

Представлено реологічні та органолептичні дослідження емульсійних систем за використання напівфабрикату на основі згущеної низьколактозної молочної сироватки та ферментованого торе м'якоті гарбуза (НЗНМС). Встановлено позитивний вплив НЗНМС на структуру емульсійних систем, що підтверджено експертною сенсорною оцінкою. Підтверджено компонентну сумісність НЗНМС та олії рослинної у складі емульсійних систем. Науково обґрунтовано вплив технологічних чинників на параметри емульгування напівфабрикату для забезпечення реалізації його цільових властивостей як емульгатора та стабілізатора у технології емульсійних соусів. Експериментально встановлено зміну кількісних значень визначальних показників емульсійних систем, таких як в'язкість та інверсійна стійкість, залежно від значень рН середовища, температури емульгування, швидкості викапування олії та обертання робочого органу мішалки. Встановлено, що закислення середовища сприяє підвищенню в'язкості емульсійної системи, в зв'язку з чим доцільним є використання НЗНМС у складі солоних соусів емульсійного типу. Встановлено пряму залежність між проявами інверсійної нестійкості та підвищенням температури процесу емульгування. Виявлено обернено пропорційний вплив швидкості обертання робочого органу мішалки на зростання в'язкості досліджуваних систем. Здійснено математичну оптимізацію визначених діапазонів числових значень параметрів окремих показників технологічного процесу. Встановлено раціональні параметри процесу емульгування: температурний показник – 18 °С, швидкість емульгування – 0,09...0,11 мл/с, рН від 5,0 до 5,5, швидкість обертання робочого органу мішалки – 500 об/хв. Підтверджено можливість використання НЗНМС у складі емульсійних систем, зокрема соусів емульсійного типу

Ключові слова: низьколактозний згущений напівфабрикат, емульгувальні властивості, ефективна в'язкість, інверсійна стійкість

VALIDATION OF EMULSIFYING PROPERTIES OF SEMI-FINISHED PRODUCT BASED ON LOW-LACTOSE MILK WHEY

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1. Introduction

The tendency to keep a healthy lifestyle leads to an increase in demand for special foods. In particular, lactose-free or low-lactose products are intended for use in case of functional gastrointestinal disorders (FGID), namely irritable bowel syndrome (IBS), functional abdominal bloating, constipation, diarrhea, etc. [1].

Partial lactose intolerance, characterized by incomplete absorption by the intestinal walls, is called lactose malabsorption [2]. Regardless of the cause, lactase deficiency leads to the formation of unabsorbed lactose in the intestinal tract, which can lead to IBS [3]. Most often, IBS is caused by foods that contain lactose [4]. This fact suggests that the exclusion of dietary components that cause symptoms may be a promising treatment option for IBS [5]. Accordingly, the exclusion of lactose-containing foods from the diet or their partial restriction should

theoretically promote recovery. However, such dietary adjustments contribute to partial improvement, but do not lead to recovery [6]. The consequence of such adjustment is the consumption of insufficient amounts of essential nutrients such as calcium, phosphorus, vitamin B (riboflavin) and vitamin D (ergocalciferol), which may lead to their deficiency and the development of co-morbidities [7, 8]. Diet also negatively affects the microbiology of the large intestine [9].

This problem could be resolved through the consumption of low-lactose dairy raw materials and culinary products.

The consumer goods market offers a wide range of food products based on raw milk. But the range of dairy products for patients with lactose intolerance remains limited.

Thus, there is an urgent issue of developing an assortment of low-lactose dairy products for special nutrition of lactose intolerant patients. Whey and its derivatives are valuable raw materials for solving this problem.

The research suggests a technology of obtaining condensed low-lactose whey in the installation at a rarefaction of $P = -0.1$ Pa and a temperature of 50 ± 2 °C with a concentration factor of 10 and a lactose content of 2–2.2 % [10]. The research identifies its high emulsifying properties and possibility of use as a basis of sauce production. Fermented pumpkin pulp [11] with high pectin content is suggested as a stabilizer for emulsion systems. These fermented components were used to develop the technology of low-lactose semi-finished product of milk and plant origin (hereinafter SPCLLW) [12]. The use of semi-finished products in the food industry and restaurants will expand the range of products with low lactose content for a balanced diet of patients with lactose intolerance.

In particular, due to the excellent emulsifying properties of the components of the semi-finished product, its use in emulsion-type sauces is possible. That is why it is advisable to determine the rational parameters and ratios of the system components for the manufacture of emulsified products based on the developed technology of the semi-finished product.

The most common emulsion-type sauce is mayonnaise. However, due to its composition, mayonnaise sauce has low nutritional and biological value, is not used in therapeutic and prophylactic nutrition, narrowing down the range of products consumed [13]. Thus, it is advisable to improve the technology of mayonnaise sauce in order to enhance its consumer qualities.

