogenization, pasteurization and fermenting by mesophilic lactic acid bacteria. Then thickeners were introduced to the clot: elamin, dry banana, flax seed flour in mass fractions of 0.01%, 0.03% and 0.05%, as well as fromase preparation in the same amount. A control batch of sour cream was made without the use of additives. The ripening process lasted from 8 to 9 hours to obtain a dense consistency. The viscosity of the samples was determined using a rotational viscometer, consisting of two coaxial brass cylinders, between which the test liquid was located. The effective viscosity and its dependence on the shear rate γ in research samples as non-Newtonian fluids were determined.

Results. Sour cream is characterized by the presence of a structure quickly destroyed by external forces at shear rates greater than 10 s^{-1} , so exceeding the given value in the production of sour cream is not rational. The dependences of the rheological parameters of sour cream on the content of the additives elamin, flour from flax seeds and dry banana puree, used as thickeners, showed that the greatest strength of intermolecular

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bonds and the stability of the studied mixtures can be expected with a share of additives ranging from 0.01 to 0.03% (by mass). At the same time, when the said share exceeds 0.05%, the structure of sour cream is weakened – this is especially characteristic in the case of adding dry banana.

Conclusion. The research showed that natural thickeners can be chosen to improve the rheological parameters of low fat sour cream without deteriorating its sensorial characteristics. This leads to the conclusion that the studied thickeners can improve the viscosity of sour cream with a low fat content – and dry banana is the best of those studied. Correspondingly, viscous properties are among the principal ones which define customers' perceptions of the product, its low fat content being a possible spoiler of sensorial traits.

Keywords: sour cream, plant thickeners, milk-clotting enzyme preparation, rotational viscometer, viscous properties

INTRODUCTION

A special place in the human diet belongs to fermented milk products. The assortment of dairy products in Ukraine is represented by such traditional products as kefir, riazhanka (fermented baked milk), and yogurt, as well as dairy products enriched with probiotic strains, biologically active substances and dietary fiber. Typically, manufacturers position such products as having pronounced therapeutic, prophylactic or health-improving properties (Sychevskiy and Romanchuk, 2016).

Now a significant number of consumers, taking daily care of limiting the energy value of the food they use, prefer to have foods with the usual sensorial characteristics inherent in the traditional assortment – first of all, the indicated refers to the content of fat in the product. The above trend fully applies to dairy products, in particular sour cream (Narvhus et al., 2019).

Sour cream is in great demand by consumers in Ukraine. According to Article 1 of the Law of Ukraine “On milk and dairy products” (Law..., 2004), sour cream is a traditional milk product which shall be made exclusively from raw milk with pure cultures of lactic acid bacteria (Verbytskyi and Teslenko, 2010).

The rheological properties of fermented milk drinks play a significant role both in the consumer assessment of the finished product and in determining the parameters of technological processes and equipment. Improving the consistency of fermented milk drinks remains an urgent problem, especially when using different compositions of fermented cultures (Romanchuk et al., 2017). For liquid and liqueous foods, rheological characteristics (mechanical properties) are

usually determined that are essential for assessing the course of technological processes and quality indicators of food masses and the finished products produced as a result of their implementation: ultimate shear stress, viscosity, strength, etc. A characteristic indicator is dynamic viscosity, equal to the ratio of the internal friction force acting on the surface of the liquid layer, according to the velocity gradient, equal to one at the surface of a layer. The physical sense of “dynamic viscosity” is the product’s ability to resist sliding or displacement (Verbytskyi et al., 2014). The milk clot is an amorphous body occupying an intermediate position between the liquid and solid state and has a porous protein structure that has not been adequately studied. The basis of a milk clot is a network of protein chains covering serum which prevents the mesh from connecting into a compact mass (Sychevskiy and Orliuk, 2016). A deformed clot cannot be completely restored, but the depth of deformation and the speed of its elimination differ for types of fermented milk drinks (Romanchuk et al., 2017). There is evidence that the rheological behavior of clots of fermented milk can be described by curves, according to which it can be stated that there are plastic and pseudoplastic properties. Therefore, sour milk clots are non-Newtonian thixotropic fluids, since their viscosity decreases over time (Sychevskiy and Orliuk, 2016). The structure of sour cream of a low (10 to 15%) fat content is determined by the acid gel of milk proteins, while sour cream of a high ($\geq 30\%$) fat content is determined by the gel formed by fat globules coated with protein. Sour cream with a fat content of about 20% is an

