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Lactose-free synbiotic yogurt products containing biologically active plant chlorophylls and carotenoids

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Developing new technologies is crucial for the production of new products whose chemical composition has been modified to best meet the needs of the human body in modern lifestyles. Based on this, the objective of our research was to develop a formulation and technology of symbiotic lactose-free yogurt products with biopolymers and biologically active plant pigments. The study was based on a combination of theoretical generalizations, experimental approaches, and laboratory analyses (physicochemical, microbiological, and biochemical), conducted using validated standardized methods. The enzyme preparation NOLA™ Fit 5500 was used and the carbohydrate composition of the normalized milk mixture for yogurt was adjusted in terms of lactose content from 4.75% to 0.02%. To ensure effective fermentation, we used the topinambour concentrate characterized by high prebiotic activity. We selected a symbiotic composition of probiotic microorganisms (*Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, *Bifidobacterium*, and *Lactobacillus reuteri*), which ensured a high level of viable microorganisms in the developed products and reduced the fermentation time to three hours. We established the effectiveness of increasing biological and consumer properties of lactose-free yogurts by introducing a complex of symbiotic microorganisms and biologically active compounds of plant raw materials (namely, extracts of chlorophylls [3.5%] and carotenoids [4.0%]) into their composition. Lactose-free symbiotic yogurts with carotene or chlorophyll pigments showed a significant increase in antioxidant activity (by 4.7 and 5.6 times for carotenes and chlorophyll, respectively), compared with the control sample, and provided the original inherent color of pigments. In terms of the parameters of microbiological contamination, compared with the permissible values, the developed samples of yogurt have less contamination and do not contain prohibited pathogens that cause food poisonings, which positively characterizes the developed products. The presented technological scheme for the production of colored lactose-free symbiotic yogurts in a vector image shows the possibility of using preexisting technological lines.

Keywords: symbiotic lactic acid microorganisms; *Lactobacillus reuteri*; prebiotic ingredients; plant biologically active ingredients; colored attractants; biosafety.

Introduction

The issue of providing the population with high-quality food products is of great social importance (Buzhanska & Davydovych, 2024). Therefore, the global market, including the Ukrainian market, is focused on lactose-free yogurt products containing plant-based ingredients to enhance their biological activity (Dekker, et al., 2019).

In the twenty-first century, the concept of healthy nutrition has been increasingly focused on the use of safe functional foods, which are defined as a priority direction for the development of the food industry. Among the wide range of food products, lactose-free fermented milk products are of particular scientific and practical value, as they are distinguished by their high nutritional and biological value (Bolhova, 2024). In this regard, it is important to develop technologies for producing fundamentally new products with targeted modifications of their chemical composition, capable of meeting the needs of the human organism to the greatest extent in the context of modern lifestyles. Among the diverse range of food products of plant and animal origin, probiotic dairy products—namely the line of fermented milk products—are in constant demand among the population. Innovative technologies for the production of probiotic dairy products are aimed at improving sensory characteristics and rheological properties, as well as enhancing nutritional and biological value (Solomon, 2023; Ustymenko et al., 2023; Yerlikaya, 2023). Lactose-free products constitute a special category. The food market offers a range of alternative dairy products oriented at consumers with lactase deficiency. In particular, lactose-free cow milk, as well as plant-based substitutes (coconut, soy, and almond milks) are popular among both lactose-intolerant individuals and those who follow a vegan or functional diet (Bal-Prylypko et al., 2023; Plamada et al., 2023).

