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INFLUENCE OF ULTRASOUND VIBRATIONS ON THE FERMENTATION PROCESS OF FERMENTED MILK DRINKS

Fermented dairy products are one of the critical sources of essential amino acids, vitamins, minerals, and other biologically active compounds that support the functioning of the human immune system and reduce the impact of adverse environmental factors. Therefore, daily consumption of such products is recommended for people of all ages.

Fermentation is the longest stage in producing these products, requiring significant production space and high energy consumption to maintain the required temperature. Therefore, reducing the duration of this process without harming the quality of the product is an essential area of research.

Creating different dairy products naturally enriched with nutrients and avoiding artificial additives is also essential. This contributes to developing the natural and eco-friendly products segment, reducing production costs, and making medical diets more affordable.

The sonication of fermented mixtures is a promising method to achieve these goals. In recent years, ultrasound has shown its effectiveness as an economical means to change the aggregate state, dispersion, and emulsification and accelerate substance diffusion, crystallization, and dissolution. Furthermore, it activates chemical and biochemical processes.

This method is becoming increasingly widespread in various manufacturing processes due to its cost-effectiveness and the availability of inexpensive and reliable ultrasonic equipment. Its properties make it a financially viable option for improving fermented dairy production.

The change in active acidity of milk during fermentation with mesophilic lactic acid bacteria was chosen as a control indicator. Experimentally, it was found that ultrasonic treatment with a wave frequency of 30 ± 1 kHz, a duration of 60 seconds, and a power of 240 W allows achieving optimal conditions for active fermentation by mesophilic starter cultures of direct application. This treatment mode improved the fermentation process, promoting more efficient development of starter cultures and significantly increasing the fermentation activity. This allows the preservation of valuable nutrients in the product, improves its texture and taste characteristics, and reduces production time, an essential aspect of industrial conditions.

Keywords. *Raw milk, fermented beverage, kefir, acidity, ultrasonic vibrations.*

Statement of the problem. In recent years, the consumption of fermented dairy products has been growing steadily. Their popularity is due to their pleasant taste and medicinal properties, specific consistency, and variety of composition, which allows them to meet the requirements of a wide range of consumers. The quality and safety of dairy products depend on the quality of the raw milk, determined by its sanitary and hygienic condition, chemical composition, and physicochemical properties [1, 2].

Milk and dairy products account for 41% of the total consumption of all beverages in the consumption structure of the Ukrainian population.

The production of fermented dairy products in Ukraine is significantly below the required consumption, affecting the quality of nutrition of the Ukrainian population. The increase in dairy production is limited by the low profitability of livestock farming and the fact that most of the Ukrainian population cannot buy the required amount of dairy products due to their high cost.

Fermented dairy products are one of the most important sources of essential amino acids, vitamins, trace elements, and other biologically active substances that support the activity of the human immune system, so their daily presence in the diet of people of all ages is recommended. Short-term low-frequency ultrasonic treatment of the fermented mixture is a promising tool to increase such products' profitability by reducing the fermentation process's duration, improving consumer properties, and enriching the products with biologically active substances.

Fermented dairy products are a complex mixture of coagulated protein and whey, subject to protein clot syneresis during storage. In addition, these products contain live lactic acid bacteria cells and their enzymes. These factors cause a gradual increase in acidity and proteolysis. These processes occur simultaneously and interdependently. At the same time, other physicochemical properties of the product change, such as electrical conductivity, viscosity, clot density, etc. [3, 4].

Kefir is one of the healthiest fermented milk products, accounting for almost two-thirds of products at dairy processing plants today.

The word "kefir" is of Turkish origin. In Turkish, "kef" means "health". This fermented milk product has a vast supply of nutrients and, at the same time, is a dietary food. The primary nutrients are easily digestible, making kefir especially valuable, and it is suitable for children, the elderly, and the seriously ill. The therapeutic properties of kefir are widely used in national medicine. Antibiotic substances (nisin and others produced by yeast fungi) accumulate in kefir. The main difference of kefir is its ability to have a probiotic effect on the body, i.e., favorably affecting the composition of microbes in the intestines. Kefir reduces the growth of pathogenic microorganisms, so it can prevent the development of intestinal infections and help with dysbiosis.

The risk of declining milk production, mainly due to seasonality, leads to specific difficulties in the dairy industry. That is why producing many dairy products, including fermented milk drinks based on reconstituted milk, is gaining relevance.

The fermentation process is the longest stage in fermented milk products. Ultrasonication is a promising direction for solving problems and reducing fermentation time.