The research justifies the development of a technology of low-lactose products for the nutrition of patients with intolerance. The use of semi-finished products and emulsion sauce based on it in the food industry and restaurants will expand the range of low-lactose products for a balanced diet of patients with lactose intolerance.

This goal is achievable through the use of the proposed low-lactose semi-finished product for the production of emulsion-type sauces, provided that the structural and mechanical properties inherent in mayonnaise sauces are preserved.

In connection with all the above, it is important to study the emulsifying properties of the semi-finished product based on low-lactose whey for the development of “Mayonnaise” emulsion sauces.

2. Literature review and problem statement

Widespread emulsifiers approved for use in emulsion sauces such as mayonnaise are carboxymethyl cellulose and polysorbate. However, clinical studies found that these emulsifiers have a detrimental effect on the intestinal microbiota. Even at low concentrations of carboxymethyl cellulose and polysorbate, inflammatory bowel disease even in healthy individuals and a significant deterioration in the condition of those people who already had gastrointestinal disorders were observed. In addition, researchers claim that the widespread use of emulsifying agents may increase the overall incidence of obesity and irritable bowel syndrome, be accompanied by other chronic inflammatory diseases and even **contribute** to the development of **cancer** [14]. Therefore, it is important to study the emulsifying properties of alternative components of emulsion products, in particular SPCLLW. The study of the nature of emulsification processes with SPCLLW will provide evidence in favor of the use

of the developed semi-finished product in the composition of emulsion sauces.

Finally, there is a significant increase in demand for the use of natural food systems that exhibit emulsifying and stabilizing properties, such as egg and vegetable protein systems, due to the desire to consume useful natural products [15]. At the same time, there has been significant growth in the segment of consumers who prefer alternatives to eggs to meet allergic, vegan, or other dietary needs [16]. Ultrafiltered whey peptide fractions and soy protein were found to have improved emulsifying properties. The research [17] investigated the dependence of organoleptic parameters of the emulsion sauce on the size and distribution of fat droplets in the oil-vinegar emulsion in the presence of whey protein. Indirectly, it was concluded that there is a direct dependence of organoleptic parameters of the formed systems on the amount of whey protein introduced as a thickener, but there was no further study on this topic.

The use of hydrolyzed whey protein concentrate was suggested as an effective substitute for egg white in the research [18]. The latter showed stronger surface-active properties, but its high hygroscopicity during storage contributed to the reduction of the ability to form complexes, which does not allow to obtain a product of uniform quality. The research [19] reached similar conclusions: the use of dehydrated whey protein increases the viscosity of emulsions by binding fat droplets, and is directly related to the organoleptic characteristics of the product.

However, the emulsifying properties of concentrated unfiltered whey with non-hydrolyzed protein fraction are not explored and neither are the presence and potency of emulsifying properties of low-lactose concentrated whey.

For the same reason, interest in the use of hydrocolloids grew due to high stabilizing properties [20]. Thus, for therapeutic purposes, the use of microencapsulated bifidobacteria with corn starch and calcium alginate was suggested for the production of symbiotic sauce of the “Mayonnaise” type [21]. However, despite a significant improvement in the biological value of the product and satisfactory organoleptic characteristics, the high cost and complexity of production did not ensure the widespread use of this technology.

The stabilizing properties of gelatin fermented hydrolyzate were also studied [22]. However, its excellent viscosity properties manifested only during the short-term storage of emulsions. During long-term storage, the weighted average volume of the average diameters of fat droplets increased significantly and the emulsion collapsed.

The research [23] found that the addition of gum compounds to emulsion systems increases their viscosity, slowing down the movement of fat droplets, which are captured by the gel-like structure. However, the addition of gum compounds has a negative effect on other organoleptic characteristics, which did not contribute to the spread of this method in production.

The study [24] proposed the replacement of egg yolk with starch paste in the technology of emulsion sauces of the “Mayonnaise” type. However, the use of the substitute increases the duration and cost of sauce production in conjunction with the adverse effects of starch paste on the texture and aroma of mayonnaise.

Therefore, the use of pumpkin puree in SPCLLW, due to its stabilizing properties, is very important. It is relevant to study the structure-forming properties of the semi-finished product using pectin-containing vegetable raw materials.

At the same time, the use of hydrocolloids, depending on their nature, has both a number of advantages and disadvantages. In particular, the use of purified hydrocolloids may be accompanied by microbiological instability and adversely affect the texture of sauce products. At the same time, scientists note the weakening of the negative effects of crude hydrocolloids in plant components [24, 25]. That is why it is important to assess the dependence of the sensory characteristics of sauce products based on semi-finished products using pectin-containing vegetable raw materials, in particular texture. To this end, it is advisable to determine the optimal values of structural indicators of emulsification, taking into account the expert evaluation of the obtained food systems.

