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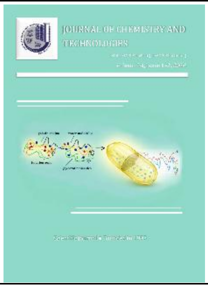

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IMPACT OF FORMULA OPTIMIZATION ON ENHANCING BIOLOGICAL VALUE AND MICROBIOLOGICAL SAFETY INDICATORS OF LACTOSE-FREE YOGURT PRODUCTS

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Abstract

The influence of formula optimization on the microbiological safety indicators of lactose-free yogurt products enriched with plant-based biologically active components was investigated. The purpose of the study was to optimize the formula using dry oat and corn milks and Jerusalem artichoke powder in order to increase nutritional and biological values and ensure regulatory quality and microbiological safety indicators. Lactose-free pasteurized milk with 2.6 % fat and *Danisco Yo-Mix 495* starter culture were used as raw materials; additional ingredients were dry oat/corn milk and Jerusalem artichoke powder. The formulation was optimized using the Statistica 10 software and the response surface method. Conditional viscosity and sensory evaluation of the product were selected as the optimization criteria. The optimal mass fractions of the raw ingredients were determined: for the formulation containing dry oat milk and Jerusalem artichoke powder – 1.43 % and 1.11 %, respectively; for the formulation containing dry corn milk and Jerusalem artichoke powder – 1.45 % and 1.07 %, respectively. It was shown that after 14 days of storage, the developed samples met the requirements of DSTU 4343:2004 in terms of physical and chemical indicators and had good microbiological safety indicators: absence of coliforms, *E. coli*, *S. aureus*, *B. cereus*, and *Salmonella* spp. The number of lactic acid bacteria was $9.0 \cdot 10^7$–$1.1 \cdot 10^8$ CFU/ml. The results obtained confirm the technological feasibility of using the studied plant components in lactose-free yogurt health-enhancing products and creation of prerequisites for expanding the range of functional fermented milk products.

Keywords: lactose-free yogurt products; dry plant milk; Jerusalem artichoke powder; optimization; response surfaces, Pareto method, microbiological safety.

ВПЛИВ ОПТИМІЗАЦІЇ РЕЦЕПТУРНОГО СКЛАДУ НА МІКРОБІОЛОГІЧНІ ПОКАЗНИКИ БЕЗПЕЧНОСТІ ЙОГУРТОВИХ ПРОДУКТІВ

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Анотація

У роботі досліджений вплив оптимізації рецептурного складу на мікробіологічні показники безпечності безлактозних йогуртових продуктів, збагачених рослинними біологічно активними компонентами. Метою дослідження була оптимізація рецептури із використанням сухого вівсяного та кукурудзяного молока і порошку топінамбура для підвищення харчової й біологічної цінності та забезпечення нормативних показників якості й мікробіологічної безпечності. Як сировину використовували безлактозне пастеризоване молоко з масовою часткою жиру 2.6 % та закваску *Danisco Yo-Mix 495*; додатковими інгредієнтами були сухе вівсяне/кукурудзяне молоко та порошок топінамбура. Оптимізацію рецептури здійснювали в програмному пакеті Statistica 10 із застосуванням методології поверхні відклику. Критеріями оптимізації були обрані умовна в'язкість та сенсорна оцінка продукту. Встановлені оптимальні масові частки сировинних інгредієнтів: для композиції з сухим вівсяним молоком і порошком топінамбура – 1.43 % та 1.11 % відповідно; для композиції з сухим кукурудзяним молоком і порошком топінамбура – 1.45 % та 1.07 % відповідно. Показано, що розроблені зразки після 14 діб зберігання відповідають вимогам ДСТУ 4343:2004 за фізико-хімічними показниками та характеризуються належною мікробіологічною безпечністю за БГКП, *E. coli*, *S. aureus*, *B. cereus* і *Salmonella spp.*; кількість молочнокислих бактерій становила ($9.0 \cdot 10^7$–$1.1 \cdot 10^8$) КУО/см^3. Отримані результати підтверджують технологічну доцільність використання досліджених рослинних компонентів у безлактозних йогуртових продуктах оздоровчого спрямування та створюють передумови для розширення асортименту функціональних кисломолочних продуктів.

Ключові слова: безлактозні йогуртові продукти; сухе рослинне молоко; порошок топінамбура; оптимізація; поверхні відклику; Парето; мікробіологічна безпечність.

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Introduction

Statement of the problem in general terms and the relevance of the study. Current food trends are characterized by a growing demand for organic yogurts with plant-based ingredients. The microbiological safety of the target product is ensured by the use of natural food additives, modern packaging, and strict hygiene standards throughout the production process. In addition, the quality of yogurt depends not only on the quality of milk raw materials, but also on the fermentation process and additional recipe ingredients, including those of plant origin [1].