The use of ultrasonic intensification of biotechnological processes in the production of fermented dairy products with other methods of ultrasonic processing of dairy raw materials will increase labor productivity, reduce energy consumption, improve the quality of finished products, extend shelf life, and create functional and innovative products with enhanced consumer qualities.

Analysis of recent research. In recent decades, ultrasound has proven to be a powerful and cost-effective tool for changing the aggregate state of matter, dispersing, emulsifying, changing the diffusion rate, crystallizing and dissolving substances, and activating chemical and biochemical reactions.

It is becoming increasingly used in various technological processes due to these properties and the emergence of relatively inexpensive, efficient, and reliable ultrasonic equipment, which allows the generation of ultrasounds of different frequencies and intensities.

Studies of the effect of ultrasound on biotechnological systems of the food industry are reflected in the works of many domestic and foreign scientists, namely Luhovskyi O.F., Bernyk I.M., M. Ashokkumar, J. Chandrapala, Y. Chisti, MF. Ertugay, N. Masuzawa, T.M.P. Nguyen, M. Sakakibara, P. Sfakianakis, B. Sizu, M. Palmer, T. Toba and others.

Consumer demand is for high-quality natural food without preservatives and other chemical additives. Due to this, various non-chemical methods of modernizing production technologies are gaining popularity in the food industry, one of which is ultrasonic processing [5, 6].

Currently, ultrasonic vibrations are used in technological processes to change the aggregate state of a substance, disperse, emulsify, change the diffusion rate, crystallize and dissolve substances, and activate chemical and biochemical reactions [7, 8].

Fermented dairy products from milk subjected to ultrasonic homogenization have increased viscosity, improved rheological properties, and textural characteristics [9].

Furthermore, ultrasound is successfully used in the dairy industry to inactivate pathogenic bacteria such as Escherichia coli, Staphylococcus aureus, and Listeria monocytogenes in raw milk [10, 11] up to complete sterilization of the product [12].

Short-term sonication for the processing of dairy products is preferable, as cavitation-induced pyrolysis reactions and oxidation of the lipid component by free radicals result in the formation of volatile organic compounds that give the milk a rubbery taste [13].

Currently, two approaches to the intensification of lactic acid bacteria fermentation processes are known, such as the preliminary ultrasonic preparation of the milk medium [14, 15] and cultivation under continuous exposure to ultrasound.

Ultrasound is an effective technology that helps preserve nutrients, increase shelf life, and improve the quality of dairy products. In the dairy industry, sonication promotes the inactivation of microorganisms: intracellular cavitation leads to cell membrane damage, the formation of free radicals, and DNA damage of microorganisms [16].

High-intensity ultrasound also increases the viability of probiotic strains in starter cultures, which are used to produce fermented milk drinks and foods. It accelerates the hydrolysis of lactose by releasing lactase and stimulating acid production, which shortens the fermentation time. Ultrasonic processing improves the organoleptic properties of fermented milk products and increases their nutritional qualities by increasing the number of bioactive peptides and oligosaccharides and reducing lactose levels [17].

Ultrasound also reduces cheese maturation time by promoting the release of intracellular enzymes, accelerating the breakdown of proteins, which improves texture, taste, and nutritional characteristics [18].

High-intensity ultrasound in the production of yogurt reduces the size of fat globules, improves viscosity, reduces syneresis and increases gel strength, and promotes the stable formation of a dense consistency due to the denaturation of whey proteins, the breakdown of casein micelles and the recombination of protein fractions [19].

The work aimed to develop the technology of a fermented milk drink (kefir) using ultrasonic processing, which would ensure the maximum intensification of biotechnological processes.

The main material. The fermented dairy products obtained from fermentation have a vibrant composition of various microorganisms, lactobacteria, and bifidobacteria, which benefit the human body as a whole.

The favorable properties of kefir have been known for a long time and are indisputable. The famous physiologist and Nobel Prize winner I.I. Mechnykov, one of the main initiators of kefir production, claimed that many pathogenic bacteria accumulate in the human intestine, causing accelerated aging and the source of many diseases.

You can destroy these microorganisms with the help of fermented milk products, especially with kefir.

Kefir is considered one of the most healthful fermented milk products for the human body, a source of proteins, fats, and carbohydrates. In addition, due to its high content of healthy microflora, kefir has a positive effect on digestion and is recommended for use in case of gastrointestinal diseases. This product is made by fermenting milk using a unique kefir starter.

Milk is the primary raw material, so kefir production would not be possible without it. Moreover, cow's milk is mainly used for kefir production.