There is a technology of obtaining an emulsion sauce, which involves the use of skimmed milk powder as an emulsifier and vegetable or fruit puree as a structure stabilizer. However, the disadvantage of this recipe, as well as the previous one, is the use of a large number of flavouring additives, organic acids and alkalis, which adversely affect the biological value of the product, in particular: baking soda to adjust the pH, acetic acid to extend the shelf life of sauce, salt, sugar and other flavouring additives (mustard, horseradish, garlic or black pepper) [26]. At the same time, the use of a large amount of puree gives an unusual bright colour to the sauce and a pronounced taste and aroma inherent in the main component of the puree. The consistency of the sauce according to the proposed technology is unsatisfactory, marked by wateriness, due to the high moisture content in the puree.

The study [27] suggests using, as an effective emulsifying system, a protein-carbohydrate semi-finished product, which is made on the basis of skim milk and berry puree. It is found that the protein-carbohydrate semi-finished product has high stabilizing and emulsifying properties. The rational share of semi-finished product in emulsion products is determined, the concentration of guar gum to stabilize emulsion systems is substantiated, and the dependence of their stability on pH and emulsification temperature is determined. However, this sauce contains stabilizers and cannot be used to feed patients with lactose intolerance.

The study [28] also proposes the use of the protein-pectin complex to stabilize the emulsion system. However, the use of a dehydrated mixture contributes to a long process of the product processing in order to combine the components of the mixture to provide emulsification and heterogeneity of the resulting system. It can be assumed that the use of the protein-pectin complex in the liquid state will promote better interaction with the fat component.

In general, the disadvantage inherent in the technology of emulsion sauces is the use of egg products, mono- and diglycerides of fatty acids, potassium sorbitol, sodium benzoate, organic acid salts and other artificial additives, which makes them impossible to use in special and dietary nutrition [29–33].

A similar situation is observed on the food markets of other countries. However, in contrast to Ukraine, food production abroad changed its direction from reducing the fat content in products to creating a functional product that not only meets the nutritional needs of the consumer, but has therapeutic properties. For this purpose, probiotics, prebiotics, antioxidants and phytosterols and other functional components are added to mayonnaise [16].

Thus, the market launch of emulsion-type sauces based on lactose-free protein-carbohydrate raw materials is held back by the lack of applied research in this area. Although,

the issue of improving the existing technologies in order to provide the product with medicinal properties is very relevant. Therefore, there is a need for research aimed at substantiating the modes of production of low-lactose emulsion sauces for the nutrition of patients with lactose intolerance, considering the functional and technological properties of the recipe components.

3. The aim and objectives of the study

The aim of the study is to substantiate the technological parameters of emulsification of the semi-finished product to obtain an emulsion-type sauce with specified properties for special nutrition of patients with lactose intolerance.

To achieve this goal, the following objectives were set out:

- to determine the influence of technological factors on the emulsifying properties of model systems of sauces based on SPCLLW;
- to investigate and optimize the parameters of the process of emulsifying sauces based on SPCLLW.

4. Materials and methods of research of rheological properties of emulsion systems depending on technological factors

The subjects of the research were determined as: semi-finished dairy and plant product based on condensed low-lactose whey, consisting of condensed low-lactose whey and fermented pumpkin pulp, as well as deodorized refined sunflower oil, model systems of emulsion sauce.

The phase inversion point was determined by the O.M. Gurov method. This required placing a test sample with a volume of 10 ml in a beaker with a capacity of 100 ml, and then the oil was added until the inversion of the phases, i.e. the transition of the oil/water emulsion into a water/oil emulsion. The volume of oil corresponded to the value of the phase inversion point.

The effective viscosity index was determined using the rotational viscometer ULAB 1-51A by the Brookfield method [13]. Measurements are made at temperatures of 5–35 °C in the measurement range of 10–2,000.000 s·Pa.

The process of choosing the optimal parameters of the emulsification process took into account the weighted average expert evaluation of consistency (EE points). The calculation of the weighting factor of a particular expert is based on the calculation of the sum of the squares of the deviations of their proposed values from the average values obtained as a result of the analysis of all results. The weight is higher for the expert whose results differ less from the corresponding averages. Consistency evaluation was performed simultaneously by 10 experts.

The method of experiment planning according to the orthogonal symmetric Box-Wilson plan was applied in order to determine the optimal parameters of the emulsification process. The data obtained during the experiments were processed by mathematical methods in order to identify the regression dependence and find the response functions for the given parameters. The method consists in choosing the objective function (Y) limited to the set value and describing the constraints from the system of equations. All experimental factors varied at the upper («+») and lower («-») levels, the values of which were selected from previous

experiments. A full three-factor experiment with variation levels of -1 ; 0 ; $+1$ [35]. For each processing process, systems of equations characterizing the process were developed, and the search for optimal parameters of product processing by the method of connected gradients was carried out with the help of the MS Excel package “Solution Search” add-in. In the calculations, a relative error of $1 \cdot 10^{-6}$ is allowed, the permissible deviation of the objective function is 5% . Research data are given in SI units. All experiments and analyses are repeated at least three times.