Unlike the milk segment, the range of lactose-free fermented milk products remains relatively limited. In Ukraine, commercially available products include, for example, Karpatsky lactose-free yogurt (2.2% fat, no added sugar) and Galychyna drinking yogurt, which has a mild sour cream flavor and contains no sweeteners or preservatives. A distinctive feature of these products is not only that they are tailored to the needs of people with lactase deficiency, but also that they are enriched with B and A vitamins and enzymes during the fermentation process (Odarchenko et al., 2020). In particular, the consumption of lactose-free yogurts has a positive effect on the condition of the skin and hair, and supports the normal functioning of the digestive and nervous systems, contributing to the overall strengthening of the immune system. Various types of enzymes, characterized by different compositions and activities, are used in the production of lactose-free dairy products, and yogurts in particular. One of the most effective approaches is the use of the enzyme β-galactosidase (lactase), which catalyzes the hydrolysis of lactose into glucose and galactose, and these monosaccharides are easily absorbed by the body. Research also shows that enzymatic hydrolysis of lactose can help increase the viability of probiotic cultures during storage, which has a positive effect on the biofunctional properties of yogurt (Abdul Hakim et al., 2023). Thus, the use of enzymes is a promising direction in the development of lactose-free yogurt products that can meet the needs of consumers with various dietary restrictions (Mir Khan & Selamoglu, 2020; Wang et al., 2025). The studies determined the duration of enzymatic hydrolysis of lactose and established the dosages of the β-galactosidase enzyme preparations Godo-YNL2 and Maxilact LGi 5000 required to achieve 85–90% breakdown of lactose in skim milk and buttermilk relative to the initial content (Romanchuk et al., 2021; Minorova et al., 2023).

At the same time, analysis of scientific sources shows a limited range of yogurt products with added plant-based ingredients (Cardoso et al., 2025; Lipșa et al., 2025). In view of this, it is advisable to expand the range of lactose-free yogurts with a modified composition by introducing plant ingredients containing biologically active compounds to enhance the biofunctional properties of the final product.

The scientific hypothesis consists in the assumption that the combined application of enzymatic lactose hydrolysis, a symbiotic probiotic consortium, a prebiotic Jerusalem Artichoke concentrate, and plant-derived biologically active pigments (carotenoids or chlorophylls) induces statistically significant changes in fermentation kinetics, probiotic viability, antioxidant capacity, and physicochemical parameters of lactose-free yogurt in comparison with lactose-free yogurt produced without plant pigments and without a symbiotic microbial composition.

Our objective was to develop lactose-free symbiotic yogurts with biologically active plant pigments. To achieve this goal, the following was necessary: to select an enzyme preparation for lactose hydrolysis; to substantiate the choice of a prebiotic ingredient; to determine the range of biologically active pigments from plant raw materials for product enrichment; to substantiate the composition of the probiotic microbial consortium for yogurt products; to establish the effect of the selected probiotic microbial culture on the microbiological landscape (contamination levels) of yogurt products; to determine the main quality parameters of the developed products and establish the storage terms.

Materials and methods

The research was conducted in 2024–2025 at the laboratories of Odesa National University of Technology (Odesa, Ukraine). The material for the scientific research were: whole cow's milk from Agrofirma Petrodolynske LLC, the village of Petrodolynske, Odesa Oblast, Ukraine, in accordance with the State Standard of Ukraine; Yo-Flex starter cultures (*Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*) produced by Chr. Hansen Ukraine LLC, Kyiv, Ukraine; *Bifidobacterium animalis* subsp. *lactis* BB-12 culture (Chr. Hansen Ukraine LLC, Kyiv, Ukraine); and *Lactobacillus reuteri* culture produced by Vitamatic LLC, USA. The following agents were used as biologically active plant pigments: chlorophyll extracts produced by Biotus LLC Kyiv, Ukraine; our own isolated carotenoid extract (Różyło, R., 2020; Pylypenko et al., 2021); enzyme preparation NOLA™ Fit 5500 (Chr. Hansen Ukraine LLC, Kyiv, Ukraine) with activity of 5500 BLU/g.

To produce lactose-free yogurt, an innovative, highly purified, and standardized liquid preparation NOLA™ Fit 5500 (Chr. Hansen Ukraine LLC, Kyiv, Ukraine) was added to the milk. This preparation contains *Bifidobacterium bifidum* ß-galactosidase (lactase), produced by fermenting a plant substrate using a selected strain of *Bacillus licheniformis*, which is eliminated from the final product by a special technological process. Preliminary experiments established a proper enzyme concentration, which made it possible to reduce the lactose content in the initial product from 4.75 ± 0.20% to 0.02 ± 0.01%, i.e. to almost completely break down the lactose. For the effective fermentation of the normalized milk mixture for yogurt, the Jerusalem Artichoke concentrate was selected. It is characterized by high prebiotic activity due to the presence of inulin (75%) and contributes to the formation of a pleasant sweet taste in yogurt, which allows to exclude sugar from the recipe. The exact recipe for the lactose-free yogurts developed will not be published until the patent is obtained.