However, producing kefir products using direct-applied starter cultures (dry or deep-frozen) has become increasingly common. The kefir product does not differ in taste from natural kefir, but its production requires significantly less labor and economic costs.

The effect of ultrasonic treatment at a frequency of 30 ± 1 kHz, which corresponds to the operating modes of industrial homogenizers, on the activity of mesophilic cultures of direct-injection starter was also determined by measuring several indicators of fermented samples obtained from four parallel cultivations.

A lyophilized mesophilic direct-applied starter from the Italian manufacturer Good Food was used as an experimental culture.

Bacterial composition of the starter: Leuconostoc Cremoris Lactococcus Cremoris Lactococcus Lactis Lactococcus Diacetylactis Saccharomyces Cerevisiae Lactobacillus Bulgaricus Lactobacillus Acidophilus Bifidobacterium Bifidum.

The bacteria were cultivated at a constant temperature of 32±2 °C. The fermented milk samples were sonicated before and 2 hours after cultivation using an ultrasonic setup with a piezoceramic transducer at a frequency of 30±1 kHz. The processing time for different samples ranged from 60 to 180 seconds; the total power output varied from 80 to 320 W/dm^3.

An ultrasonic bath was used for the study (Fig. 1).

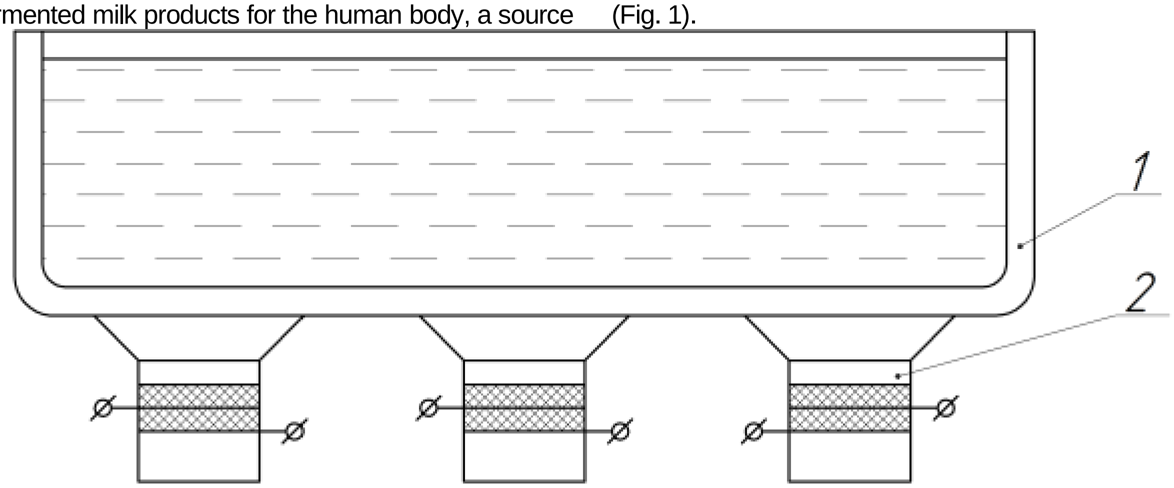

Fig. 1. Scheme of the ultrasonic bath: 1 - working chamber; 2 - ultrasonic emitter

The setup consists of a rectangular container with ultrasonic emitters on the bottom.

Technical specifications

Power consumption from the circuit, no more W 60	50
Supply voltage, V	220 ± 22
Frequency, Hz	50
Device operating frequency, kHz	18 ± 1.2
Electrical oscillation conversion principle	reverse piezoelectric effect
Piezoceramic material	lead zirconate-titanate
Number of piezo elements, pcs.	3
Geometric shape of transducers	circles

The working chamber was filled with the test liquid and processed following the developed experimental program.

The titratable acidity of the samples was monitored during the cultivation. The formation of a stable clot in the control sample determined the end of the cultivation.

The activity of the direct inoculation starter was higher than that of the freeze-dried culture; the total duration of each cultivation was 6 hours until the clot was ready.

The titratable acidity of the samples was measured after sonication at the beginning of the cultivation and two hours after the start of the cultivation. Measurements were performed every hour until the clot was ready.

The values of titratable acidity after cultivation in the samples are shown in Table 1.

Table 1

Titratable acidity of fermented milk samples after the end of fermentation with mesophilic direct inoculation starter cultures under different modes of ultrasonic processing

Processing capacity, W/dm^3	Titratable acidity, °T		
	Processing time, s		
	60	120	180
80	69±1	70±2	70±2
120	70±1	72±2	72±2
160	71±2	73±1	72±2
200	72±2	72±2	74±2
240	73±1	71±2	72±2
280	71±2	71±3	71±1
320	72±1	73±3	70±3
Control	68±2		

The fastest increase in titratable acidity is observed when using a treatment mode of 240 W/dm^3 for 60 seconds.

