CHAPTER 6

OPTIMIZATION OF THE BUTTERMILK FERMENTATION PROCESS IN THE TECHNOLOGY OF LOW-LACTOSE YOGURT

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INTRODUCTION

In the current conditions of global transformation of food systems, the implementation of the principles of sustainable development, resource efficiency, and ESG-oriented (Environmental, Social, and Governance) production in the food industry is of particular importance. The FoodTech concept involves the active use of innovative technologies aimed at the rational utilization of raw material resources, minimization of food waste, increasing the nutritional value of products, and adapting food technologies to modern requirements of healthy nutrition. In this context, the dairy industry requires new technological solutions related to the comprehensive processing of secondary dairy raw materials, reducing environmental impact, and creating functional products with enhanced biological value.

One of the promising directions for implementing circular economy principles in the dairy industry is the use of buttermilk as a valuable secondary raw material in the technology of fermented dairy products. Buttermilk is characterized by a high content of proteins, phospholipids, minerals, biologically active components of fat globule membranes, and possesses good functional and technological properties. At the same time, a significant portion of buttermilk in production conditions is underutilized, which contradicts modern ESG principles and the sustainable development of food systems. Its inclusion in the production of low-lactose fermented dairy products allows not only for increasing the resource efficiency of enterprises but also for expanding the assortment of functional and special-purpose products.

The relevance of developing low-lactose yogurts is driven by the steady growth in the number of consumers with lactase deficiency and an increased demand for healthy food products. Reducing the lactose content in fermented dairy products improves their digestibility, enhances consumption comfort, and expands the target audience of the products. However, using buttermilk in low-lactose yogurt technology requires the optimization of technological parameters, as changes in the composition of the dairy base affect the lactic acid fermentation process, the rate of acidity accumulation, the formation of the clot structure, water-holding capacity, and the organoleptic characteristics of the finished product.

The optimization of the buttermilk fermentation process is of particular importance, as it is one of the key stages in forming the quality of low-lactose yogurt. A rational selection of starter cultures, temperature regimes, fermentation duration, and the degree of lactose hydrolysis makes it possible to intensify the technological process, ensure the stability of the product's structure, and enhance its consumer properties. Furthermore, optimizing the fermentation process contributes to increasing the energy efficiency of production and reducing technological losses, which aligns with modern requirements of ESG-oriented food manufacturing.

Thus, research aimed at optimizing the buttermilk fermentation process in the technology of low-lactose yogurt is relevant from both scientific and practical perspectives. It combines the principles of FoodTech, the innovative transformation of food systems, resource conservation, and the creation of functional products tailored to the modern needs of consumers and the sustainable development of the food industry.

1. Definition of prerequisites and formulation of the research problem

milk and dairy products are valuable sources of essential nutrients required for the normal functioning of the human body, including complete proteins of animal origin, calcium, phosphorus, as well as vitamins B2 (riboflavin) and D (calciferol)[1]. Due to their balanced composition, dairy products play an important role in the formation and maintenance of bone tissue, ensuring the normal course of metabolic processes, the functioning of the nervous system, and supporting immunity. Lactic proteins are of particular significance, characterized by high biological value and containing all essential amino acids necessary for growth, tissue repair, and the synthesis of enzymes and hormones[2].

Fermented dairy products are a source of probiotic microorganisms that help maintain a normal balance of the gut microbiota, improve digestive processes, and enhance the barrier functions of the body. Disruption of the gut microflora

[1] Sharikadze O. Malabsorption and lactose intolerance: pathophysiology, diagnosis and treatment of pathogenesis. *World Science*. 2022. Vol. 75. No. 3. P. 1–13.

[2] Essa, M. M., Bishir, M., Bhat, A., Chidambaram, S. B., Al-Balushi, B., Hamdan, H., Govindarajan, N., Freidland, R. P., & Qoronfleh, M. W. Functional foods and their impact on health. *Journal of food science and technology*. 2023. Vol. 60. No 3. P. 820–834. https://doi.org/10.1007/s13197-021-05193-3.

composition can lead to a decrease in immune defense, impaired absorption of nutrients, and the development of functional disorders of the digestive system[3].