5. Results of studies of emulsifying properties of model systems depending on technological factors and optimization of the emulsification process

5.1. Research of emulsifying properties of model systems depending on technological factors

One of the main requirements for the culinary products of the emulsion type is the presence of the necessary texture and the ability not to change the structural characteristics over time. One way to solve this issue is to use food compositions that have both emulsifying and structure-forming properties.

The emulsion sauce model systems under study are a two-component system consisting of refined deodorized sunflower oil and a semi-finished product based on low-lactose fermented whey.

It is important to determine the influence of technological factors on the process of emulsification to obtain an emulsion structure with predetermined structural and mechanical parameters. In the production of emulsion sauces in the emulsification phase, the viscosity (η , Pa·s) and inversion stability (V , %) are the most complete characteristics of the process. The main factors that influence them are the pH value of the medium, the emulsification temperature (t , °C), the rate of oil emulsification (v , ml/s), and the speed of rotation of the working body of the mixer (V , rpm).

Previous studies found that the emulsifying ability of a semi-finished product can vary in the range of $40-90\%$ depending on the content of fermented pumpkin puree. The research into the influence of technological parameters on the process of emulsification uses a semi-finished product containing 30% fermented pumpkin puree. The oil content of the emulsion sauce model composition was 60% .

The effect of pH on the effective viscosity of the model system was studied (Fig. 1).

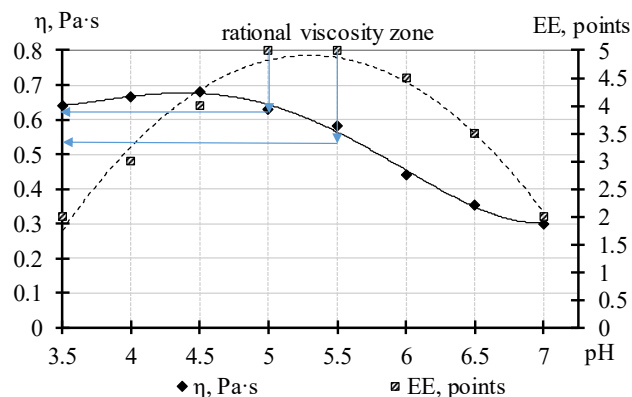


Fig. 1. Dependence of the effective viscosity of emulsion systems (η , Pa·s) and expert evaluation of consistency (EE, points) on the pH of the medium

Fig. 1 shows the dependence of the effective viscosity on the pH of the medium. This dependence is extreme with a maximum in the pH range $=4.0...4.5$. There is an increase in viscosity from 0.3 to 0.75 Pa·s with a decrease in pH from 7.0 to 4.5 . A decrease in the effective viscosity below 0.64 Pa·s is observed with an increase in the acidity of the medium to 3.5 . Thus, the highest viscosity of the emulsion is achieved at a pH of 5.0 to 5.5 at the same high scores set by experts for consistency.

The dependence of the viscosity of the model system on the emulsification temperature is presented in Fig. 2. Emulsification was carried out in the temperature range from 14 °C to 26 °C.

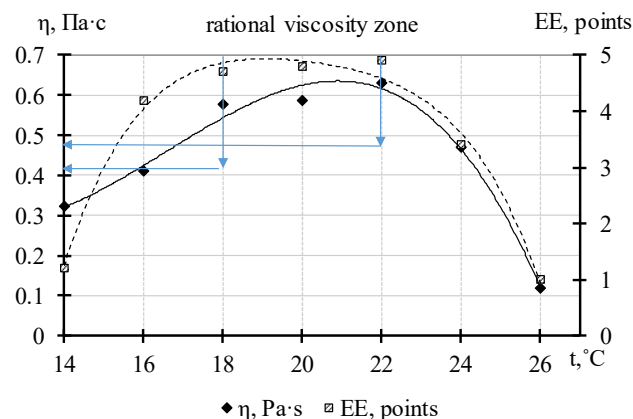


Fig. 2. Dependence of effective viscosity of emulsion systems (η , Pa·s) and expert evaluation of consistency (EE, points) at different temperatures (t , °C)

The data presented in Fig. 2 show that a decrease in the emulsification temperature from 18 °C to 14 °C leads to a decrease in the effective viscosity by 1.79 times (from 0.587 ± 0.004 Pa·s to 0.322 ± 0.004 Pa·s). Thus, in terms of stabilizing properties, the temperature range from 18 °C to 22 °C is rational.

The dependence of phase inversion of the emulsion systems on the process temperature is presented in Fig. 3.