To increase the biological value of the yogurts, the introduction of plant-based biologically active pigments (chlorophyll and carotenoid extracts) was tested. Carotenoid and chlorophyll additives, which have the properties of coloring agents and biologically active substances, were added to the recipes of lactose-free yogurts in amounts ranging from 2.0 to 6.0%. Concentrations higher and lower than the studied range did not meet the expected sensory characteristics. The sensory characteristics of the yogurt samples were assessed at the accredited educational and scientific laboratory for sensory analysis at Odesa National University of Technology (room B-302), which is designed to evaluate food products from various industries, in accordance with Accreditation Certificate No. 201520 (2021). The involvement of experts complied with the requirements of the *WMA Declaration of Helsinki* (1964). The sensory evaluation was carried out by an expert commission of 10 people with experience in sensory analysis of food products. The consistency, taste, smell, and color of the product were evaluated. All test samples were compared with a control sample without added colorants. Lactose was determined using the Bertrand method, which is based on measuring the amount of copper (II) oxide precipitate formed when the sample is boiled (Tkachenko et al., 2018). The viscosity of the finished fermented milk product was determined according to V. Yukalo (2018). The content of probiotic microorganisms was determined by inoculating serial decimal dilutions of the test samples onto selective culture media, followed by cultivation under optimal temperature conditions, and counting viable cells (Boyte et al., 2023; Pylypenko et al., 2024).

To select a working culture for yogurt production, four samples with probiotic microorganisms were developed: sample 1 (YS) – *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*; sample 2 (YSB) – *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, and *Bifidobacterium*; sample 3 (YSR) – *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, and *Lactobacillus reuteri*; sample 4 (YSBR) – *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, *Bifidobacterium*, and *Lactobacillus reuteri*.

The specific growth rate of microbial cells (μ, h^{-1}), i. e. the increase in the number of cells per unit of time in the exponential phase, was calculated using the formula (1):

$$\mu = \frac{\lg x - \lg x_0}{\lg e\left(t - t_0\right)}, \quad (1)$$

where x, x_0 indicate the number of microbial cells at time t and t_0, respectively, and lg e = 0.43429.

Carotenoids were isolated and identified by comparing the chromatographic mobility of the studied samples with reference caroteneid preparations (Fluka, Switzerland), as well as based on the maximum absorption of pigments in the range of 200–700 nm according to Pylypenko et al. (2021). Antioxidant activity was determined by the volumetric method, and the total concentration of antioxidants was estimated based on the induction period of isopropylbenzene oxidation (Pylypenko et al., 2021).

The study was conducted in three replicates (n = 3). Statistical analysis of the experimental data was performed using ANOVA. Results are presented as the mean ± standard error (x ± SE). The statistical significance of differences among samples was assessed using the Bonferroni correction for multiple comparisons; differences were considered statistically significant at a corrected significance level of $P < 0.05$.

Results

To develop lactose-free symbiotic yogurts with biologically active plant pigments, we studied the organoleptic characteristics of samples with different concentrations of carotenoid and chlorophyll pigments, the effect of probiotic microbial cultures, and determined the quality, stability, and safety indicators of the developed samples of fermented milk products. The results of sensory studies of samples with the tested natural pigments are presented in Tables 1 and 2.

Based on the results of sensory analysis (Tables 1, 2), samples with the addition of 4.0% carotene and 3.5% chlorophyll dyes were selected. For these samples, the growth intensity was studied according to the increase in the number of microbial cells (Fig. 1) and the growth rate of microorganism cells (Table 3).