intermediate gel structure, and is not characterized by high viscosity (Narvhus et al., 2019). To increase the viscosity of the product, as well as to prevent the separation of whey during storage, thickeners and stabilizers (gelatin, various types of starch, etc.) are added to the composition of sour cream. At the same time, the introduction of these substances into the composition of the above thickeners and stabilizers leads to a decrease in sensorial characteristics of traditional dairy products, in particular, reducing their creamy taste and smell (Tasneem et al., 2014).

The consistency and taste of sour cream is influenced by such factors as the composition of raw milk, especially the mass fraction of fat and bacterial starter cultures, which ensure the intensity and direction of microbiological and biochemical processes that occur during cream ripening, maturation and storage.

Creaminess is among the sensorial parameters used to evaluate sour cream. The said parameter is associated with the sour-milk taste and smell of foods of a high milk fat content. Studies have established that the decisive indicator of such product's creaminess is their flavor. Also, to assess the quality of sour cream, structural parameters are important, in particular, the consistency characteristics: dense or liquid or, otherwise, solid, semi-solid and liquid (Jervis et al., 2014).

To improve emulsifying and stabilizing properties, microparticulate protein (MPP) produced from milk is used, the microparticles of which have a regular spherical shape and a size from 1 to 10 microns, which corresponds to the parameters of fat globules in milk products. The introduction of MPP into low-fat sour cream made it possible to increase its water-holding ability and creaminess without increasing the fat content of the product at shear rate gradient values from 3 to 437.4 s⁻¹ (Musiy et al., 2017). There is evidence that the increase in the sour cream's water-holding ability and its viscosity was facilitated by the addition of the ingredients of starch- and oil-containing plant raw materials: not fried buckwheat seeds (Evdokimov et al., 2010), leaf extract of *Moringa oleifera* or oil made of the said raw material (Salem et al., 2015). Another type of plant raw material used for these purposes are varieties of pectin, which can gel in the presence of ions (Ca²⁺) or a solute at low pH (Tyagi et al., 2015). A product of the processing of algae, elamin contains

a balanced complex of trace elements and macrocells in an organically bound form. The content of iodine, phosphorus, calcium and iron exceeds several times that of other food products. The specified substance is effectively used as a thickener, and, moreover, it helps to reduce iodine deficiency in the population (Bondarenko et al., 2010). Another material of plant origin, used as a thickener and functional additives, which increases the nutritional and biological value of sour cream, is flax seeds (Kajla et al., 2015).

In the process of the ultrafiltration processing of whey, the separation of which accompanies the production of cottage cheese, a retentate is formed. This was also added to the recipes of sour cream in the amount of 2, 5 and 10%. The use of a small amount of retentate did not lead to a noticeable change in texture or deterioration in the sensorial characteristics of the product, but the addition of retentate in an amount of more than 5% led to a significant deterioration in the sensorial profile (Csanádi et al., 2016). From the point of view of the manufacturing technology of low fat sour cream, enzyme preparations of microbial origin are of considerable interest, however, the bitter taste of the final product (Rylkova and Shingareva, 2012) in the case of excessive addition of these preparations to sour cream is a significant obstacle to their widespread use. The issue of rational dosing of microbial enzyme preparations for the production of sour cream still needs an appropriate solution.