The dynamics of the titratable acidity increase in fermented milk samples during 6 hours of cultivation are shown in Figures 2-4.

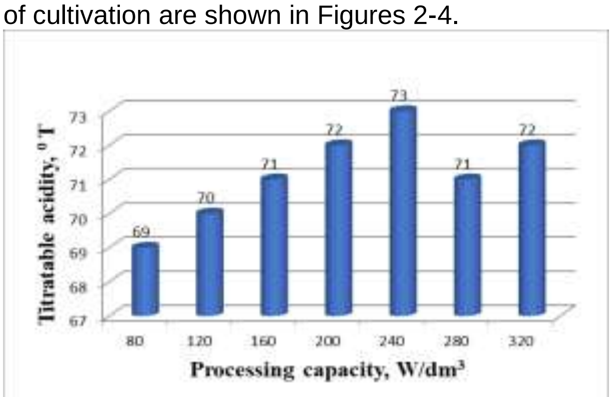

Fig. 2. Dynamics of titratable acidity increase in milk samples during fermentation with mesophilic starter cultures of direct application at a sonication duration of 60 seconds and different power levels

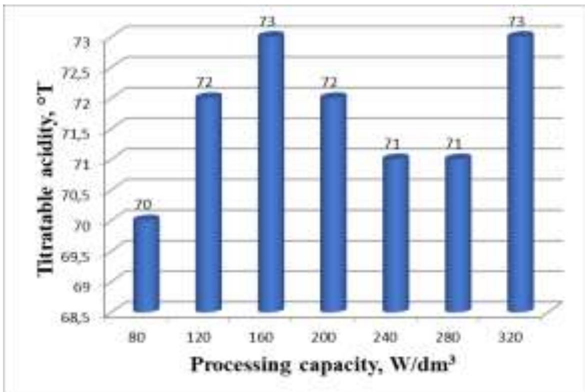

Fig. 3. Dynamics of titratable acidity increase in milk samples during fermentation with the mesophilic starter of direct application at a duration of sonication of 120 seconds and different power

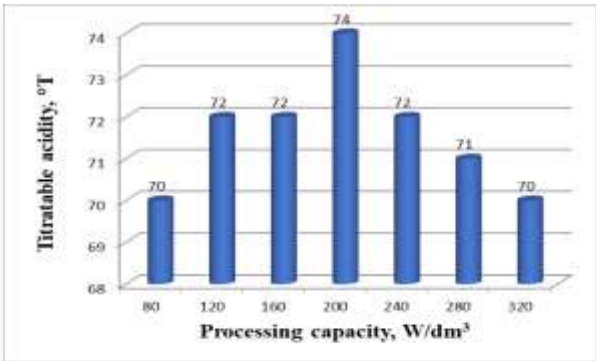

Fig. 4. Dynamics of titratable acidity increase in milk samples during fermentation with mesophilic starter cultures of direct application at a sonication duration of 180 seconds and different power levels

The technological process of natural kefir production in this way includes the following processes: milk preparation, which involves pasteurization and homogenization. At these stages, it is essential to comply with all technological requirements, as the quality and performance of the finished product depend on their correctness. It is about ensuring certain taste qualities of kefir and preventing pathogenic forms of microflora from being present in it. The product is cooled after pasteurization and homogenization at high temperatures. The optimal temperature for fermentation is 20-25 °C.

We use a direct inoculation starter for the production of kefir. According to classical technology, fermentation occurs for 12 hours at a temperature until the required acidity (90-100 °T) is reached. At this stage, the microflora grows, and the acidity of the product increases.

The use of ultrasound makes it possible to accelerate the exchange between cells and the nutrient medium, reduce the duration of enzymatic hydrolysis, and maintain the activity of some enzymes, which allows the stimulation of the growth of microorganisms and increases the rate of biosynthesis of biologically active substances, biomass accumulation, as well as accelerate the adaptation of cells to new conditions and, accordingly, accelerate the efficiency of fermentation processes.

The kefir production technology using the tank method was carried out according to the following scheme (Fig. 5).

After fermentation, the kefir is stirred and cooled to the ripening temperature. Mixing of the product begins 60-90 minutes after the start of its cooling time and is carried out for 10-30 minutes. After mixing and cooling to 20 ^{0}C, the clot is left alone.

