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DEVELOPMENT OF FUNCTIONAL YOGURT ENRICHED WITH CHIA SEEDS USING ULTRASOUND

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Introduction. Formulation of the problem

In the current context of the dairy industry's development, the implementation of innovative technologies aimed at improving product quality, streamlining production processes, and reducing energy consumption is of paramount importance.

Yogurt is one of the most popular fermented dairy products, and its consumption is growing due to its probiotic properties and high nutritional value. At the same time, traditional yogurt production technology has a number of limitations, including prolonged fermentation, the need for consistency stabilization, and the risk of syneresis.

According to the authors, a priority area is the use of functional additives to improve biological value,

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Abstract. The article investigates the effect of ultrasonic treatment on the quality indicators of set-type yogurt enriched with chia seeds (*Salvia hispanica*). The relevance of the study is conditioned the need to introduce innovative technologies in the dairy industry in order to increase the biological value of products, improve their textural characteristics, and intensify technological processes. Chia seeds are considered a promising functional ingredient rich in proteins, dietary fiber, polyunsaturated fatty acids, and antioxidants; however, their use may negatively affect the consistency and fermentation process. The aim of the study is to determine the effect of ultrasonic treatment on the physicochemical, microbiological, and organoleptic properties of yogurt with the addition of chia seeds. The object of the study is the process of ultrasonic treatment of a milk–plant system, while the subject is the changes in the properties of the finished product. The study employed a set-type yogurt production method with different concentrations of chia seeds (2–6%), as well as ultrasonic treatment (frequency 20 kHz, duration 8 minutes) at the stage of raw material preparation. According to the results of sensory evaluation, the optimal concentration of chia seeds was found to be 2%, which ensures the best consumer properties and quality of the final product. It has been proven that the use of ultrasound intensifies the fermentation process, as evidenced by an increase in titratable acidity (up to 105 °T), a decrease in pH (to 4.3), an increase in effective viscosity, and a reduction in fermentation time from 8 to 6 hours. A positive effect of ultrasonic treatment on microbiological indicators has also been established, particularly the stimulation of lactic acid bacteria growth and a reduction in the level of contaminating microflora. Additionally, it was found that ultrasonic treatment enhances the homogeneity of the system and improves the water-holding capacity of the product. The obtained results indicate the feasibility of using ultrasonic treatment in the technology of yogurts with functional additives, which allows improving product quality and increasing production efficiency.

Keywords: functional product, plant-based raw materials, starter culture, ultrasonic treatment, microbiological parameters, sensory analysis.

physical-mechanical, and organoleptic properties [1]. In the dairy industry, innovative food ingredients rich in amino acids, dietary fiber, minerals, polyunsaturated fatty acids, and antioxidants play a fundamental role [2].

One promising area is the use of ultrasonic processing, which is being actively introduced into food technology due to its ability to influence the structure and properties of raw materials.

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The use of ultrasound allows for the modification of milk's physicochemical properties, improves the dispersion of protein structures, increases the homogeneity of the system, and activates the activity of

starter cultures. This helps reduce fermentation time, improve yogurt texture, and increase product stability without the use of additional stabilizers.

In addition, ultrasonic treatment ensures effective disruption of fat globules and can contribute to increased bioavailability of nutrients, which is important in the context of developing functional foods.

Thus, studying the effect of ultrasonic treatment on the technological parameters and quality of yogurt is a relevant scientific and practical task aimed at improving the technology of fermented milk products and expanding their functional properties.

Analysis of recent research and publications

In Ukraine, the production of fermented milk products offers a wide variety. Based on their production method, they can be divided into two main groups: naturally fermented products (spontaneous fermentation) and products produced using pure cultures of lactic acid bacteria and bifidobacteria (yogurt, ryazhenka, acidophilin, sour cream, and others).

Among fermented milk products, yogurt stands out for its wide variety and high level of consumer popularity.

Yogurt is a fermented milk product fermented by *Streptococcus salivarius subsp. thermophilus* and *Lactobacillus delbrueckii subsp. bulgaricus*, but may be supplemented with *Lactobacillus*, *Bifidobacterium*, or other probiotic microorganisms [3].