MATERIALS AND METHODS

Flaxseed flour (Zemledar Ltd, Ivano-Frankivsk, Ukraine) used as a thickener for sour cream with a low fat content contains up to 45% protein, in which high-molecular globulins predominate, up to 9% carbohydrates, and up to 36% dietary fiber.

Another thickener was dried banana (Fruitland s.r.o., Prague, Czech Republic) with a high fiber content and low fat content. Each 100 g of banana contains carbohydrates up to 25.8 g, protein up to 1.8 g, and fiber up to 1.07 g. The content of vitamins is: B1 – from 0.04 to 0.54 mg, B2 – from 0.05 to 0.067 mg, PP – from 0.60 to 1.06 mg, C – from 5.60 to 36.4 mg, the essential amino acid lysine – from 58 to 76 mg. Phosphorus, iron, potassium, calcium and magnesium are present as well.

The elamin (PJSC Plant of Lactic Acid, Kyiv, Ukraine) thickener is a brown or dark green powder with a characteristic smell of kelp (containing up to 35% alginates). Elamin is characterized by a high protein content of up to 9%, biologically active carbohydrates (alginates, laminarin, mannitol) up to 45%, minerals – about 30%, vitamins A, B, D, E – from 0.01% to 0.02%. The energy value of 100 g of elamin is 165 cal.

Also, an enzyme preparation of microbial origin – Fromase®750XLG (DSM Food Specialities B.V., Delft, the Netherlands) – was used.

To make sour cream, whole cow's milk was separated. The resulting cream was normalized by mass fraction of 10% fat. The cream had been homogenized before pasteurization at a temperature of 60–85°C and a pressure of 12–15 MPa. The homogenized cream was pasteurized at a temperature of 85 ± 2°C with an exposure of 8 ± 2 min, and then cooled to a temperature of 30 ± 2°C. For direct fermenting of lab-scale batches of cream, a starter culture, Iprovit-SSK (Institute of Food Resources of the National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine), containing *Lactococcus lactis* subsp. *lactis*, *Lactococcus lactis* subsp. *cremoris*, *Lactococcus lactis* subsp. *diacetylactis*, *Streptococcus thermophilus* in the amount of 1,2 · 10⁻⁵ kg per 1 kg of milk was used. After reaching an acidity of 45°T, plant ingredients were additionally introduced to the clot: elamin, dry banana, flax seed flour in mass fractions of 0.01%, 0.03% and 0.05%, and fromase preparation in the same amount.

A control batch of sour cream was made without the use of additives. The ripening process lasted from 8 to 9 hours to obtain a dense consistency. For an acidity of 50–52°T, all the samples of sour cream were put into the refrigeration chamber for further cooling and aging for 24 hours.

The viscosity of the samples of sour cream of the composition described above was determined using a specially designed wide-range rotational viscometer (Malafaiev and Pogozhykh, 2007), consisting of two coaxial brass cylinders, between which the test liquid is located. The outer cylinder is rotated by a controlled motor through a multi-speed gearbox. The mechanical moment on the measuring cylinder, proportional to the viscosity of the liquid, is compensated by the mechanical moment of the working

spring, which determines the shear stress in the liquid. The effective viscosity and its dependence on the shear rate γ in research samples as non-Newtonian fluids were determined, plotting, for the indicated purposes, a product rheogram – the dependence of the shear stress τ on the shear rate γ and determining its effective viscosity:

$$\mu = \tau / \gamma \quad (1)$$

where:

μ – effective viscosity, Pa·s,

τ – shear stress, Pa,

γ – shear rate, s⁻¹.

The temperature of the samples of sour cream during the said measurements was (17 ± 1°C).

The sensorial characteristics of the sour cream samples were evaluated according to the norms of the National Standard of Ukraine DSTU 4418:2005 Sour cream. Specifications (DSTU 4418:2005).