The most common ingredients used to enrich yogurt products are fruits, vegetables, cereals, nuts, seeds, vegetable oils, plant and herbal extracts, fruit and vegetable fibers, as well as by-products of fruit processing. The use of such additives significantly affects the physicochemical and microbiological indicators, as well as the structural, mechanical, and organoleptic properties of products. Analysis of the composition of enriched yogurts indicates an increase in their nutritional and biological value, in particular in terms of the content of functionally significant components such as dietary fiber, phenolic compounds, vitamins, fatty acids, and minerals. A rationally selected high-quality plant additive can improve both the general health-promoting and antioxidant properties of the product [2; 3].

An analysis of recent studies and publications. In recent years, there has been a growing demand for yogurt products made from alternative sources of raw materials to milk. In this regard, scientists have studied the viability and developmental characteristics of lactic acid bacteria in the presence of plant ingredients, including cereals, nuts, pseudocereals, fruits, etc., as well as technological solutions related to the enzymatic and thermal processing of raw materials [4; 5].

Consumer demand for dairy alternatives has grown significantly. In particular, 249 samples of non-dairy yogurt alternatives were analyzed, which included extracts of coconut, almonds, various types of seeds, oats, legumes, and their combined mixtures [6; 7].

In studies devoted to enriching yogurts with ingredients of high nutritional value, pasteurized cow's milk inoculated with *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus*, which was additionally enriched with walnut and pumpkin flour. The results showed that enrichment significantly affected the pH, titratable acidity, dry matter, fat, and protein content, as well as the moisture retention capacity and total concentration of phenolic compounds in the finished product [8].

It is known that casein micelles in yogurt form aggregates with whey proteins and participate in the formation of a protein gel, which determines the consistency of the product. Due to their ability to increase the viscosity of solutions, emulsions, and suspensions, polysaccharides can be considered effective thickeners in yogurts; however, the number of studies devoted to their use in this area remains limited [9; 10].

Along with studying the physical and chemical properties, considerable attention is paid to researching the impact of plant components on the sensory indicators of product appeal, consumer perception, and the formation of emotional, holistic, and conceptual associations in consumers [11; 12].

Taking into account the trends in food personalization, lactose-free yogurts are produced with the addition of flax, sesame, and chia seeds, which are rich in vitamins and biologically active compounds. The consumption of plant-based beverages has attracted considerable attention in recent years due to the growing demand for non-dairy and non-animal sources of protein, which is caused by lactose intolerance, allergic reactions, and the diversity of consumers' food preferences and lifestyles [6; 13; 14].

A potential solution for consumers with lactose intolerance or those who prefer plant-based products, while preserving the health benefits of traditional yogurt products, is to use oat milk in combination with melon juice [15].

Scientific studies have evaluated the quality characteristics of yogurt products made from mixtures of plant-based milk from chufa and soy with cow's milk compared to yogurt made from 100 % skimmed cow's milk, which was used as a control sample. Plant-based products were characterized by higher health potential compared to traditional dairy yogurt. The results obtained indicate the possibility of using plant milk as a functional substitute for traditional components of dairy yogurts [16; 17].

An analysis of the scientific sources cited indicates the advisability of using plant-based raw materials in the production of yogurt products as an alternative to traditional dairy yogurts. The use of plant milk and functional plant ingredients not only increases the nutritional and biological value of products, but also ensures an adequate level of microbiological safety, provided that rational thermal and enzymatic treatment regimes are followed. This is especially important when developing products adapted to the needs of consumers with lactose intolerance and advocates of plant-based nutrition.

The aim of the study is to optimize the recipe composition of a lactose-free yogurt products using oat and corn milk and Jerusalem artichoke concentrate to increase its nutritional and biological value, as well as to ensure adequate quality and microbiological safety indicators.

To achieve this goal, the following tasks are to be accomplished:

- justify the choice of oat and corn milk and Jerusalem artichoke powder for use in the recipe for yogurt products;
- optimize the recipe composition of yogurt products using oat or corn milk and Jerusalem artichoke concentrate, taking into account safety indicators and functional properties;
- determine a set of sanitary-hygienic and microbiological indicators confirming the safety of the developed products;
- develop recommendations for the use of the studied plant biologically active components in the recipes of fermented milk and yogurt products.

Materials and Methods

For experimental studies, pasteurized lactose-free milk with a fat content of 2.6 % from TM "Miskmolzavod No. 1" [18] and *Danisco Yo-Mix 495* dry bacterial starter culture (*Streptococcus thermophilus*, *Lactobacillus bulgaricus*) from Danisco France SAS (France). The following new ingredients were selected for the composition of yogurt products: MANTeca dry oat milk, MANTeca dry corn milk, and Zdorovo brand Jerusalem artichoke powder.

Jerusalem artichoke powder is made by drying and grinding Helianthus tuberosus tubers. The chemical composition of the product is characterized by a high content of carbohydrates, which account for about 60.0–80.0 % in terms of dry matter, with inulin being the main component, accounting for at least 60.0 %. The content of dietary fiber, represented by pectins, cellulose, and hemicelluloses, averages 10.0 %.