Despite yogurt's high biological value, scientists are developing new recipes by enriching it with functional ingredients to expand the product range, improve organoleptic properties, and enhance nutritional value. Fruits, berries, nuts, seeds, grains, and dried fruits are added to yogurt. An innovative trend involves adding plant-based ingredients (superfoods) that are sources of biologically active substances: chia, flax, amaranth, and quinoa seeds. However, it is known that excessive use of plant-based ingredients can lead to texture defects.

Thus, optimizing the amount of natural additives is crucial for achieving optimal textural properties in yogurt [4].

In an article by Bolgova N. V. [5], the addition of quinoa flour to the recipe for a fermented milk drink was investigated, and it was determined that the organoleptic properties of the finished drink improved slightly and the shelf life increased to 20 days.

Flaxseed is widely used in the food industry as a source of vegetable oil, which contains polyunsaturated fatty acids (linoleic and linolenic) and fiber. Thanks to water-soluble polysaccharides, flaxseed has gelling properties [6]. Thus, flaxseed is used as a new ingredient in fermented milk products. In [7], it was demonstrated that the addition of flaxseed powder provided high moisture-retention capacity and improved the viscosity and rheological properties of yogurts.

In the production of gluten-free lactic acid beverages, it is advisable to use amaranth, which consists of approximately 61.3–76.5% carbohydrates (primarily starch), 13.1–21.5% crude protein, 5.6–10.9% crude fat, 2.7–5% crude fiber, and 2.5–4.4% ash [8]. The addition of amaranth contributes to the formation of a more stable and uniform yogurt structure [9].

Adding chia seeds to yogurt is a promising approach to enhancing its nutritional and biological value, in line with current trends in the development of functional foods [10].

Chia seeds are characterized by a high protein content—approximately 15–23% of dry weight. They contain a complete set of essential amino acids, and their ratio is close to the optimal one for the human body, which determines the high biological value of chia protein and makes it more balanced compared to soy protein. An important advantage is the absence of gluten, which allows it to be used in gluten-free food technologies. In addition, chia seeds are a source of dietary fiber, minerals, vitamins, and bioactive compounds, particularly antioxidants, which determine their functional properties [11].

In modern dairy processing technologies, homogenization is widely used as an effective method for ensuring uniformity in terms of organoleptic and physicochemical characteristics, including color, taste, and fat content. It helps improve product consistency, enhance the intensity of the white color, increase storage stability, prevent fat phase separation, and create a more pronounced flavor profile [12,13]. At the same time, homogenization is an energy-intensive technological process, which makes it advisable to seek alternative approaches, in particular the use of ultrasonic treatment proposed in this work.

It is known that in yogurt production, ultrasonic treatment is used to impart a homogeneous structure by reducing fat globules and water-holding capacity [14], and contributes to the strengthening and densification of the gel structure by increasing the coagulation capacity of whey proteins, shortening the duration of the fermentation process through improved lactose hydrolysis, and activating probiotic microorganisms [14].

The aim and objectives of the study are to determine the effect of ultrasonic treatment on the physicochemical, microbiological, and organoleptic properties of yogurt enriched with chia seeds (*Salvia hispanica*), as well as to establish the optimal treatment parameters for improving product quality. The object of the study is the process of ultrasonic treatment of yogurt with added chia seeds (*Salvia hispanica*). The subject of the study is changes in the physicochemical and microbiological properties of yogurt under the influence of ultrasound.

Research materials and methods

The research was conducted in the laboratory of the Department of Food Technology at Cherkasy State Technological University. The yogurt was produced

using a thermostatic method, with milk containing 2.5% fat by weight as the primary raw material. The Vivo bacterial starter culture, which contains *Lactobacillus delbrueckii subsp. bulgaricus*, *Lactobacillus acidophilus*, *Bifidobacterium lactis*, and *Streptococcus thermophilus*, was used to ferment the mixture. As part of a comprehensive analysis and in-depth synthesis of scientific and literature data, chia seeds (*Salvia hispanica L.*) were used to enhance the functionality of the yogurt. Within this process, attention was focused on the feasibility of applying ultrasonic treatment during the preparation of chia seeds in the development of yogurt technology.