Milk quality assessment and collection
↓
Cold cleaning
↓
Cooling, (4 ± 2) °C
↓
Storage, (4 ± 2) °C up to 24 h
↓
Heating, 40-45 °C
↓
Mechanical cleaning and normalization
↓
Heating (65 ± 5) °C
↓
Deodorization, homogenization: (65 ± 5) °C, (15±2.5) MPa
↓
Pasteurization (92 ± 2) °C, 3-30 min
↓
Cooling to fermentation temperature
↓
Fermentation
↓
Fermentation to pH = 4.6, sonication
↓
Cooling to t = 15 - 20°C (mesophilic microflora)
↓
Mixing
↓
Packing in airtight containers, packaging, labeling
↓
Aftercooling (4 ± 2) °C
↓
Storage, (4 ± 2) °C no more than 14 days

Fig. 5. Flow diagram of kefir production with ultrasonic treatment of the starter

The maturation of kefir takes 6-10 hours. During maturation, yeast is activated, and alcoholic fermentation occurs, forming alcohol, carbon dioxide, and other substances that give this product its specific properties.

After the ripening, the tank's kefir is stirred for 2-10 minutes before bottling.

Packaging and labeling are carried out following the standard requirements for this product. It is recommended that packaged kefir be kept in a refrigerator before sale to improve the consistency of the finished product.

When the kefir reaches the required conditional viscosity and temperature of 6 ^{0}C, the technological process is considered complete, and the product is ready for sale.

Conclusions. Today, consumers prefer high-quality natural foods that do not contain preservatives or other chemical additives. This contributes to the growing popularity of non-chemical methods of improving technologies in the food industry. One such method is ultrasonic processing, which ensures product quality preservation without using artificial substances.

During experimental studies, it was found that ultrasonic treatment with a wave frequency of 30 ± 1 kHz, a duration of 60 seconds, and a power of 240 W allows achieving optimal conditions for active fermentation by mesophilic starter cultures of direct application. This treatment mode improved the fermentation process, promoting more efficient development of starter cultures and significantly increasing the fermentation activity. This allows the preservation of valuable nutrients in the product, improves its texture and taste characteristics, and reduces production time, an essential aspect of industrial conditions.

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ВПЛИВ УЛЬТРАЗВУКОВИХ КОЛИВАНЬ НА ПРОЦЕС ФЕРМЕНТАЦІЇ КИСЛОМОЛОЧНИХ НАПОЇВ

Ферментовані молочні продукти є одним з ключових джерел незамінних амінокислот, вітамінів, мікроелементів та інших біологічно активних сполук, що підтримують функціонування імунної системи людини та зменшують вплив негативних чинників довкілля. Тому щоденне споживання таких продуктів рекомендоване для людей різного віку.

Найбільш тривалим етапом у виробництві цих продуктів є ферментація, яка потребує значних виробничих площ та високих енерговитрат для підтримки необхідного температурного режиму. Тому скорочення тривалості цього процесу без шкоди для якості продукту є важливим напрямком наукових досліджень.

Також актуальним є створення різних видів молочної продукції, яка природно збагачена корисними речовинами, що дозволяє уникнути використання штучних добавок. Це сприяє розвитку сегменту натуральної та екологічної продукції, знижує витрати виробництва і робить лікувальні дієти більш доступними.

Перспективним методом для досягнення цих цілей є використання ультразвукової обробки ферментованих сумішей. Останніми роками ультразвук показав свою ефективність як економічний засіб для зміни агрегатного стану, дисперсії, емульгування, а також для прискорення дифузії, кристалізації та розчинення речовин. Крім того, він активує хімічні та біохімічні процеси.

Завдяки цим властивостям, а також доступності недорогого і надійного ультразвукового обладнання, цей метод набуває все більшого поширення у різних виробничих процесах.

У дослідженнях як контрольний показник обрали зміну активної кислотності молока під час ферментації мезофільними молочнокислими бактеріями. Експериментально було встановлено, що ультразвукова обробка з частотою хвиль 30 ± 1 кГц, тривалістю 60 секунд і потужністю 240 Вт дозволяє досягти оптимальних умов для активної ферментації мезофільною закваскою прямого внесення. Виявлено, що вказаний режим обробки покращує процес сквашування, сприяючи більш ефективному розвитку заквасочних культур і значно підвищуючи активність ферментації. Це дозволяє зберегти цінні поживні речовини в продукті, поліпшити його текстуру та смакові характеристики, а також скоротити час виробництва, що є важливим аспектом для промислових умов.

Ключові слова. *Молоко-сировина, ферментований напій, кефір, кислотність, ультразвуковові коливання/*

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