RESULTS AND DISCUSSION

In Figure 1, the rheograms $\tau(\gamma)$ for the control sample – sour cream with a fat content of 10% without additives – are shown. Measurements were made twice in the forward direction (increase in shear rate) and in the reverse direction (decrease in shear rate).

On the rheogram, we observed thixotropy, that is, the bias stress in the upward direction (τ_1) is much higher than in the reverse (τ_2). For shear rates ranging 10 s⁻¹ or more in the forward direction τ_1 , we observed a rather rapid decrease in the shear stress with time. This indicates the destruction of the structure of sour cream with the fact that it grows with an increasing shear rate. This process was limited by the measurement time between the points of the rheogram – from 1 to 2 minutes.

Having reached the maximum shear rate, it remained stable within a period of 2 to 3 minutes rotation of the cylinder of the viscometer. There was a large destruction of the structure, causing a significant decrease in shear stress for the last point of the curve τ_1 and for the starting point of the curve τ_2 in the opposite direction of the shear rate. Further, the shear stress value (Fig. 2) almost linearly approached the value that corresponded to the limiting shear stress,

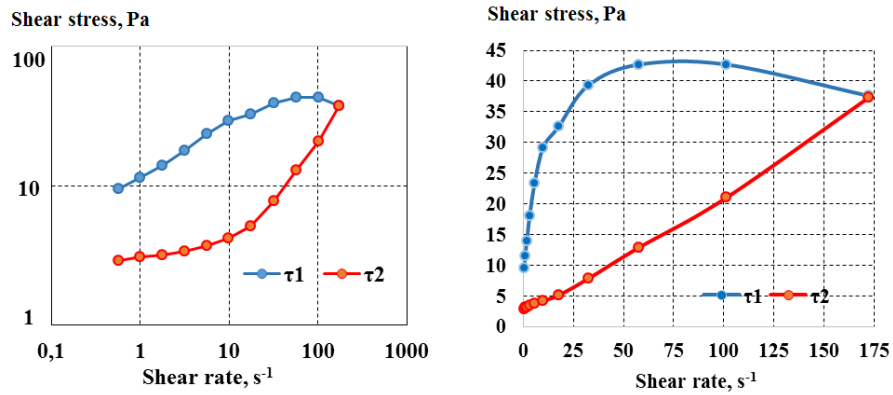


Fig. 1. Rheogram for control samples of sour cream: a) double logarithmic frame, b) Cartesian frame

i.e. the curve τ_2 was consistent with the Bingham model (Yang et al., 2017).

Figure 2 shows the viscosity dependences μ (γ) for the control sample in double logarithmic and Cartesian coordinates. The measurement was performed in the forward μ_1 , and in the reverse directions μ_2 . We see that in double logarithmic coordinates to a shear rate of 10 s⁻¹, the curves are linear, that is, they correspond to the Ostwald model (Dogaru et al., 2014). Therefore, in this range of shear rates, the parameters of the samples were determined using the Ostwald model (K , n) for forward direction measurements, and the parameters

using the Bingham model (μ_m , τ_0) and the value of the fractured structure viscosity μ_∞ (at maximum displacement rates) were determined for the reverse direction of measurements.

For large shear rates, the viscosity decreases rapidly with their growth for the forward direction μ_1 and almost does not change for the opposite. On the contrary, for the last point μ_2 , the possibility of rheopexy (up to 9 ... 12%) shall be considered for shear rates exceeding 100 s⁻¹. For the opposite direction of measurements and subsequent measurements, we can talk about preserving the destroyed structure for a considerable