The yogurt was produced in two stages. In the first stage, three samples with different concentrations of chia seeds (2%, 4%, and 6%) were prepared and compared in terms of organoleptic characteristics relative to a control sample produced using the classical method.

The sensory profile was established in accordance with DSTU 4343:2004 “Yogurts. General Technical Requirements” based on the following characteristics: taste, color, aroma, consistency, and appearance. Tasters were presented with three test samples (with varying concentrations of chia) and one control sample. The evaluation was conducted using a paired method, which allows for the assessment of a test sample by comparing it to the control sample. The evaluation was conducted on a 5-point scale. A sample that was not liked at all was rated 1 point, moderately satisfactory—2 points, satisfactory—3 points, good—4 points, and excellent—5 points. After the tasting, the total number of points for each yogurt sample was calculated based on the evaluated characteristics. The sample with the highest organoleptic score was recommended for further studies to determine the effect of ultrasonic treatment on the physicochemical and microbiological parameters of yogurt compared to the control.

In the second stage of the study, a comparative analysis was conducted on two samples: a control sample (without ultrasonic treatment) and an experimental sample (after ultrasonic treatment). During the fermentation process, changes in titratable and active acidity were monitored. The titratable acidity method is based on neutralizing the acids contained in the yogurt with an alkali solution (NaOH) in the presence of the phenolphthalein indicator until a pale pink color appears. Active acidity was measured using a pH-121 pH meter. The viscosity of the curd during yogurt production was assessed by the duration of flow at 20 °C from a 10-mL pipette. The finished product was tested for compliance with the requirements of the current standard DSTU 4343:2004. To assess the biological value of proteins, a method was used that involves calculating changes in amino acid composition upon the addition of chia seeds.

Results of the research and their discussion

Growing consumer demand for products that support and improve health is driving the rapid development of the functional food market. Such products, enriched with biologically active components—particularly probiotics and prebiotics—provide additional health benefits beyond their basic nutritional value. Yogurt, as a traditional fermented dairy product with a natural content of probiotic cultures, is a promising basis for the creation of functional products [15,16,17]. The use of chia seeds as an additive to yogurt is an innovative approach to enhancing its nutritional and biological value, fully in line with current trends in the functional food industry [18]. However, the use of chia seeds (*Salvia hispanica L.*) in yogurt production is accompanied by a number of technological and sensory challenges. One of the main issues is the high hydrophilicity of the seeds, which leads to the intensive formation of a mucilaginous gel due to the swelling of soluble dietary fibers. The formed mucous layer can act as a barrier, limiting the diffusion and availability of nutrient substrates for lactic acid bacteria fermentation. As a result, this can indirectly reduce the rate of acid formation [19].

Additionally, one should take into account the possible deterioration of the product’s sensory properties (the sensation of foreign particles, changes in taste and appearance) [18].

Thus, the use of chia seeds in yogurt production requires the optimization of technological parameters and the application of high-intensity modern technologies. This study proposes a technology for producing thermostatic yogurt enriched with chia seeds, with preliminary ultrasonic treatment.

To determine the optimal seed concentrations in yogurts, we relied on organoleptic indicators, as these are decisive in developing a new product and ensuring its consumer appeal. The sensory profile was established in accordance with DSTU 4343:2004 based on the following indicators: color, consistency, taste, and aroma (Table 1).

Four samples were prepared for the study: a control sample without chia seeds and three experimental samples containing 2%, 4%, and 6% chia seeds.

The control yogurt sample was prepared using a thermostatic method, with 2.5% fat drinking cow’s milk used as the main raw material (DSTU 2661:2010 Drinking Cow’s Milk. General Technical Conditions).

When adding the starter culture, the milk was heated to 40°C and thoroughly mixed. The starter culture contains the following types of microbial cultures: Bulgarian bacillus (*Lactobacillus delbrueckii subsp. bulgaricus*), acidophilic lactobacillus (*Lactobacillus acidophilus*), *Bifidobacterium lactis*, and thermophilic streptococcus (*Streptococcus thermophilus*).