Protein substances are present in an amount of 6.0%, and the content of mineral substances (ash) varies between 3.0 % and 6.0 %. The powder also contains organic acids (1.0 %–3.0 %) and phenolic compounds and other biologically active components in an amount of 0.5 %–2.0 %. The mass fraction of moisture, depending on the drying conditions, usually does not exceed 5.0 % [19].

Dry oat milk is characterized by a high carbohydrate content – 67.0 %, a significant part of which is dietary fiber (10.0 %), including β-glucans (3.0–6.0 %). The protein content is 4.0 %, lipids – 22.0 %, ash elements – 3.0 %, residual moisture – 4.0 %. This composition provides increased viscosity, moisture retention capacity, and prebiotic properties of the product [20].

Dry corn milk contains mainly carbohydrates (66.0 %), the main part of which is starch and its hydrolysis products. The dietary fiber content is lower and usually amounts to 11.0 %. The amount of protein is 0.5 %, lipids – 27.0 %, ash – 1.5 %, moisture – 5.0 %. This composition contributes to the formation of a soft consistency and stable texture of yogurt systems [21].

Dry oat milk and dry corn milk differ significantly in terms of the quantitative composition of their main nutrients, which determines the different functional and technological properties of these ingredients in yogurt products [22].

During the studies, the sensory characteristics of the produced samples were evaluated on a 20-point scale according to the sensory analysis methodology [23], and the rheological properties were assessed based on the flow time of 100 cm^3 of product [24], which served as the basis for optimization.

To optimize the recipe composition of yogurt products, the response surface methodology was used [25]. The experiment was conducted according to a design that included 12 experimental points (n = 12), with the central point repeated four times to estimate the systematic error. The results were analyzed at a confidence level of 0.95. Modelling and processing of experimental data were performed using the *Statistica 10* package (*StatSoft, Inc.*).

Physical, chemical, and microbiological indicators were determined in accordance with the requirements of the basic standard – DSTU 4343:2004 "Yogurts. General technical conditions" [26].

Lactose was determined according to DSTU 8059:2015 [27]. The conditional viscosity of the finished fermented milk product was determined using a VZ-246 viscometer.

Microbiological safety indicators were determined using classical methods, namely, the determination of MAFAnM was carried out in accordance with DSTU 8446:2015 [28]; the content of lactic acid microorganisms was

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determined in accordance with DSTU 7999:2015 [29]; the presence of yeast and mold fungi according to ISO 21527-1:2008 [30]; the presence of *Escherichia coli* according to DSTU ISO 16649-2:2014 [31]; *Staphylococcus aureus* – according to DSTU EN ISO 6888-1:2022 [32]; *Bacillus cereus* – DSTU 8040:2015 [33]; *Salmonella spp.* – according to DSTU EN ISO 6579-1:2022 [34], as well as accelerated methods using Compact Dry chromogenic media (manufacturer Nissui Pharmaceutical CO. LTD, Japan)

Results and discussion

The experimental studies were conducted using a traditional lactose-free yogurt recipe with a fat content of 2.6 %, but with skim milk powder – the primary source of lactose – completely excluded from the recipe.

Pasteurized lactose-free milk with a fat content of 2.6 % was heated to a temperature of 40…50 °C, and the dry matter content was adjusted by adding Jerusalem artichoke powder and either dry oat milk or dry corn milk. After thorough mixing, the mixture was filtered to remove undissolved particles, then heated to a temperature of 60…65 °C and homogenized at a pressure of 12.5…17.5 MPa. The resulting homogeneous mixture, standardized for fat and dry matter content, was pasteurized at 90…92 °C for 2…3 minutes. After pasteurization, it was cooled to a fermentation temperature of 42…45°C. *Danisco Yo-Mix 495* yogurt starter culture was added in the appropriate amount according to the manufacturer’s recommendations; the mixture was stirred and left to ferment for 6–8 hours. After reaching an acidity of 95–110 °T, the finished product was cooled in a refrigerator to a temperature of 4–6 °C and held for 24 hours to stabilize the structure.

To determine the effect of Jerusalem artichoke powder and dry oat or dry corn milk on the structural and mechanical properties of a yogurt product, three experimental samples were prepared using the previously described method. In the first sample, skim milk powder was replaced with an equivalent amount of Jerusalem artichoke powder; in the second, with dry oat milk; and in the third, with dry corn milk. The results of the studies showed that the addition of Jerusalem artichoke powder does not cause statistically significant changes in the apparent viscosity compared to the control sample. In contrast, the addition of dry oat and dry corn milk results in a significant increase in the value of apparent viscosity, indicating enhanced structure formation and the development of a denser product consistency.

In the experimental samples of yogurt products, organoleptic parameters (taste, aroma, consistency, color, and appearance) and apparent viscosity based on the product’s flow time were determined.