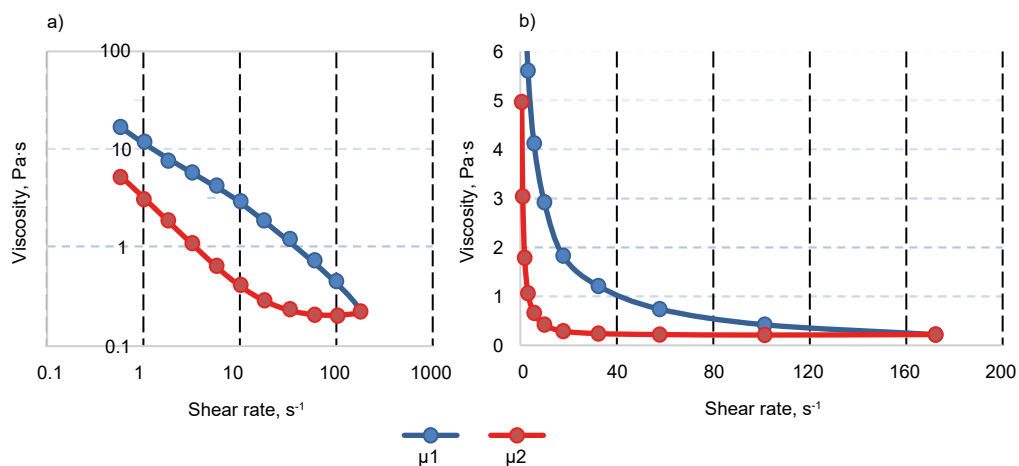


Fig. 2. Viscosity of the control sample affected by shear rate: a) double logarithmic frame, b) Cartesian frame

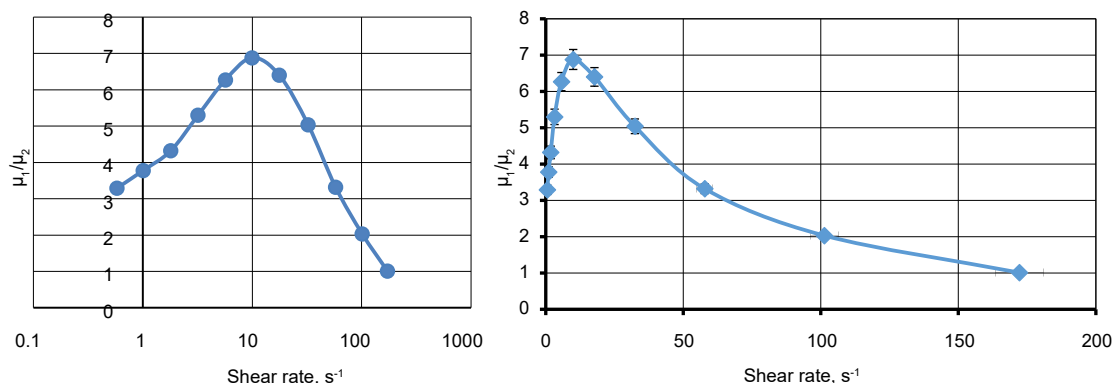


Fig. 3. Viscosity hysteresis μ_1/μ_2 of control sample depending on shear rate

time and about the slow progress of restoration of the structure; it is restored only after settling the sample for a long time in the refrigerator. During repeated measurements, values close to the values of the inverse measurements of μ_2 were obtained, although somewhat less due to the fact that the destruction of the structure continued.

In Figure 3, we can see the process of destruction of the sour cream structure according to the graph of viscosity hysteresis μ_1/μ_2 or shear stresses τ_1/τ_2 , as a decrease in the ratio μ_1/μ_2 for the forward and reverse directions of measurements at the same shear rates. The existing hysteresis maximum $(\mu_1/\mu_2)_{\max} = 6.9$ at a shear rate of $10\ s^{-1}$, which indicates the beginning of an intensive process of destruction of the sour cream structure with high shear rates. So, when processing sour cream, it is necessary not to exceed the shear rate of $10\ s^{-1}$. It should be noted that the magnitude of the hysteresis depends not only on the composition of the samples, but also on the exposure time between the points under study, especially at high shear rates. Similar dependences were obtained for other samples (their maxima $(\mu_1/\mu_2)_{\max}$ varied from 2.9 to 14.2 times – Table 1.