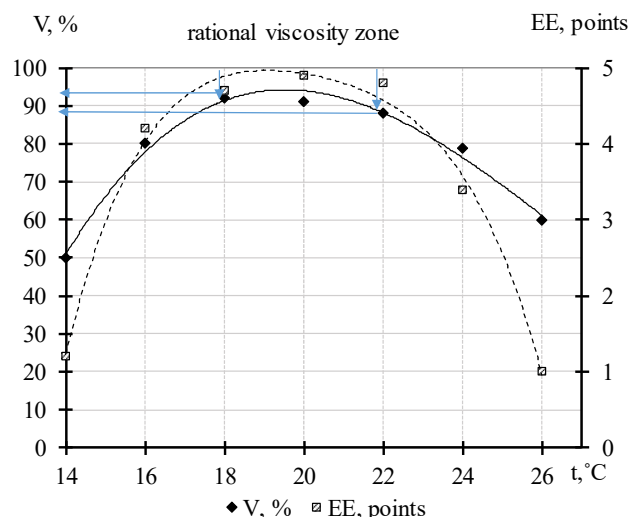


Fig. 3. Dependence of inversion (V , %) and expert evaluation of consistency (EE, points) at different temperatures (t , °C)

According to Fig. 3 it is obvious that the maximum emulsifying ability of the system is manifested in a certain temperature range from 18 °C to 22 °C and is respectively 60... 92 %. This fact is marked by high scores of the weighted average expert evaluation. A further increase in process temperature contributed to the stratification of the system with much smaller volumes of emulsified fat. At temperatures below 18 °C, the system was excessively dense and emulsification was much slower. The inversion occurred earlier, which was manifested in non-emulsified drops of oil between the layers of viscous product.

The dependence of the viscosity of the system on the rate of oil emulsification is shown in Fig. 4.

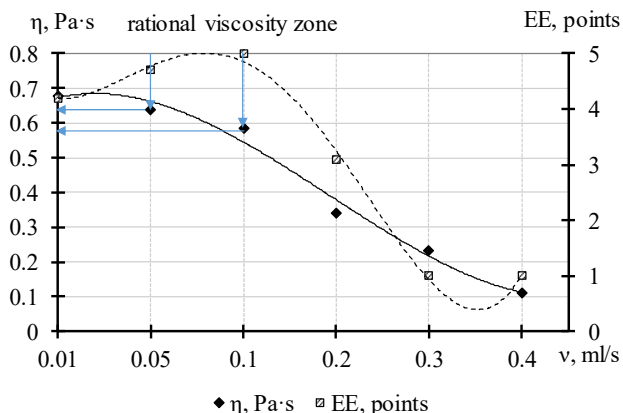


Fig. 4. Dependence of effective viscosity of emulsion systems (η , Pa·s) and expert consistency evaluation (EE, points) on oil emulsification rate (v , ml/s)

The rational zone of effective viscosity, according to experts, was characterized by indicators ranging from 0.586 Pa·s to 0.640 Pa·s. This value corresponded to the oil emulsification rate of 0.05 and 0.1 ml/s. The increase in the intensity of the oil flow to 0.2...0.4 ml/s led to incomplete emulsification and accelerated the time of system inversion. According to the data of Fig. 5, the rational range of oil dripping rate is 0.05–0.1 ml/s.

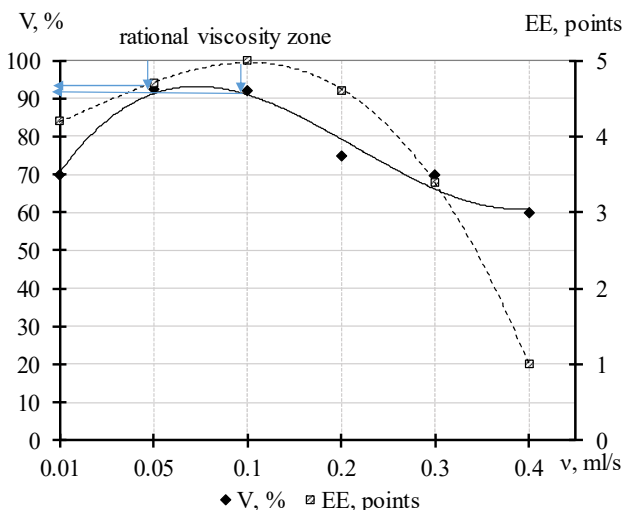


Fig. 5. Dependence of inversion (V , %) and expert evaluation of consistency (EE, points) on oil emulsification rate (v , ml/s)

Fig. 5 shows the effect of changing the rate of oil emulsification and the stability of the emulsion to delamination.