Table 1
Organoleptic characteristics of lactose-free yogurt samples with carotenoid plant pigment

Indicators	Yogurt without colorant (control)	Yogurt with colorant (amount of carotenoid coloring, %)		
		2.0	4.0	6.0
Consistency	homogeneous, intact mass, dense, no gas formation	homogeneous, intact mass, dense, no gas formation	homogeneous, intact mass, dense, no gas formation	homogeneous, intact mass, dense, no gas formation
Taste and smell	clean, sourmilk, sweet	clean, sourmilk, sweet	clean, sourmilk, sweet	clean, sourmilk, sweet
Color	uniform, with a gray tint	uniform, with a yellow-gray tint	uniform, with a pleasant rich yellow tint	uniform, rich orange

Table 2
Organoleptic characteristics of lactose-free yogurt samples with chlorophyll plant pigment

Indicators	Yogurt without colorant (control)	Yogurt with colorant (amount of chlorophyll colorant, %)		
		2.0	3.5	5.0
Consistency	homogeneous, intact mass, dense, no gas formation	homogeneous, intact mass, dense, no gas formation	homogeneous, intact mass, dense, no gas formation	homogeneous, intact mass, dense, no gas formation
Taste and smell	clean, sourmilk, sweet	clean, sourmilk, sweet	clean, sourmilk, sweet	clean, sourmilk, sweet
Color	uniform, with a gray tint	uniform, with a faint green-gray tint	uniform, with a pleasant fresh green color	uniform, dark green in color

Table 3
Specific rate of viable cells of probiotic microorganisms and their growth in 1 cm^3
during the fermentation process ($x \pm SE$, $n = 3$, duration of experiment – 6 hours)

Test sample	Sample code	Duration of experiment, hours					
		1	2	3	4	5	6
Yogurt with *Lactobacillus delbrueckii subsp. bulgaricus*, and *Streptococcus thermophilus*	YS	0.46 ± 0.02^{a}	2.07 ± 0.07^{a}	1.38 ± 0.02^{a}	0.92 ± 0.04^{a}	0.36 ± 0.02^{b}	0.07 ± 0.01^{a}
Yogurt with *Lactobacillus delbrueckii subsp. bulgaricus*, *Streptococcus thermophilus*, and *Bifidobacterium*	YSB	0.81 ± 0.01^{b}	2.05 ± 0.02^{a}	1.75 ± 0.03^{b}	0.92 ± 0.08^{a}	0.3 ± 0.01^{a}	0.07 ± 0.03^{a}
Yogurt with *Lactobacillus delbrueckii subsp. bulgaricus*, *Streptococcus thermophilus*, and *Lactobacillus reuteri*	YSR	1.15 ± 0.02^{c}	2.07 ± 0.01^{a}	1.84 ± 0.08^{b}	0.92 ± 0.05^{a}	0.46 ± 0.01^{c}	0.07 ± 0.02^{a}
Yogurt with *Lactobacillus delbrueckii subsp. bulgaricus, Streptococcus thermophilus, Bifidobacterium*, and *Lactobacillus reuteri*	YSBR	1.61 ± 0.04^{d}	2.07 ± 0.01^{a}	2.07 ± 0.03^{c}	0.92 ± 0.04^{a}	0.46 ± 0.04^{c}	0.07 ± 0.05^{a}

Note. Different letters indicate values that reliably differed one from another within one line of the table according to the results of comparison using the Tukey test with Bonferroni correction.