The optimal ratio of formulation components was determined using an integral quality index, which accounts for the combined influence of structural-mechanical (apparent viscosity) and sensory characteristics of the finished product. The integral index was calculated by summarizing the normalized values of the studied parameters, taking into account their weight, which allowed for an objective selection of the optimal ingredient composition.

In yogurt products formulated with raw ingredients in optimal proportions, physicochemical and microbiological parameters were determined to assess the safety of the tested samples; based on these results, conclusions were drawn regarding the feasibility of producing a range of products using this formulation.

The criteria for optimizing the formulation of the yogurt product were its apparent viscosity (AV, s) and sensory evaluation (SE, points). The independent variables varied in experiment series A were the mass fraction of dry oat milk (C_{OM}, %) and the mass fraction of Jerusalem artichoke powder (C_P, %), and in experiment series B – the mass fraction of dry corn milk (C_{CM}, %) and the mass fraction of Jerusalem artichoke powder (C_P, %).

To model the apparent viscosity (AV, ~~Pa·~~s) and sensory evaluation (SE, points) of the products, a response function in the form of a second-degree polynomial was selected.

For sample series A:

$$AV = b_0 + b_1 \times C_P + b_{11} \times {C_P}^2 + b_2 \times C_{OM} + b_{22} \times {C_{OM}}^2 + b_{12} \times C_P \times C_{OM}, \quad (1)$$

$$SE = b_0 + b_1 \times C_P + b_{11} \times {C_P}^2 + b_2 \times C_{OM} + b_{22} \times {C_{OM}}^2 + b_{12} \times C_P \times C_{OM}, \quad (2)$$

where AV is the apparent viscosity, s; SE is the sensory evaluation, points; b_0 is the constant; C_P is the mass fraction of the Jerusalem artichoke powder, %; C_{OM} is the mass fraction of the dry oat milk, %; b_1, b_{11}, b_2, b_{22}, b_{12} are the coefficients for each element of a polynomial.

For sample series B:

$$AV = b_0 + b_1 \times C_P + b_{11} \times {C_P}^2 + b_2 \times C_{CM} + b_{22} \times {C_{CM}}^2 + b_{12} \times C_P \times C_{CM}, \quad (3)$$

$$SE = b_0 + b_1 \times C_P + b_{11} \times {C_P}^2 + b_2 \times C_{CM} + b_{22} \times {C_{CM}}^2 + b_{12} \times C_P \times C_{CM}, \quad (4)$$

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where AV is the apparent viscosity, s; SE is the sensory evaluation, points; b_0 is the constant; C_P is the mass fraction of the Jerusalem artichoke powder, %; C_{CM} is the mass fraction of dry corn milk, %; b_1, b_{11}, b_2, b_{22}, b_{12} are the coefficients for each element of a polynomial.

The studies utilized a central composite rotatable design, which can be used for the selected optimization method [25]. The selection of levels and variation intervals for the factors was based on the results of preliminary experiments and an analysis of the literature.

A previous series of experiments found that adding Jerusalem artichoke powder in amounts less than 0.5 % does not produce a significant functional effect (in terms of inulin content), whereas adding it in amounts of 1.8–2.0 % results in undesirable graininess and changes in taste characteristics.

The addition of dry oat or corn milk in amounts less than 0.5 % has no significant effect on the viscosity and structure of the product, whereas at concentrations above 2.0 %, the consistency becomes excessively dense and the sensory characteristics deteriorate.

The mass fractions of Jerusalem artichoke powder and dry oat (or corn) milk varied within the ranges of 0.50–1.50 % and 1.0–2.0 %, respectively.

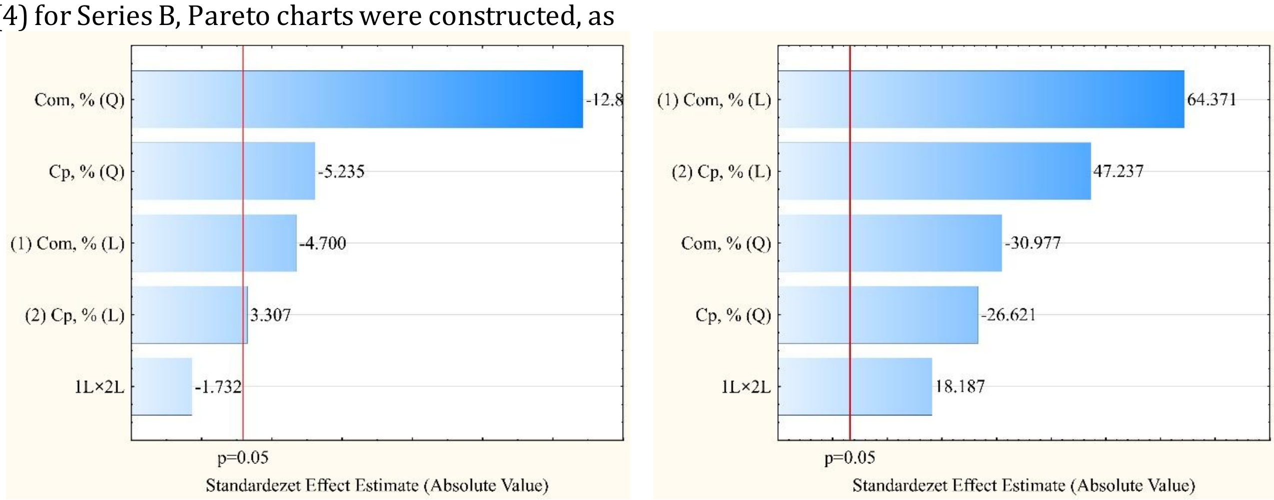
The design matrix and experimental values of the response functions are presented in Table 1. To minimize the influence of systematic errors caused by external conditions, the order of the experiments was randomized.