The nature of the dependence of the stability of the emulsion on the rate of emulsification correlates with the expert estimates of the consistency of the product. At the intensity of oil dripping from 0.01 to 0.05 ml/s, the resistance of the system to delamination is reduced by 1.3 times compared to its maximum value at 0.05–0.01 ml/s. Instead, at speeds above 0.1 ml/s, the system delaminates even faster, its stability decreases by more than 1.5 times.

The dependence of viscosity on the speed of rotation of the working body of the mixer was found. The data are shown in Fig. 6.

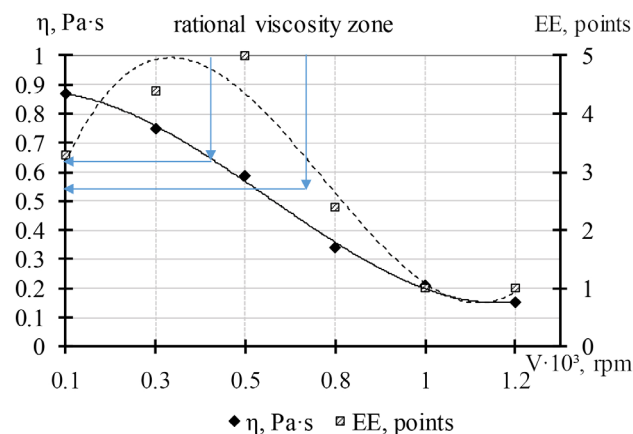


Fig. 6. Dependence of effective viscosity of emulsion systems (η , Pa·s) and expert evaluation of consistency (EE, points) on the speed of rotation of the working body (V , rpm)

The data in Fig. 6 show that the increase in the viscosity of the systems is inversely proportional to the increase in the speed of rotation of the working body of the mixer. At maximum speeds of up to 1.2·10³ rpm, the viscosity drops sharply to 0.16 Pa·s. Obtaining a system whose consistency corresponds to the values of the rational viscosity range from 0.55 to 0.63 Pa·s is achieved by rotating the working body at 0.5·10³ rpm. Instead, the mixing efficiency of the system at speeds of 0.1·10³ and 0.3·10³ rpm is low, the fat droplets are not uniform in size, they are situated between the layers of the system.

Fig. 7 clearly shows the dependence of the resistance of the system to delamination on the speed of rotation of the working body of the mixer.

According to the schedule presented in Fig. 7, the maximum stability of the system in 92 % of the absorbed oil is achieved at speeds of rotation of the working body of the mixer from 0.1·10³ to 0.5·10³ rpm. At higher values of the rotational speeds of the working body, the inversion stability drops sharply by 1.2 and by more than 3 times at 0.8·10³ rpm and 1.2·10³ rpm, respectively.

The conducted research defined the value range of rational parameters of separate indicators of the technological process of preparation of emulsion-type sauces. Therefore, it is necessary to determine the optimal values of the emulsification parameters using mathematical modelling.

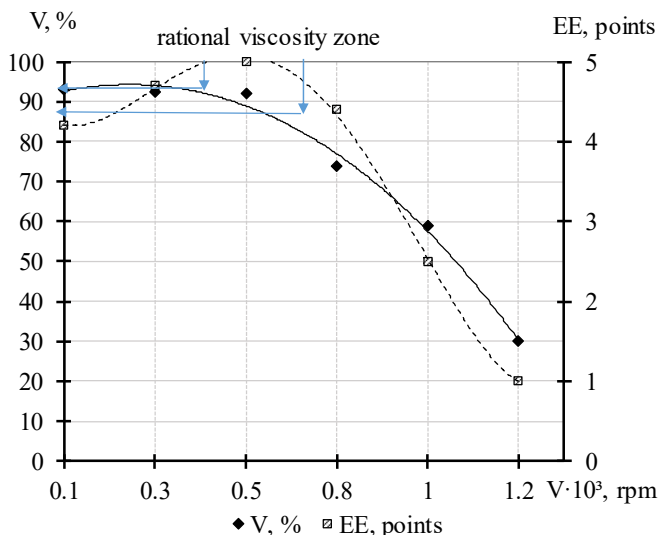


Fig. 7. Dependence of inversion (V , %) and expert evaluation of consistency (EE , points) on the speed of rotation of the working body (V , rpm)

5.2. Determination and optimization of parameters of the process of emulsification of sauces on the basis of SPCLLW

The optimal parameters of emulsification processes were determined by the method of planning a multifactor experiment according to the orthogonal symmetric Box-Wilson plan.

The most significant factors influencing the emulsification process are quantitatively measurable and controlled features:

- X_1 – content of fermented pumpkin puree, %;
- X_2 – emulsification temperature, °C;
- X_3 – emulsification rate, ml/s.

Table 1 shows the conditions for a complete three-factor experiment.