The viscosity dependences for the control sample were studied for large shear rates less than the gap between the cylinders of the viscometer. Measurements showed that at these shear rates the structure collapses even more: there was a 3–4-fold decrease in the values of μ_∞ , μ_m , and τ_0 , as well as an increase in the hysteresis of $(\mu_1/\mu_2)_{\max}$ to 14.2 times. These parameters are given in Table 1, where n – exponent value, K_1 is the data for increased displacement rates relative to K_0 – for the shear rates that were recorded during studies of sample systems with additives ($\gamma_{\max} = 172\ s^{-1}$).

The effects of various additives on the rheological properties of sour cream was investigated. Elamin, banana and flax seed flour were added to sour cream in mass fractions of 0.01%, 0.03% and 0.05%. The obtained dependences were qualitatively close to the dependences characteristic of pure sour cream.

Figure 4 shows data for samples of sour cream with the addition of flour from flax seeds. We can see a noticeable increase in the parameter of consistency K and a decrease in the exponent n and the viscosity of the fractured structure μ_∞ for mass fractions from 0.01 to 0.03%. This behavior of the consistency parameter K indicates the introduction of high polymer molecules

Table 1. Viscosity parameters of control sample by different maximal values of shear rate

	$\gamma_{\max},\ s^{-1}$	$K, Pa \cdot s$	n	$\mu_\infty, Pa \cdot s$	$(\mu_1/\mu_2)_{\max}$	$\mu_m, Pa \cdot s$	τ_0, Pa
K_0	172	12.77	0.276	0.207	6.9	0.156	2.87
K_1	1 146	10.78	0.247	0.050	14.2	0.046	0.97

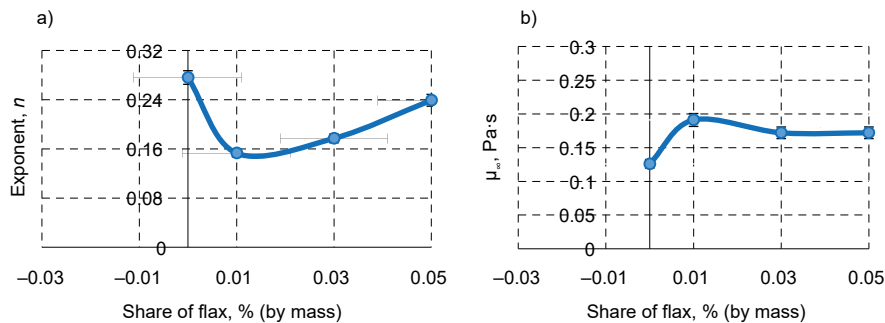


Fig. 4. Parameters of sour cream viscosity depending on the share of flax seed flour (by mass): a) exponent n , b) viscosity of destroyed structure

of additives to the sour cream and the strengthening of the total intermolecular bonds in its structure for these additives. A decrease in n also indicates an increase in the bonds between macromolecules in the system with the formation of time-stable for a given shear rate of their conglomerates (Dogaru et al., 2014; Malafaiev and Pogozhykh, 2007; Yang et al., 2017).

Figure 5 shows data for samples of sour cream with the addition of dry banana puree. We see a noticeable increase in the parameter of consistency K and a decrease in the viscosity of the fractured structure μ_{st} , exponent n for the mass fraction from 0.01 to 0.03% and the ultimate shear stress τ_o . We see that the behavior of this system of samples is close to the behavior of the system containing flax seeds. For the share of banana additives of 0.05% (by mass), we see a more significant destruction of the structure – all parameters,

except the exponent n , decrease. This indicates a decrease in the forces of intermolecular bonds for such an additive.