Table 1

Design Matrix and Response Functions

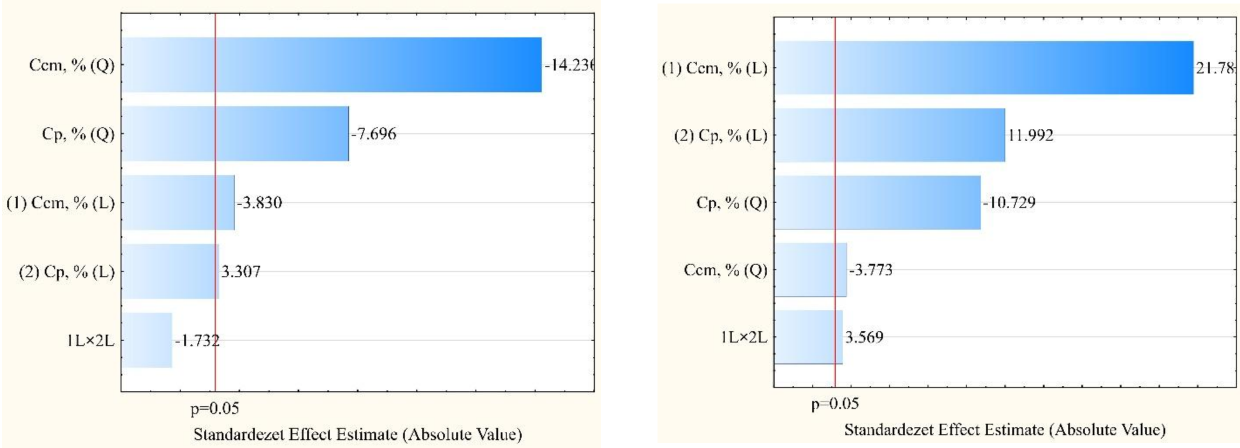
No. of experiment	Mass fraction of the Jerusalem artichoke powder (C_P)		Mass fraction of the dry oat milk (C_{OM}) or corn milk (C_{CM})		Apparent viscosity (AV), s		Sensory evaluation (SE), points	
	Coded level	%	Coded level	%	Series A	Series B	Series A	Series B
1	−1	0,65	−1	1,15	128	120	12	11
2	0	1,00	0	1,50	146	162	14	13
3	0	1,00	$-\sqrt{2}$	1,00	178	174	15	14
4	$+\sqrt{2}$	1,50	0	1,50	389	223	16	15
5	$-\sqrt{2}$	0,50	0	1,50	442	370	13	12
6	+1	1,35	+1	1,85	397	294	10	10
7	0	1,00	0	1,50	245	256	12	11
8	0	1,00	0	1,50	182	140	15	14
9	0	1,00	0	1,50	352	256	17	17
10	+1	1,35	−1	1,15	361	260	18	18
11	0	1,00	$+\sqrt{2}$	2,00	356	274	17	17
12	−1	0,65	+1	1,85	353	270	18	18

To test the significance of the regression coefficients (1) and (2) for Series A, and (3) and (4) for Series B, Pareto charts were constructed, as shown in Fig. 1 (L is the linear effect, Q is the quadratic effect)



a **b**

Fig. 1. Pareto chart for testing the significance of coefficients: a is the regression (1); b is the regression (2)



a b

Fig. 2. Pareto charts for testing the significance of coefficients: a – regression (3); b – regression (4)

The Pareto charts shown present standardized coefficients sorted by their absolute values. Analysis of the data in Fig. 1a and Fig. 2a indicates that the product of the mass fraction of Jerusalem artichoke powder (C_P) and the mass fraction of oat (or corn) milk for regressions (1) and (3) is insignificant, since the column of the estimate for this effect does not cross the vertical line representing the 95 % confidence interval. Taking this into account, the specified regression term was eliminated from models (1) and (3). For regressions (2) and (4), according to the data presented in Fig. 1b and Fig. 2b, all coefficients are significant. The resulting equations with the calculated coefficients are as follows:

For series A:

$$AV = -1017.23 + 426.38 \times C_P - 342.26 \times {C_P}^2 + 1156.24 \times C_{\mathrm{OM}} - 398.26 \times {C_{\mathrm{OM}}}^2 + 300.00 \times C_P \times C_{\mathrm{OM}} \quad (5)$$

$$SE = -43.088 + 21.151 \times C_P - 9.616 \times {C_P}^2 + 68.120 \times C_{\mathrm{OM}} - 23.616 \times {C_{\mathrm{OM}}}^2 \quad (6)$$

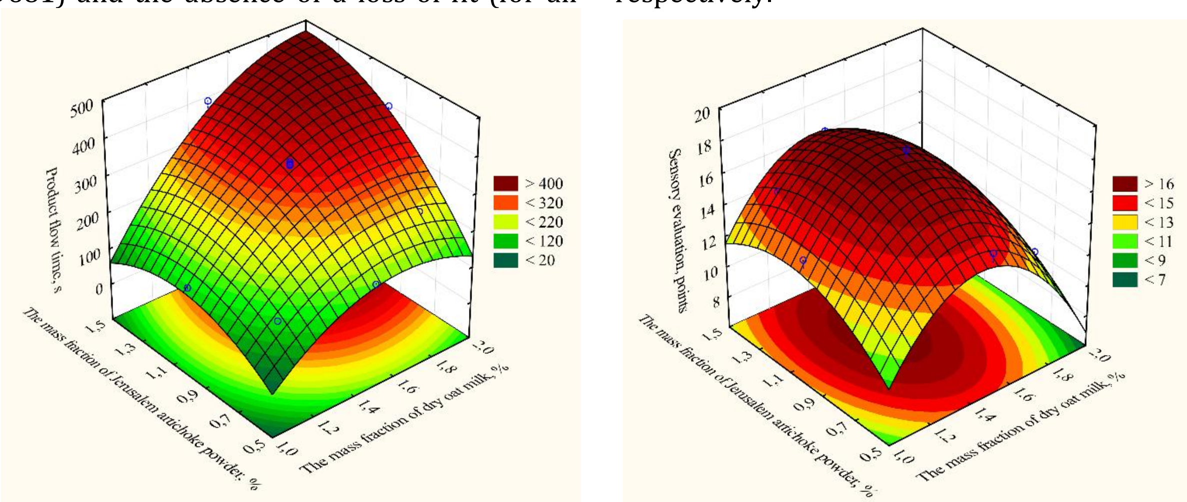
For series B:

$$AV = -442.415 + 491.461 \times C_P - 286.911 \times {C_P}^2 + 364.323 \times C_{\mathrm{CM}} - 100.911 \times {C_{\mathrm{CM}}}^2 + 122.449 \times C_P \times C_{\mathrm{CM}} \quad (7)$$

$$SE = -54.034 + 30.189 \times C_P - 14.135 \times {C_P}^2 + 76.182 \times C_{\mathrm{CM}} - 26.135 \times {C_{\mathrm{CM}}}^2 \quad (8)$$

The adequacy of the developed models for Series A (5) and (6) and Series B (7) and (8) was tested using analysis of variance. Its results, in particular, include the values of the coefficients of determination (for model (5), R^2 = 0.98178; R^2_{adj} = 0.96659; for model (6) R^2 = 0.92083; R^2_{adj} = 0.87559; for model (7) R^2 = 0.92215; R^2_{adj} = 0.85727; for model (8) R^2 = 0.93433; R^2_{adj} = 0.89681) and the absence of a loss of fit (for all four models, the significance level of this indicator is $p>0.05$) indicate that the models adequately describe the experiment.

The combined effect of the mass fraction of dry oat milk (C_{OM}, %) and Jerusalem artichoke powder (C_P, %) on the apparent viscosity (AV, s) and sensory evaluation (SE, points) of lactose-free yogurts is presented graphically in Fig. 3, a and b, respectively.



a б

Fig. 3. Relationship between apparent viscosity (*AV*, s) – a, and sensory evaluation (*SE*, points) – b, as a function of the mass fraction of dry oat milk (%) and the mass fraction of Jerusalem artichoke powder (%)