Insufficient consumption of milk and dairy products throughout a person's life is associated with an increased risk of developing chronic non-communicable diseases, particularly pathologies of the cardiovascular and musculoskeletal systems. A deficiency in calcium and vitamin D can cause a decrease in bone mineral density, the development of osteoporosis, and an increased risk of fractures. At the same time, a lack of complete protein and micronutrients negatively affects metabolic processes, the functional state of the body, and the overall quality of life of the population. However, the consumption of dairy products becomes impossible for individuals suffering from lactose intolerance – a functional disorder of the gastrointestinal tract caused by the impaired breakdown of lactose in the small intestine by the enzyme lactase[4].

According to WHO data, approximately 70% of the world's population is unable to fully digest the lactose contained in milk and dairy products. For Ukraine, this figure stands at 15–35% of the adult population[5]. When lactase enzyme activity is greater than 50%, symptoms of lactase deficiency usually do not manifest. The primary method for treating lactase deficiency is dietary therapy, which involves the complete exclusion or limited consumption of products containing lactose[6].

Since milk and dairy products are valuable sources of essential nutrients, excluding them from the diet will lead to an insufficient intake of many beneficial substances and, as a result, a decrease in work capacity and body resistance to diseases and other negative environmental factors[7]. Therefore, a promising direction for resolving this issue is the creation of technologies for dairy products that are lactose-free or have a reduced lactose content.

Market analysis of lactose-free and low-lactose dairy products in Ukraine indicates that the largest share belongs to domestic goods such as kefir and

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[3] Faienza M. F., Giardinelli S., Annicchiarico A., Chiarito M., Barile B., Corbo F., & Brunetti, G. Nutraceuticals and Functional Foods: A Comprehensive Review of Their Role in Bone Health. *International Journal of Molecular Sciences*. 2024. Vol. 25. No. 11. P. 5873–5885. https://doi.org/10.3390/ijms25115873.

[4] Corgneau M., Scher J., Ritie-Pertusa L., Le D. T., Petit J., Nikolova Y., Gaiani C. Recent advances on lactose intolerance: Tolerance thresholds and currently available answers. *Critical reviews in food science and nutrition*. 2017. Vol. 57. No. 15. P. 3344–356.

[5] Кравченко М., Перепелиця М. Технологія смузі на основі молочної сировини. *Міжнародний науково-практичний журнал «Товари і ринки»*. 2024. № 1. С. 117–126. https://doi.org/10.31617/2.2024(49)08.

[6] Гніцевич В. А., Юдіна Т. І., Гончар Ю. М. Технологія напівфабрикату на основі низьколактозної молочної сироватки та пюре гарбуза. *Міжнар. наук.-практ. журнал «Товари і ринки»*. 2018. № 4. С. 105–117. https://doi.org/10.31617/tr.knute.2018(28)10.

[7] Suchy F. J., Brannon P. M., Carpenter T. O., Fernandez J. R., Gilsanz V., Gould J. B., Miller N. J. NIH consensus development conference statement: lactose intolerance and health. *NIH Consens State Sci Statements*. 2010. Vol. 27. No. 2. P. 1–27.

sour cream, while the smallest share belongs to yogurts[8]. Yet, the consumption of yogurts provides the body with beneficial biologically active substances and metabolites of lactic acid and bifidobacteria, promotes better calcium absorption, lowers blood cholesterol levels, and ensures the normalization of the intestinal microflora. They are in high demand among consumers and occupy a significant segment of the dairy market (27%)[9]; therefore, saturating it with yogurts of domestic production that are lactose-free or low-lactose is a relevant direction for the development of the country's dairy processing enterprises.

The current state of the domestic dairy market is characterized by an increased level of instability caused by the prolonged impact of military actions on the territory of Ukraine. Some dairy processing enterprises were forced to terminate or significantly limit their activities, leading to a reduction in milk production volumes. According to available estimates, the decline in production in recent years amounted to about 10...15%, which, in turn, led to an increase in prices for dairy products of domestic origin and exacerbated the problem of providing the population with accessible food products[10].

Under these conditions, the effective use of secondary dairy raw materials –specifically buttermilk, which is formed during the production of butter – becomes particularly urgent. The rational involvement of such resources allows not only for increasing production efficiency but also for expanding the assortment of accessible food products with high biological value, corresponding to modern principles of resource saving and sustainable development of the food industry. In the general structure of secondary dairy raw materials, their share is relatively small, accounting for about 5%. At the same time, buttermilk is characterized by high nutritional and biological value.