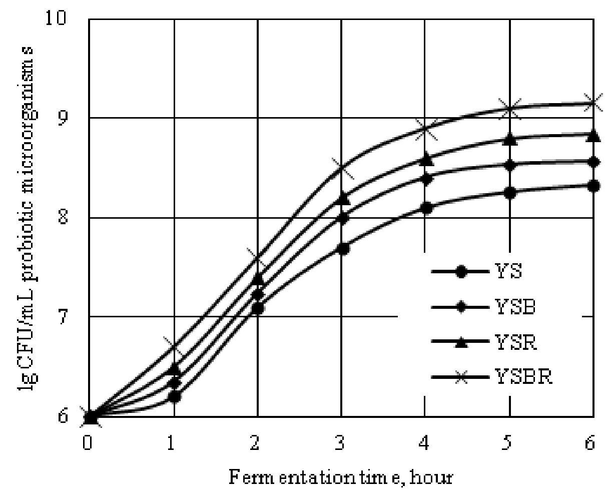

Fig. 1. Change in the number of viable probiotic microorganisms

According to the results, after six hours of fermentation, the number of microbial cells accounted for 3.2–3.3•10^8 CFU/mL in the control sample (yogurt with *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Streptococcus thermophilus*), 4.0–4.2•10^8 CFU/mL in the sample of yogurt with *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, and *Bifidobacterium*, 5.0–5.3•10^8 CFU/mL in the sample of yogurt with *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, and *Lactobacillus reuteri*, and 1.0–1.1•10^9 CFU/mL in the sample of yogurt with *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, *Bifidobacterium*, and *Lactobacillus reuteri* (Fig. 1). The addition of *Lactobacillus reuteri* to the microbial compositions (sample of yogurt with *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, and *Lactobacillus reuteri*) reduced the cultivation time to 3–4 hours compared with the traditional starter culture (sample of yogurt with *Lactobacillus delbrueckii* subsp. *bulgaricus*, and *Streptococcus thermophilus*), whereas the composition of four species of microorganisms (sample of yogurt with *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, *Bifidobacterium*, and *Lactobacillus reuteri*) reduced the cultivation time to about three hours, i.e. twice as fast. Accordingly, the growth rate of microbial cells changes (Table 3). It was found that the highest values of the specific growth rate were observed at the initial stages of fermentation, which gradually decreased later on. Such dynamics can be associated with the accumulation of metabolic products, increased acidity of the medium, and reduced availability of nutrients. The same values of the parameter at individual stages of fermentation, in particular at the fourth and sixth hours, are probably due to a very close increase in the number of viable cells in the corresponding time intervals after rounding the calculated values. Thus, the proposed composition of microorganisms exhibited symbiotic properties.

We determined a set of quality, microbiological, and safety parameters of the developed lactose-free yogurts with biologically active plant pigments (Table 4). The studies revealed that the key quality indicators listed in Table 4 remained within the standard limits specified for yogurt under the State Standard of Ukraine. The presence of carotenoids, chlorophylls, Jerusalem Artichoke concentrate, and symbiotic composition of microorganisms provided the product with a complex of properties, in particular antioxidant activity, indicating the possibility of prolonging the shelf life. With the addition of carotene dye, the lactose-free yogurt acquired an attractive yellow color, which received the highest rating from the expert commission. According to the experts, the chlorophyll dye colored the target product in a pleasant fresh green color, which was also awarded the maximum score. Lactose-free symbiotic yogurts with carotene or chlorophyll colorants showed a significant increase in antioxidant activity compared with the control sample by 4.7 and 5.6 times, respectively. The addition of the prebiotic component and the proposed symbiotic consortium made it possible to reduce the fermentation time and obtain a product with a concentration of microorganisms at 1.0•10^9 CFU/mL, while this parameter was significantly lower when using other types of fermenting consortia of microorganisms, (Fig. 1). The results make it possible to expand the range of lactose-free yogurts with symbiotic properties by introducing new biologically active products.

Table 4
Quality, microbiological, and safety parameters for symbiotic lactose-free yogurts with biologically active plant pigments (x ± SE, n = 3)

Indicators	Lactose-free yogurt without colorant (control)	Lactose-free yogurt	
		with carotene dye	with chlorophyll dye
Physical, chemical, and biochemical			
Fat mass fraction, %	2.5 ± 0.1[a]	2.5 ± 0.1[a]	2.5 ± 0.1[a]
Amount of whey discharged, %	3.0 ± 0.7[a]	2.9 ± 0.4[a]	2.7 ± 0.5[a]
Mass fraction of dry defatted substances, %	10.5 ± 0.4[a]	10.5 ± 0.2[a]	10.5 ± 0.3[a]
Mass fraction of sucrose, %	absent	absent	absent
Peroxidase or acid phosphatase	absent	absent	absent
Conditional viscosity (flow time), seconds	93.0 ± 6.0[a]	95.1 ± 4.2[a]	94.0 ± 3.1[a]
Acidity, °T	98.0 ± 10.5[a]	101.0 ± 8.3[a]	102.0 ± 9.1[a]
Active acidity (pH)	4.3 ± 0.1[a]	4.2 ± 0.1[a]	4.1 ± 0.1[a]
Concentration of antioxidants, 10^{-6} [In H], mol/kg	4.5 ± 0.1[a]	21.5 ± 0.1[b]	25.1 ± 0.1[c]
Carotenes, 10^{-3}% including:	0	19.0 ± 0.5[b]	0.4 ± 0.1[a]
β-carotene, 10^{-3}%	0	16.9 ± 0.3[b]	0.2 ± 0.1[a]
α-carotene, 10^{-3}%	0	2.0 ± 0.2[b]	0.1 ± 0.1[a]
Chlorophylls, 10^{-3}%	0	0	70.0 ± 2.1[a]
Microbiological and safety			
Number of probiotic bacteria, 10^8 CFU per 1 mL	9.6 ± 0.1[a]	11.0 ± 0.2[c]	10.0 ± 0.1[b]
Coliforms, in 0.1 mL	absent	absent	absent
Pathogenic microorganisms, including *Salmonella*, in 25 g	absent	absent	absent
Staphylococcus aureus in 1.0 mL	absent	absent	absent
Yeasts, CFU/mL	9.0 ± 3.0[a]	8.0 ± 1.0[a]	6.0 ± 1.0[a]
Molds, CFU/mL	4.0 ± 3.0[b]	3.0 ± 1.0[b]	1.0 ± 1.0[a]