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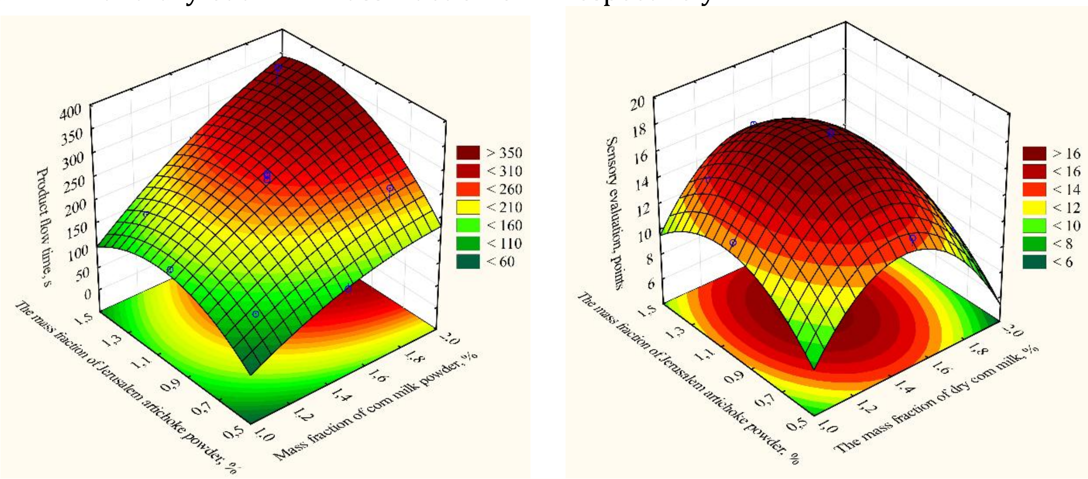
Increasing the mass fraction of hydrocolloids in the form of Jerusalem artichoke powder and dry oat milk in the formulation of lactose-free yogurts contributes to an increase in the apparent viscosity of the system (Fig. 3, a). At the same time, increasing the mass fraction of Jerusalem artichoke powder from 0.5 to 1.11 % has a more significant effect on the sensory evaluation score than increasing the mass fraction of dry oat milk. The maximum sensory evaluation score – 17.8 points (Fig. 3, b) – is achieved by the lactose-free yogurt drink with a dry oat milk mass fraction of 1.43 % and a Jerusalem artichoke powder mass fraction of 1.11 %. At the same time, the product's apparent viscosity is 349.6 s, which falls within the standard values for the product. Therefore, the specified mass fractions of Jerusalem artichoke powder and dry oat milk are optimal.

The combined effect of the mass fractions of dry corn milk (C_{CM}, %) and Jerusalem artichoke powder (C_P, %) on the apparent viscosity (AV, s) and sensory evaluation (SE, points) of lactose-free yogurts is presented graphically in Fig. 4, a and b, respectively.



a б

Fig. 4. Relationship between apparent viscosity (*AV*, s) – a, and sensory evaluation (*SE*, points) – b, as a function of the mass fraction of dry corn milk (%) and the mass fraction of Jerusalem artichoke powder (%)

As in sample A, increasing the mass fraction of hydrocolloids in the form of Jerusalem artichoke powder and dry corn milk in the lactose-free yogurt formulation contributes to an increase in the apparent viscosity of the system (Fig. 4a). Increasing the mass fraction of Jerusalem artichoke powder from 0.5 to 1.07 % and the mass fraction of dry corn milk from 1.0 to 1.45 % improves the product's sensory characteristics (Fig. 4b), whereas a further increase in the mass fraction of Jerusalem artichoke powder from 1.07 to 1.50 % and the mass fraction of dry corn milk from 1.45 to 2.0 % deteriorates the organoleptic properties of the lactose-free yogurt product. As in sample A, an increase in the Jerusalem artichoke powder content has a more significant effect on the sensory evaluation of the target product (Fig. 4b), The lactose-free yogurt drink achieves the highest sensory evaluation score – 17.6 points – at a dry corn milk content of 1.45 % and a Jerusalem artichoke powder content of 1.07 %. At the same time, the product's apparent viscosity is 261.1 s, which (as in sample A) falls within the standard values for the product. Therefore, the specified mass fractions of Jerusalem artichoke powder and dry corn milk are optimal.

The main quality indicators of the lactose-free yogurt samples studied after 14 days of storage, produced using raw materials in optimal proportions, are presented in Table 2.

Table 2

Comprehensive characteristics of the quality, stability, and safety of lactose-free yogurt products (n = 3, p ≤ 0.05)

Indicators	Lactose-free yogurt (control)	Lactose-free yogurt	
		Sample 1	Sample 2
Sensory indicators			
Taste and smell	A clean, tangy flavor with a sweet aftertaste characteristic of lactose-free products, with no off-odors.	A sour milk flavor with a sweet aftertaste characteristic of lactose-free products, with a light oat aftertaste and no foreign odors.	A sour milk flavor with a sweet aftertaste characteristic of lactose-free products, with a faint corn aftertaste.
Consistency	A uniform, smooth texture with an intact clump. Moderately dense, without gas formation		