Figure 6 shows the data for the system of additives of elamin. For this system, we see a different pattern of changes: a noticeable decrease in the consistency parameter K and an increase in n . This indicates a weakening of the bonds between the polymer molecules in the structure of the samples, causing a more Newtonian behavior of these samples. The constancy of the critical shear stress value indicates the preservation of the total forces between the bonds of macromolecules in its structure.

For most of the parameters, there is a maximum near the mass fraction of 0.03% and a decrease in the values of these parameters with a subsequent increase in the mass fraction of elamin. The presence of these

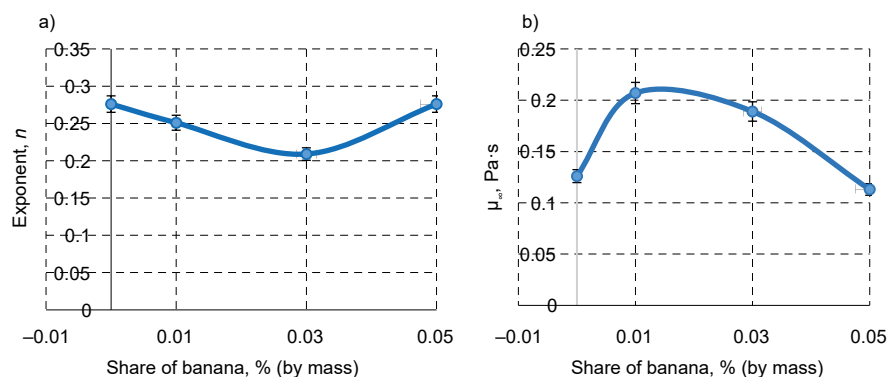


Fig. 5. Parameters of sour cream viscosity depending on the share of dry banana puree (by mass): a) exponent n , b) viscosity of destroyed structure

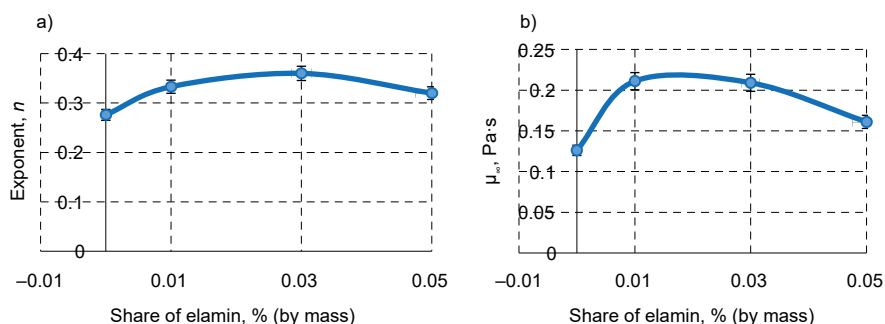


Fig. 6. Parameters of sour cream viscosity depending on the share of elamin (by mass): a) exponent n , b) viscosity of destroyed structure

maxima may indicate the strongest structure of the system of additives of elamin. Further addition of elamin causes a weakening of the structure of the system. An increase in n indicates a weakening of the bonds between the macromolecules in the system, their lower molecular weight.

The final Table 2 shows the rheological parameters of the studied systems of samples, calculated according to the models of Ostwald and Bingham.

For samples of sour cream with additives of flour from flax seeds and dry banana, it was found that the maximum hysteresis of viscosity (μ_1/μ_2) broadens toward lower shear rates to 2 ... 3 s⁻¹, especially at the maximal content values of said additives. This indicates the appearance of new weaker intermolecular bonds in them, which can lead to less stability of these samples and the structure of the system during storage.

However, an increase in the consistency parameter K and the presence of minima for the indices n from the concentration of additives for systems with flour additives from flax seed flour and banana puree (Fig. 4b and 5b) may indicate the formation of conglomerates of macromolecules and the integrated strengthening of intermolecular bonds in the samples.