Note. See Table 4.

Discussion

There is a well-established global trend toward modifying the composition of yogurt in order to enrich it with bioactive ingredients and enhance its biological activity. In particular, analytical sources indicate various modifications to yogurt formulations through the addition of:

– 5% inulin, which, according to a study (Soh et al., 2021), improved viscosity, reduced calorie content, and increased the antioxidant activity of the yogurt product without compromising consumer properties;

– 2% inulin and banana flour, improved the survival of *Lactobacillus plantarum* and *Bacillus coagulans* for 28 days of storage, reduced syneresis, and improved the texture of the product (Hussien et al., 2022);

– inulin at concentrations ranging from 3% to 15%, which reduced acidity, increased viscosity, reduced syneresis, and improved the stability of natural yogurt (Żbikowska et al., 2020);

– inulin in concentrations of 0.2%, 0.4%, and 0.6%, which improved the viability of *Bifidobacterium bifidum* and the sensory properties of yogurt (Kamel et al., 2021).

There is a known model of a yogurt-based product with Jerusalem Artichoke powder (Ndhlala et al., 2022) that belongs to the group of products of increased biological value and can be used in the production of fermented milk drinks at milk processing plants. The use of Jerusalem Artichoke powder does not require significant changes in traditional yogurt technology and, accordingly, any auxiliary equipment or space, which provides a certain economic effect (Melnyk et al., 2021). A technology has been developed for yogurt to which probiotic microorganisms immobilized on sea buckthorn berries are added, but the technological process leads to a 50% reduction in the number of probiotic cells (Terpou et al., 2019). Aqueous extracts from dried salal berries and blackcurrant pomace were used as sources of phenolic compounds to enrich yogurt drinks (Raikos et al., 2019). The addition of moringa extract to yogurt significantly accelerated the fermentation process by activating the growth of lactobacilli. The use of the extract reduced the level of syneresis to 21% and increased the moisture retention capacity of the product by 17%. The viscosity of yogurt with 0.2% moringa extract was five times higher than that of the control sample. In addition, the antioxidant activity (radical binding ability) of yogurt with the extract increased by up to 40% in a dose-dependent manner during 21 days of cold storage (Zhang et al., 2019). Similar results regarding the increase in antioxidant activity and stimulation of the growth of probiotic microorganisms were obtained when using *Spirulina platensis* powder in concentrated yogurt, where a noticeable increase in the growth of bifidobacteria and an improvement in the oxidative stability of the product were observed (Abbas et al., 2024). Moreover, algae of the Phaeophyceae family were observed to promote the growth of *Limosilactobacillus reuteri* and *Lacticaseibacillus rhamnosus* GG (Ricós-Muñoz et al., 2025). In the production of yogurts, the use of different types of probiotic bacteria leads to different fermentation products, affecting the taste, rheological, and other properties (Meybodi et al., 2020). According to Zhang et al. (2020) and Soni et al. (2020), when creating a new product, it is advisable to use symbiotic preparations of microorganisms, which are more effective than probiotic monocultures of microbes.

In this research, recipes for new types of symbiotic lactose-free yogurts were developed. The ingredients included: whole cow's milk, skimmed cow's milk, skimmed milk powder, Jerusalem Artichoke concentrate, a fermenting consortium of microorganisms, and carotene or chlorophyll dye. The technological scheme for the production of symbiotic lactose-free yogurts with biologically active plant pigments using a thermostatic method is shown in Figure 2 as a vector image.