Research results indicate that buttermilk obtained by the cream-churning method (in batch and continuous butter makers) is characterized by a higher content of biologically active substances compared to buttermilk obtained by the method of converting high-fat cream. Specifically, it contains an increased amount of complete whey proteins – 8.6% and 10.5% more compared to whole and skimmed milk, respectively[11]. The fat content in buttermilk averages

[8] Юдіна Т., Серенко А. Формування вітчизняного ринку безлактозних і низьколактозних молочних продуктів. *Міжнародний науково-практичний журнал «Товари і ринки».* 2021. № 2. С. 33–43. https://doi.org/10.31617/tr.knute.2021(38)03.

[9] Ibid.

[10] Болгова Н., Самілик М., Назаренко Ю., Соколенко В. Технологія виробництва безлактозного йогурту з дотриманням принципів системи HACCP. *Таврійський науковий вісник: технічні науки.* 2021. № 4. С. 33–46. https://doi.org/10.32851/tnv-tech.2021.4.4.

[11] Sakkas L., Evageliou V., Igoumenidis P. E., & Moatsou G. Properties of Sweet Buttermilk Released from the Churning of Cream Separated from Sheep or Cow Milk or Sheep Cheese Whey: Effect of Heat Treatment and Storage of Cream. *Foods* (Basel, Switzerland). 2023. Vol. 11. No. 3. P. 465.

0.4…0.7%, but its nutritional value is quite high due to the presence of polyunsaturated fatty acids, particularly linoleic, linolenic, and arachidonic acids, which feature an anti-sclerotic effect[12]. An important feature of buttermilk is also its increased content of phospholipids: their amount is 1.4 times higher than that of whole milk and approximately 11 times higher than that of skimmed milk[13].

The carbohydrate composition of buttermilk is close to that of whole milk and is represented mainly by lactose, the content of which can reach about 5%. The mineral composition of buttermilk corresponds to approximately 75% of the mineral composition of whole milk and includes elements such as calcium, magnesium, sodium, phosphorus, and potassium. Furthermore, buttermilk is a source of water-soluble B-group vitamins, as well as fat-soluble vitamins A, E, and K[14].

Thus, the results of the conducted research allow for the conclusion that buttermilk obtained during butter production by the cream-churning method is characterized by a significant content of complete proteins, low fat levels, and a balanced composition of vitamins and minerals. Given this, it is precisely this type of buttermilk that is advisable to use as a dairy base in the technology of low-lactose yogurts in further research.

The works of domestic and foreign scientists are dedicated to the theoretical and practical aspects of producing food products for special dietary uses, including lactose-free and low-lactose dairy products. Researchers have identified priority areas for using secondary dairy raw materials in the technologies of food products for special dietary uses.

Based on the research results of foreign scientists (Yang J., Rainville P. et al.), a technology has been developed for a biologically active product made from dairy whey with a dry matter content of 13...20% at pH 6.73...6.77 and a temperature of 30 °C, wherein the first part of the lactase enzyme and the first part of the starter culture are added to the dairy whey, held for 20 minutes, and then the second part of the enzyme and starter culture are added. The hydrolyzed whey is concentrated in vacuum-evaporation units to a dry matter content of at least 40%[15].

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[12] Contarini G., Povolo M. Phospholipids in milk fat: composition, biological and technological significance, and analytical strategies. *International Journal of MolecularSciences*. 2013.Vol. 14. No. 2. P. 2808–2831.

[13] Дмитриков В. П., Горбенко О. В., Антонов А. В. Особливості переробки вторинної молочної сировини: екологічні інновації. *Екологія плюс*. 2019. № 1. С. 7–11.

[14] Barukčić I., Lisak K., & Božanić, R. Valorisation of Whey and Buttermilk for Production of Functional Beverages – An Overview of Current Possibilities. *Food Technology and Biotechnology*. 2019. Vol. 57. No. 4. P. 448–460.

[15] Yang J., Rainville P., Liu K., & Pointer B. Determination of lactose in low-lactose and lactose-free dairy products using LC-MS. *Journal of Food Composition and Analysis*. 2021. No. 100. P. 1038–1057.