Table 1 - Characteristics of organoleptic parameters

Indicator Name	Characteristics of Yogurts	
	No food additives or fillers	With food additives or fillers
Taste and smell	Pure fermented milk with no foreign tastes or odors	
		Moderately sweet, with a hint of the corresponding filling or flavoring
Consistency	Homogeneous, smooth, with a broken or intact curd, moderately firm without gas formation. When a stabilizer is added, it has a jelly-like or cream-like consistency	
		With particles of additives or fillers distributed throughout the entire mass or in layers
Color	From white to light yellow	Determined by the color of the filler

The fermented mixture was poured into consumer containers. Fermentation was carried out in a thermostatic chamber; samples were placed in the thermostat at 40 °C for 8 hours. In this environment, a constant temperature is maintained to support bacterial activity. The next stage is cooling—the finished curd is cooled to 4–6 °C to halt fermentation and ripening.

The technological features of preparing the experimental samples involve using chia seeds at concentrations of 2%, 4%, and 8%, which are first washed and hydrated in milk for 20–30 minutes to allow them to swell. The mixture is thoroughly stirred until evenly distributed.

The rest of the process follows the classic thermostatic method (addition of starter culture, packaging, fermentation).

A panel of 12 members conducted a sensory evaluation of the finished samples using a five-point scale. The results are shown in Fig. 1.

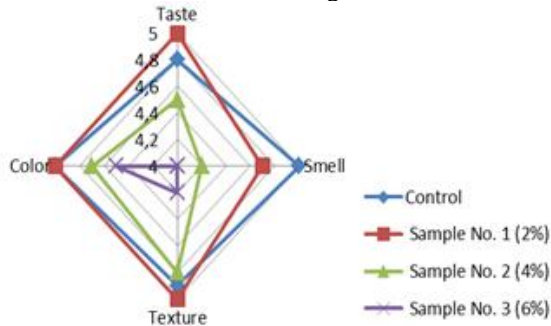


Fig. 1. Organoleptic evaluation profile

Sample No. 1 (2% chia seeds) retains the best organoleptic properties, while increasing the component concentration to 6% significantly impairs the product's taste and aroma characteristics.

The shelf life of the control and experimental samples was determined based on the dynamics of titratable acidity, as shown in Figure 2. Measurements were taken daily over a 10-day storage period.

It was found that adding 2% chia seeds resulted in a moderate increase in titratable acidity, indicating an increase in lactic acid fermentation without a significant deterioration in product quality.

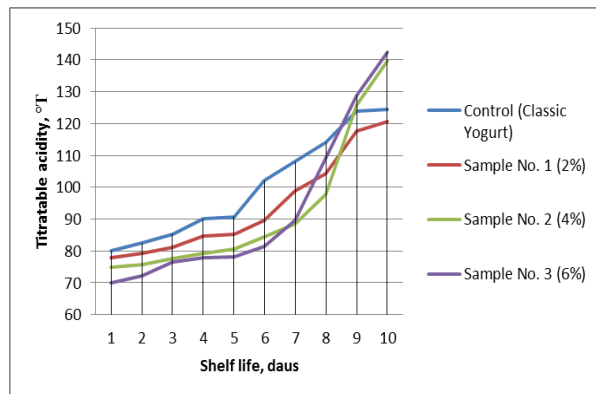


Fig. 2. Changes in titratable acidity during the storage of classic yogurt and yogurt with varying chia seed contents

On the 10th day, the addition of 4% and 6% chia resulted in the most pronounced increase in titratable acidity, accompanied by excessive acidification of the product and a potential deterioration of its organoleptic properties.

A key indicator of nutritional quality is the biological value of the product based on amino acid content, which was determined in sample No. 1 compared to the control (classic yogurt). According to Fig. 3, chia seeds have a balanced amino acid profile, with the largest proportion consisting of leucine, methionine+cystine, and phenylalanine+tyrosine [20]. These essential amino acids participate in protein synthesis, support tissue growth and repair, and contribute to metabolism. Furthermore, unlike yogurt, chia contains tryptophan, which is an important essential amino acid involved in serotonin synthesis and supports nervous system function.