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Continued from Table 2

Color	White	Light gray tint, due to the color of Jerusalem artichoke powder and dry oat milk	Light yellow tint, due to the color of dry corn milk
Physical, chemical, and biochemical indicators			
Mass fraction of fat, %	2.6	2.6	2.6
Mass fraction of non-fat solids content, %	9.5	11.9	12.2
Acidity, °T	105.0	115.0	120.0
Active acidity, pH	4.5	4.4	4.3
Mass fraction of lactose, %	Absent	Absent	Absent
Peroxidase, presence	Absent	Absent	Absent
Apparent viscosity (flow time), s	196.8 ± 18	349.6 ± 20	261.1 ± 15
Stability and safety indicators			
Lactic acid bacteria (*Lactobacillus bulgaricus, Streptococcus thermophilus*), CFU in 1.0 cm^3	$2 \cdot 10^7$	$9 \cdot 10^7$	$1.1 \cdot 10^8$
E. coli group bacteria (coliforms), in 1.0 cm^3	Absent	Absent	Absent
Escherichia coli, in 0.1 cm^3	Absent	Absent	Absent
Bacillus cereus, in 1.0 $см^3$	Absent	Absent	Absent
Staphylococcus aureus, in 1.0 cm^3	Absent	Absent	Absent
Pathogenic microorganisms, including bacteria of the genus *Salmonella*, in 25.0 cm^3	Absent	Absent	Absent
Yeast, CFU in 1.0 cm^3	11 ± 3	10 ± 1	7 ± 2
Mold fungi, CFU in 1.0 cm^3	4 ± 3	3 ± 1	1 ± 1

The results obtained (Table 2) are consistent with data from recent studies showing that the use of plant-based ingredients in yogurt products affects their physicochemical [13], sensory, and structural-mechanical properties [9]. A similar trend has been described in studies on plant-based and combined yogurt products [6; 7; 8].

The tested samples of lactose-free yogurt products (Table 2), with an optimized ratio of raw material components, meet the standardized physical, chemical, and microbiological parameters established by current regulatory documents, namely DSTU 4343:2004 “Yogurts. General Technical Requirements” [26]. The results obtained indicate high sensory properties of the products, in particular a harmonious taste, pleasant aroma, and uniform color, which is due to the inclusion of Jerusalem artichoke powder and oat or corn dry milk in their composition [6].

The developed and optimized formulation of the lactose-free yogurt products ensures stable microbiological safety indicators throughout the specified shelf life. The proposed formulation is characterized by technological adaptability to existing production lines using tank and thermostatic production methods, does not require significant equipment modernization, and can be integrated into standard pasteurization, homogenization, and fermentation processes. The presented research results are consistent with the literature regarding compliance with safety requirements and the absence of pathogens in yogurts [13; 17]. The increased number of lactic acid bacteria in the test samples compared to the control indicates a beneficial effect of plant components on the development of the fermentation microbiota and the intensification of the fermentation process [7; 16].

From a technological standpoint, optimizing the formulation composition helps increase the stability of the curd structure, reduce syneresis, and improve rheological properties, which reduces raw material losses and increases the yield of finished products. Replacing skim milk powder with plant-based formulation components allows for the formation of predictable structural and mechanical characteristics and maintains the activity of the starter culture microbiota at the required level. Our results are consistent with the literature [7; 9; 16], which indicates that the use of plant-based ingredients helps increase the viscosity and stabilize the structure of yogurt products, and does not inhibit the growth of the starter culture.

The feasibility of this initiative stems from the opportunity to expand the product range of lactose-free fermented milk products, thereby enhancing competitiveness and targeting the

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growing segment of consumers with lactase deficiency.

Based on the developed and optimized formulation base for lactose-free yogurt products, it is possible to develop and produce an expanded range of fermented milk products, including drinking and thick yogurts, bio-yogurts, functional yogurt desserts, fermented beverages, as well as products with increased dietary fiber and probiotic cultures.

Prospects for further research include the scientific and practical justification of the technological parameters for producing a line of lactose-free yogurt products with plant-based bioactive components for healthy nutrition.

Conclusions

The effectiveness of using dry oat or corn milk blends with Jerusalem artichoke powder in the production of lactose-free yogurt products has been scientifically proven. It has been established that the addition of plant-based ingredients rich in inulin and β-glucans ensures the formation of a stable curd structure by enhancing water-holding capacity and the interaction of protein-polysaccharide components.

The formulation of lactose-free yogurt products has been optimized. Optimal concentrations of the components were established: for the formulation with dry oat milk and Jerusalem artichoke powder – 1.43 % and 1.11 %, respectively; for the formulation with dry corn milk and Jerusalem artichoke powder – 1.45 % and 1.07 %, respectively. It was shown that the addition of plant-based ingredients ensures the formation of a stable curd structure and an increase in apparent viscosity to 320–349 s compared to the control sample.

It has been established that the optimized formulations promote the growth of lactic acid microbiota: the number of viable cells ranges from (9.0×10^{7} to 1.1×10^{8}) CFU/cm^3, which exceeds control values and is characterized by a standardized set of sanitary-hygienic and microbiological indicators, ensuring product safety throughout the regulated shelf life. At the same time, a decrease in syneresis and stabilization of the product structure were observed, as evidenced by improved rheological characteristics.

The practical significance lies in the possibility of implementing the developed formulations in production settings, as well as in expanding the range of health-promoting lactose-free fermented milk products with enhanced nutritional and biological value

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