Table 1

Levels and intervals of variation factors

Levels	Factors		
	Content of pumpkin puree, %	Emulsification temperature, °C	Emulsification rate, ml/s
	X_1	X_2	X_3
Upper ($X_{i\max}$)	20	16	0.05
Basic (X_{i0})	30	18	0.1
Lower ($X_{i\min}$)	40	20	0.15

The maximum emulsifying ability, %, is taken as the response function Y . According to the results of three series of measurements to determine the fat absorption capacity for the plans of the multifactorial experiment, the average value of the emulsifying ability was determined (Table 2).

Results of the experiment

X_1	20	40	20	40	20	40	20	40	17.8	42.2	30	30	30	30	30
X_2	16	16	20	20	16	16	20	20	18	18	15.6	20.4	18	18	18
X_3	0.05	0.05	0.05	0.05	0.15	0.15	0.15	0.15	0.1	0.1	0.1	0.1	0.0	0.2	0.1
Y_{avg}	53.5	49.92	57.86	57.99	59.73	64.77	68.54	66.51	89.7	92.17	78.72	94.39	48.92	59.83	87.59

Table 2

The obtained optimal values of factors $X_1=30.24$; $X_2=18.93$; $X_3=0.10$ fully correspond to the basic levels X_{i0} of each factor. The optimal value of the emulsifying ability is $Y_{\text{max}}=92.47\%$.

The plans are built taking into account the criterion of orthogonality. With the total number of 15 experiments for the orthogonal central composite plan, the value of $\alpha=1.2153$.

Due to the fact that the object of the study has significant nonlinear properties, the first-order planning did not allow to obtain an adequate regression model. The study of the extremum region and response surface areas with significant curvature used, as a mathematical description, a second-order regression equation, which contains, in addition to the main effects b_i , all paired interactions b_{ij} , quadratic effects b_{ii} and takes into account the interaction of all three factors b_{123} .

After normalization of factor levels by the least squares method, uncorrelated estimates of regression coefficients were obtained. When transforming into natural variables, a regression model of the response surface is constructed, which takes the form:

$$Y = -335.1426 - 1.5201X_1 + 35.4176X_2 + 143.5418X_3 + 0.1137X_1X_2 + 25.8471X_1X_3 + 38.0177X_2X_3 - 1.3463X_1X_2X_3 - 0.0111X_1^2 - 1.0187X_2^2 - 10342.7254X_3^2. \quad (1)$$

The test revealed the homogeneity of the reproducibility dispersion for the experimental values of Y_{avg} (Table 2) and the theoretical levels of Y calculated by the mathematical model (1). According to Fisher's criterion there is $F=0.099 < 8.73 = F_{\text{cr}}$, where $\alpha=0.05$ – significance level; degree of freedom $m=3$ – the number of factors in the model and $n-2=15-2=13$, where n the number of experiments.

Construction of a mathematical model (1) allowed to formulate the optimization problem. From the physical content of the introduced variables, it follows that they are integral: $X_i \geq 0$ ($i=1, 2, 3$). Due to the conditions of the processing process, there is a limitation of $X_i \geq 20$, because at lower concentrations of pumpkin puree, the biological value is significantly reduced. To achieve the required quality of the product, it is desirable that the emulsifying ability be as high as possible; therefore to determine the optimal values of the process parameters, the objective function Y is directed to its maximum allowable value.

By analytically solving the optimization problem of determining the maximum of the objective function Y (1) by the method of steepest ascent

$$X_1 \geq 20, X_2 \geq 0, X_3 \geq 0, \quad Y(X_1, X_2, X_3) \rightarrow \max, \quad (2)$$

in Microsoft Excel, the optimal levels of factors and the maximum value of the response function are determined (Table 3).

Table 3

Optimal process values

Indicator Name	Variables			Target Function	Function Direction
Name	X_1	X_2	X_3	$Y(X_1, X_2, X_3)$	
Value	30.24	18.93	0.10	92.47	→ max
Limitation					
$X_1=$	30.24			\geq	20
$X_2=$	18.93			\geq	0
$X_3=$	0.10			\geq	0

Taking into account the permissible deviation of 5 %, it can be concluded that under these conditions, when the content of fermented pumpkin puree is 28.73...31.76 %, the emulsification temperature is 17.99...19.88 °C, and the emulsification rate is 0.09...0.11 ml/s, the emulsification process is characterized by a maximum emulsifying ability of 92.47 %.

6. Discussion of the results of emulsifying properties of model systems depending on technological factors

Based on the analysis of the data presented in Fig. 1, it can be concluded that the dependence of effective viscosity on pH is extreme with the maximum in the range pH=4.0...4.5. The increase in the concentration of the fat phase in the studied range of pH values is likely to increase viscosity. Thus, with increasing concentration of the dispersed phase, the space for free movement of the dispersion medium decreases. Instead, a slight decrease in the effective viscosity with its subsequent sharp drop against a decrease in acidity to pH=5.5 is explained by the fact that at low pH values the ionic strength of the solution increases, there is shielding of electrostatic ion interactions, protein macromolecules coagulate into relatively dense aggregates which leads to a decrease in the viscosity of the emulsions [36].