Figure 4 shows a comparison of the amino acid composition of sample No. 1 (yogurt with 2% chia seeds) and the control sample (classic yogurt). The results showed that adding chia seeds increases the total content of essential amino acids by 46%, specifically: valine by 46.5%, isoleucine by 56.3%, leucine by 47.1%, lysine by 32.9%, methionine + cysteine by 46.7%, threonine by 60.8%, and phenylalanine + tyrosine by 45.8%.

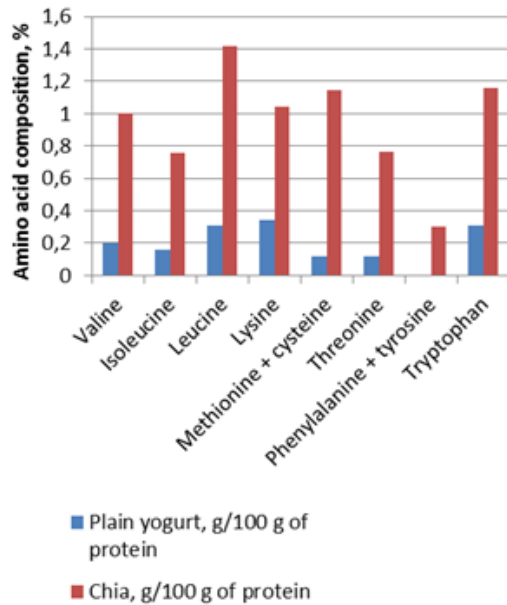
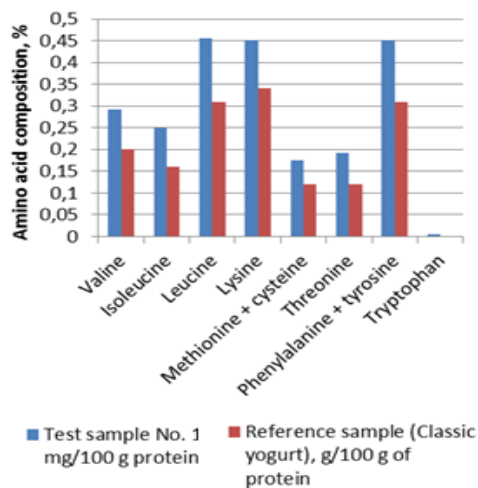


Fig. 3. Comparative analysis of the essential amino acids in classic yogurt and chia seeds.



The results of the study suggest that the developed sample, to which 2% chia seeds were added, yields a product with high biological value due to an increased content of essential amino acids.

The first sample was selected as the control sample for further studies involving the use of ultrasound. To prepare the experimental sample, pasteurized milk with 2.5% fat content was preheated to 40 °C, chia seeds (2%) were added, hydration was performed, and the mixture was treated with ultrasound at a frequency of 20 kHz for 8 minutes. This promotes: the destruction of cellular structures, better release of proteins, dietary fiber, and antioxidants, increased water-holding capacity, and activation of the particle surface for better interaction with milk proteins. The resulting sample was compared with the control sample based on the following physicochemical parameters, which are presented in Table 2.

Table 2 – Physicochemical parameters

Parameter	Reference sample	Test sample
Titrateable acidity, °T	78	90
Active acidity (pH)	4,5	4,3
Effective viscosity, Pa·s·10 ⁻³	0,68	0,77
Fermentation time, hours	8	6

The tabulated data indicate that ultrasonic treatment has a significant effect on the physicochemical and technological properties of yogurt enriched with chia seeds. In the test sample, an increase in titrateable acidity from 78 °T to 90 °T was observed, indicating a more intense accumulation of lactic acid during fermentation. This is also confirmed by a decrease in active acidity (pH) from 4.5 to 4.3, indicating a more profound acidification of the product. The effective viscosity of the yogurt after ultrasonic treatment increases from 0.68 to 0.77 Pa·s·10⁻³, which is associated with better hydration of the components, particularly the polysaccharides in chia seeds, as well as changes in the structure of the protein gel. In addition, a reduction in fermentation time from 8 to 6 hours was observed, indicating the stimulating effect of ultrasound on the growth of lactic acid microorganisms and the acceleration of biochemical processes.

The next step was to determine the effect of ultrasonic treatment on changes in titrateable acidity, as the primary indicator of yogurt's shelf life. The obtained data are presented in Fig. 5.