The lowest stability of the samples and the structure of the system in time can be expected from sour cream with additives of elamin. This sour cream has a decrease in the consistency parameter K , the maximum of the stepwise index n on the concentration dependence of the additive (Fig. 6b) and the smallest values for the viscosity hysteresis (μ_1/μ_2)_{max} (Table 2).

The samples with microparticulate protein had a clear sour-milk taste and aroma characteristic for sour cream, but richer and more expressive than the

Table 2. Viscosity parameters of the studied systems of the samples ($\gamma_{\max} = 172 \text{ s}^{-1}$)

Parameter	Control	Share, % (by mass)								
		elamin			flax seed flour			dry banana puree		
		0.01	0.03	0.05	0.01	0.03	0.05	0.01	0.03	0.05
$K, \text{ Pa}\cdot\text{s}$	12.77	8.38	8.26	7.16	17.8	15.9	18.5	19.08	18.83	8.44
n	0.276	0.333	0.360	0.320	0.153	0.177	0.239	0.251	0.209	0.276
$\mu_{\infty}, \text{ Pa}\cdot\text{s}$	0.126	0.211	0.209	0.161	0.191	0.172	0.172	0.207	0.189	0.113
$(\mu_1/\mu_2)_{\max}$	6.88	3.56	3.87	2.93	5.03	5.15	7.04	7.57	7.20	8.00
$\mu_m, \text{ Pa}\cdot\text{s}$	0.228	0.215	0.190	0.190	0.170	0.131	0.130	0.131	0.098	0.072
$\tau_0, \text{ Pa}$	2.97	3.56	3.87	2.93	3.79	3.54	3.48	3.37	3.19	1.28

control sample, the taste of which the tasters characterized as flat. The consistency, in contrast to the control sample, was softer, more tender and homogeneous, without lumps and grains. During the tasting, the experts noted an increase in creamy taste without increasing the fat content of the product.

From the viscosity research results presented above, it can be seen that:

- with an increase in the shear rate, the dynamic viscosity coefficient of the studied products decreases at a constant temperature, which indicates the non-Newtonian behavior of these products (downward line)
- the nature of the curves for these products confirms their belonging to the group of pseudoplastic fluids
- with a decrease in the shear rate (ascending line), the dynamic viscosity coefficient of the studied products at first continues to decrease, but after reaching a shear rate of 400 s^{-1} it increases.

For all the products studied, incomplete restoration of their structure was observed. The presence of an open hysteresis loop (Fig. 4–6) indicates the existence of a dependence of viscosity on time (the phenomenon of thixotropy).

The necessary consistency of the finished product can be achieved with the following values of the rheological parameters of the clot: viscosity by shear rate gradient of 48.6 s^{-1} – at least $0.460 \text{ Pa}\cdot\text{s}$, a degree of recovery of at least 8% by the sedimentation coefficient of $5.0\cdot 10$ Swedberg units.

CONCLUSIONS

So the following conclusions can be drawn.

Low-fat sour cream made with flaxseed flour, elamin, and dry banana gains new quality traits for the body. Flour from flax seeds, elamin, and dry banana are proven to effect the rheological properties of low-fat sour cream having a distinct structure. However, the structure is rapidly destroyed by external forces at shear rates of more than 10 s^{-1} , so it is not rational to exceed this value while manufacturing sour cream.

The use of thickeners for sour cream with a low fat content allows the structure to be restored from mechanical impact and thus improves the sensorial characteristics of the finished product. The greatest strength of the intermolecular bonds and stability of

the studied mixtures can be expected when the mass content of additives is in the range from 0.01 to 0.03%. At the same time, when the mass content of additives exceeds 0.05%, the structure of sour cream weakens, this being especially true in the case of adding dry banana. Increased (versus control) creaminess of the experimental batches of low fat sour cream was achieved by adding thickeners and the microbial enzyme preparation fromase. The best result, in this sense, was provided by the addition of dry banana puree in a rational amount determined experimentally.

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