The data presented in Fig. 2 show that the emulsification temperature in the range of 18...22 °C is rational in terms of stabilizing properties. A decrease in temperature below 18 °C leads to a significant decrease in the effective viscosity to 0.32 ± 0.008 Pa·s. This may be caused by mechanical destruction of protein-pectin-complexes and calcium pectates during intensive mixing of the system in the process of their formation.

Based on the data shown in Fig. 3, the onset of inversion occurs in the temperature range from 18 °C to 22 °C. In the specified temperature range, the emulsifying ability of the system is 60...92 % while maintaining stability without losing the homogeneity and glossiness of the system. Further increase in temperature leads to the destruction of the emulsion. This effect of temperature on the stabilization and inversion properties of model systems is explained by the fact that the systems under study are non-Newtonian fluids. An increase in the emulsification temperature leads to an increase in the mobility of macromolecules and a decrease in the forces of mutual attraction, which explains the decrease in the viscosity and stability of the systems [37].

Fig. 4 demonstrates that the effective viscosity of the model system is directly dependent on the intensity of oil emulsification. An increase in the intensity of the oil flow to 0.2...0.4 ml/s led to its incomplete emulsification, formation of an uneven coarse dispersion system and accelerated time

of inversion (Fig. 5). When the flow intensity is reduced to 0.01 ml/s, the stratification of the system occurs at 70 % of the introduced oil, which is explained by uneven distribution of the fat phase at the set modes of rotation of the working body of the mixer.

The data (Fig. 6) prove that the increase in viscosity of the systems is inversely proportional to the increase in the speed of rotation of the working body of the mixer. At high speeds (over 0.8-10 \geq rpm) there is a rapid decrease in the stability of the emulsion (Fig. 7). Maximum emulsification of more than 90 % is achievable at speeds from 0.1-10 to 0.5-10 \geq rpm. These data are consistent with the studies that state that the influence of intense mechanical action destroys macromolecules of proteins and polysaccharides, acting as structural agents, which results in a decrease in viscosity with the stratification of the emulsion [38]. Instead, the mixing efficiency of the system at speeds from 0.1-10 \geq to 0.3-10 \geq rpm, which are lower than rational, is not sufficient for uniform distribution of fat throughout the structure and its crushing [39].

Rational conditions for ensuring the maximum emulsifying ability of 92.47 % are pumpkin puree concentration – 28.73...31.76 %, emulsification temperature – 17.99...19.88 °C, emulsification rate – 0.09...0.11 ml/s according to the results of mathematical optimization. Under these conditions, the product acquires excellent organoleptic characteristics, as close as possible to the characteristics of the “Mayonnaise” sauce, prepared by the original technology in accordance with the requirements of DSTU 4487:2005 [13]. Given the a priori high value of products based on SPCLLW for patients with lactose intolerance, due to the reduced lactose content, it was primarily appropriate to determine the rational conditions under which the product acquired excellent organoleptic characteristics. In particular, based on the characteristics of the product, the most important organoleptic indicator is the consistency, viscosity, homogeneity and gloss of the sauce. Then, the second place in terms of relevance belongs to the biological and nutritional value of the product, which is reflected in the creation of a system of constraints in mathematical calculations, where the concentration of pumpkin puree is set above or equal to 20 % of the total output.

The above-mentioned facts prompt further study of the structural and mechanical parameters and biological and nutritional value of the product during storage under different conditions and the study of microbiological indicators.

7. Conclusions

1. The research revealed the nature of the influence of technological factors on the emulsification process. 5.0...5.5 is determined as an optimal pH value of the medium. The value of the emulsification temperature, which provides the maximum emulsifying ability is 18–22 °C. The speed of oil extraction in the process of its emulsification should be 0.05–0.1 ml/s at a given speed of rotation of the working body of the mixer 0.5-10 \geq rpm. These conditions ensure the achievement of maximum values of emulsifying ability in emulsion systems with 30 % pumpkin puree content in SPCLLW.

2. The obtained numerical values of process parameters are optimized by the method of experiment planning according to the orthogonal symmetric Box-Wilson plan, which provide the achievement of maximum values of emulsifying

ability of 92.47 %. According to the set of calculations, the rational value of the emulsification temperature, which provides the maximum emulsifying ability, is 17.99...19.88 °C. The optimal value of oil dripping rate in the process of its emulsification is determined at 0.09...0.11 ml/s. The range

of optimal values of the percentage of pumpkin puree is 28.73...31.76 % of the weight of SPCLLW. The obtained values served as the basis for constructing three-dimensional surfaces of the inversion response to represent the interdependence of variables.

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