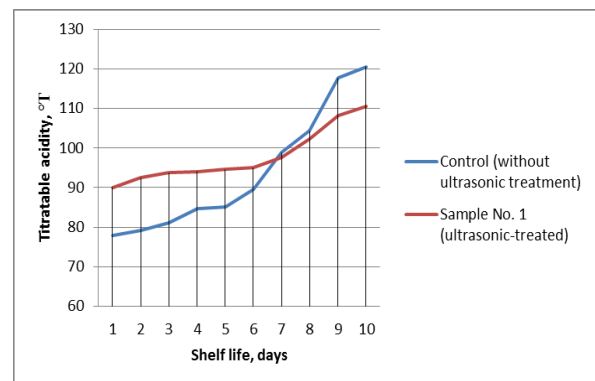


Fig. 5. Change in titrateable acidity during storage of yogurt without ultrasonic treatment compared to a sample treated with ultrasound.

The titrateable acidity in the ultrasonically treated sample increases more slowly than in the control sample, as ultrasound contributes to the stabilization of the protein-polysaccharide matrix structure and partially inhibits excessive post-acid fermentation.

Ultrasonic treatment applied during the chia seed extraction stage indirectly affects the microbiological parameters of the yogurt by altering the properties of the fermentation medium.

First, ultrasound facilitates the more complete extraction of soluble chia components—mucilaginous

polysaccharides, proteins, and bioactive substances. As a result, a more nutritious environment is formed for the development of lactic acid bacteria, which stimulates their growth and increases the total number of viable cells in the finished product.

Second, due to the cavitation effect, partial disaggregation of particles occurs, and the size of chia's structural components is reduced. This improves the availability of nutrients to microorganisms, which also contributes to the intensification of their metabolic activity, particularly the faster formation of lactic acid.

In addition, ultrasonic extraction has a moderate antimicrobial effect on foreign (contaminating) microflora, which increases the microbiological safety of the raw material. At the same time, starter cultures (*Lactobacillus*, *Streptococcus thermophilus*) are usually not adversely affected, since ultrasound is applied before the starter culture is added.

Validation of research findings. The results of the scientific research presented in this article have undergone a multi-stage scientific and practical validation process, in accordance with current requirements for publications in journals indexed in international scientometric databases.

The main theoretical principles, methodological approaches, and experimental results of the study were validated in the form of presentations and scientific reports at specialized international and national events, which ensured expert evaluation of the results by specialists in the fields of food technology, the dairy industry, and physicochemical methods for intensifying technological processes, namely at the All-Ukrainian conference "Dairy Business 2022," where the prospects for improving fermented milk product technologies were discussed and results regarding the effect of ultrasonic treatment on the intensification of fermentation and the formation of yogurt structure were presented. The research was positively evaluated at the event "Food Safety and Quality During War" in March 2023, where the co-authors participated in an expert discussion on the challenges of ensuring the stability of physicochemical and microbiological indicators of fermented dairy products. Approaches to intensifying extraction processes using physical methods of influence, which were relevant for the development of functional food products, were presented at the international scientific webinar "Funds of grant activities and fundraising: foreign and national experience" in Lublin, Poland.

To confirm the practical significance and reproducibility of the research results, this technology underwent practical testing at operating dairy processing plants, as documented in the reports on the pilot-scale testing of the technology for producing thermostatic yogurt using ultrasonic treatment and chia seeds (2024), which confirmed the stability of the technological process, a reduction in fermentation time, improved rheological characteristics and product homogeneity, and the implementation of specific

technological solutions into the production practices of dairy industry enterprises (2025), which demonstrates the feasibility of using ultrasonic treatment during the raw material preparation stage in the production of functional fermented milk products without compromising safety and quality indicators.

The research results have also been integrated into the educational process for training specialists in the specialty 181 "Food Technologies," are used in teaching professional courses, and can be recommended for further implementation and scaling up at dairy industry enterprises. This level of scientific and practical validation confirms the scientific novelty, practical significance, and international relevance of the research results.