The developed symbiotic lactose-free yogurts with biologically active plant pigments do not require any additional equipment and can be produced on existing technological lines.

Conclusion

To obtain lactose-free yogurt, the enzyme preparation Nola™ Fit 5500 was selected, which effectively reduced the lactose content in the normalized mixture for yogurt production from 4.75% to 0.02%. To improve the organoleptic properties, biological activity, and antioxidant characteristics of yogurt, it is advisable to add plant-based biologically active colorants: chlorophyll extracts in an amount of 3.5% and carotenoids in an amount of 4.0%. An effective fermentation process is achieved by using the Jerusalem Artichoke concentrate, which is characterized by high prebiotic activity, in combination with a complex of probiotic microorganisms: *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus*, *Bifidobacterium*, and *Lactobacillus reuteri*. A comparative analysis of traditional fermentation consortia with the proposed microbial symbionts demonstrated the possibility of reducing fermentation time. The probiotic effect was achieved within six hours when fermenting with a traditional composition, and within three hours when using the symbiotic composition.

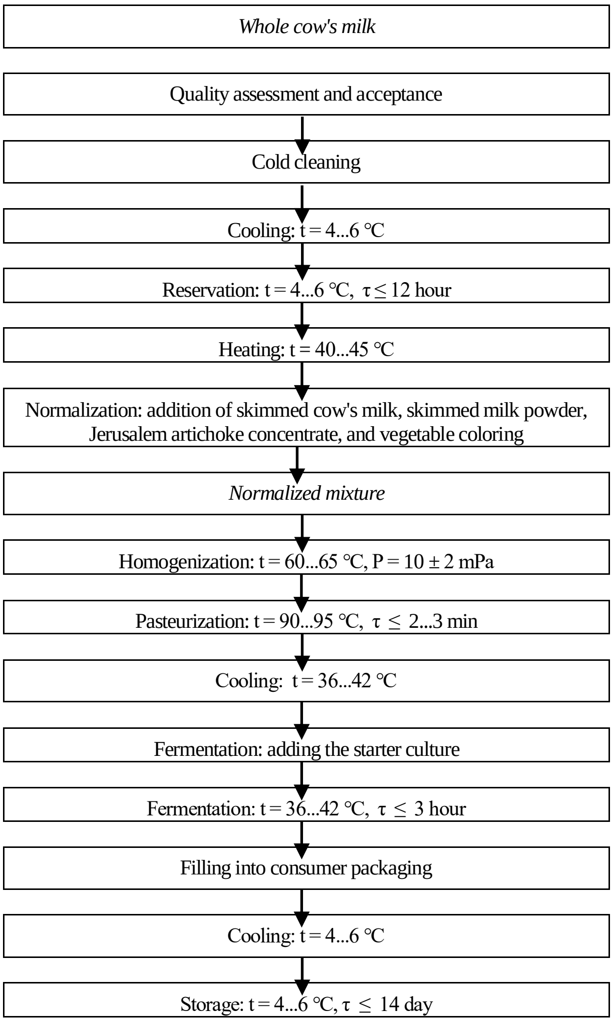

Fig. 2. Technological scheme for the production of symbiotic lactose-free yogurts with biologically active plant pigments

A range of lactose-free symbiotic yogurts was obtained, colored in pleasant fresh green and yellow colors and having 5.6 and 4.7 times higher antioxidant activities than the control sample, respectively. The main quality indicators of the developed yogurts were determined, and they meet the requirements of the State Standard of Ukraine. Studies have shown that during 14 day storage, the main quality parameters remained within the standard requirements, which indicated the possibility of prolonging the recommended shelf life.

After receiving the priority status for these studies from the National Intellectual Property Authority (State Organization Ukrainian National Office of Intellectual Property and Innovation), it will be possible to implement the recipe and technology at craft and state-owned dairy manufacturing enterprises. It is possible to expand the range of yogurt products using new natural therapeutic and prophylactic ingredients designed to correct the emotional and physical health of people in the conditions of martial law in Ukraine, and further research may focus on studying the stability of these biologically active ingredients during long-term storage and their effect on the human microbiome.

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