Conclusion

The feasibility of using chia seeds as a functional ingredient in the production of thermostatic yogurt has been demonstrated. It was found that the addition of plant-based raw materials enhances the nutritional and biological value of the product; however, the concentration needs to be optimized based on organoleptic characteristics.

Based on the results of sensory evaluation, it was determined that the optimal concentration of chia seeds is 2%, as it provides the best indicators of taste, consistency, and appearance. Increasing the content to 6% leads to a deterioration in organoleptic characteristics.

The effectiveness of ultrasonic treatment during the chia seed preparation stage has been demonstrated. It was established that ultrasound facilitates the intensification of the extraction of biologically active substances, improves the hydration of components, and increases their functional activity within the product.

A positive effect of ultrasonic treatment on the physicochemical parameters of yogurt was observed: an increase in titratable acidity to 105 °T, a decrease in pH to 4.3, an increase in effective viscosity to 0.77 Pa·s·10⁻³, and a reduction in fermentation time to 6 hours. This indicates an intensification of fermentation processes and the formation of a more stable product structure.

It has been established that ultrasonic treatment indirectly improves the microbiological parameters of yogurt: it stimulates the growth of lactic acid bacteria, increases their metabolic activity, shortens the lag phase of development, and simultaneously reduces the level of foreign microflora.

It has been demonstrated that the use of ultrasonic treatment prior to fermentation, when 2% chia seeds are added, promotes a controlled and uniform increase in titratable acidity, preventing sharp post-acidification during storage. This allows for the production of a more stable functional yogurt with an extended shelf life.

New data on the use of ultrasonic treatment in combination with the addition of chia seeds indicate a promising direction for improving the technology of

fermented dairy products, allowing for the production of a product with improved functional, structural-mechanical, and microbiological properties.

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РОЗРОБКА ФУНКЦІОНАЛЬНОГО ЙОГУРТУ ЗБАГАЧЕНОГО НАСІННЯМ ЧІА З ВИКОРИСТАННЯМ УЛЬТРАЗВУКУ

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Анотація. У статті досліджено вплив ультразвукової обробки на якісні показники термостатного йогурту, збагаченого насінням чіа (*Salvia hispanica*). Актуальність роботи зумовлена необхідністю впровадження інноваційних технологій у молочній промисловості з метою підвищення біологічної цінності продуктів, покращення їх текстурних

характеристик та інтенсифікації технологічних процесів. Насіння чіа розглядається як перспективний функціональний інгредієнт, багатий на білки, харчові волокна, поліненасичені жирні кислоти та антиоксиданти, однак його використання може негативно впливати на консистенцію та перебіг ферментації. Метою дослідження є встановлення впливу ультразвукової обробки на фізико-хімічні, мікробіологічні та органолептичні показники йогурту з додаванням насіння чіа. Об'єктом дослідження є процес ультразвукової обробки молочно-рослинної системи, предметом — зміни властивостей готового продукту. У роботі використано термостатний спосіб виробництва йогурту з різними концентраціями насіння чіа (2–6 %), а також ультразвукову обробку (частота 20 кГц, тривалість 8 хв) на етапі підготовки сировини. За результатами органолептичної оцінки встановлено, що оптимальною є концентрація насіння чіа 2 %, яка забезпечує найкращі споживчі властивості продукту та якість готового продукту. Доведено, що застосування ультразвуку сприяє інтенсифікації ферментації, що підтверджується підвищенням титрованої кислотності (до 105 °Т), зниженням рН (до 4,3), зростанням ефективної в'язкості та скороченням тривалості сквашування з 8 до 6 годин. Встановлено позитивний вплив ультразвукової обробки на мікробіологічні показники, зокрема стимуляцію розвитку молочнокислих бактерій та зниження рівня сторонньої мікрофлори. Додатково встановлено, що ультразвукова обробка сприяє підвищенню однорідності системи та покращенню водоутримувальної здатності продукту. Отримані результати свідчать про доцільність використання ультразвукової обробки у технології йогуртів із функціональними добавками, що дозволяє покращити якість продукту та підвищити ефективність виробництва.

Ключові слова: Функціональний продукт, рослинна сировина, закваска, ультразвукова обробка, мікробіологічні показники, сенсорний аналіз

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