Scientists at the Institute of Food Resources of the NAAS of Ukraine used the enzyme preparation "GODO-YNL2" in an amount of 0.01...0.02% for the production of skimmed hydrolyzed condensed milk, with a process duration of 18…20 hours at a temperature of 6...8 °C[16]. There are studies related to investigating methods of lactose removal and developing resource-saving technologies for lactose-free and low-lactose dairy products, where enzymatic hydrolysis has been identified as a promising method[17].

Researchers Trubnikova A. A., Sharakhmatova T. Ye., and Mamintova K. O. substantiated the technology of obtaining a yogurt base from buttermilk for the production of low-lactose ice cream. The effect of compositions of lactic acid cultures Streptococcus thermophilus, Lactobacillus bulgaricus, Lactobacillus acidophilus, and Bifidobacterium lactis on the fermentation process, acid formation, and lactose reduction was studied. A rational concentration of dry skimmed lactose-free milk was established at 5% of the mixture weight, ensuring the formation of a dense consistency and high foaming properties of the product. The resulting yogurt base was characterized by a protein content of 5.41%, lactose – 3.01%, a high amount of probiotic microflora, and suitability for the production of functional low-lactose ice cream[18].

The authors investigated the process of lactose hydrolysis in dairy raw materials using enzyme preparations of β-galactosidase, where its content decreases to 1…2% while the nutrients of the dairy raw materials are maximally preserved[19].

Hnitsevych V. A. and Honchar Yu. M. proposed a method for producing a fermented semi-finished product based on dairy whey with a reduced lactose content by the method of enzymatic lactose hydrolysis. This is achieved by adding an activator of the enzymatic lactose hydrolysis process – a targeted enzyme preparation produced by a microorganism culture – to the dairy raw material. The technological process includes the optimization of separated or unseparated dairy raw materials to a pH value of the medium within 5.0...5.5 using an NH4OH solution. The targeted enzyme preparation is

[16] Романчук І. О. Наукове обґрунтування та розроблення способів підвищення ресурсоефективності промислового перероблення молочної сировини : дис. ... д-ра техн. наук: 05.18.04 «Технологія м'ясних, молочних продуктів і продуктів з гідробіонтів» / Ірина Олегівна Романчук; НУХТ. Київ, 2020. 290 с.

[17] Романчук І. О., Мінорова А. В., Рудакова Т. В., Моїсеєва Л. О. Закономірності ферментативного гідролізу лактози в молочній сировині. *Продовольчі ресурси*. 2021. Том 8. № 14. С. 165–174.

[18] Трубнікова А. А. Біотехнологічні аспекти отримання йогуртної основи для виробництва низьколактозного морозива / А. А. Трубнікова, Т.Є. Шарахматова, К. О. Мамінтова, О. С. Цупра. *Вісник НТУ «ХПІ», Серія: Нові рішення в сучасних технологіях*. Харків : НТУ «ХПІ», 2018. № 9 (1285). С. 243–255. DOI: 10.20998/2413-4295.2018.09.35.

[19] Sharakhmatova T. Ye., Lozova O. O. Development of ice cream technology for people with lactase deficiency. *Scientific works of the Odessa National Academy of Food Technologies*. 2009. No. 2. P. 311–316.

introduced at a concentration of 0.03 g/L along with a catalyst solution into the prepared whey, which has been cooled to 55...65 °C after high-temperature pasteurization. The obtained hydrolysate is held in a thermostat at a temperature of 50 ± 2 °C for 12 hours. As a result of the hydrolysis process, the mass fraction of lactose decreases from 5.7...5.8% to 2.0...2.2%. The obtained low-lactose whey-based semi-finished product is used as a base for sauce production[20].

Despite the large number of scientific studies, work in this direction continues and is aimed at creating new technologies and expanding the assortment of dairy products with reduced lactose content by involving new raw materials that are natural sources of essential nutrients and possess a wide range of technological properties. At the same time, it has been established that systematic studies aimed at studying the process of lactose hydrolysis in buttermilk and developing technologies for low-lactose dairy products based on it are absent.

Based on a series of prior theoretical and experimental studies, a hypothesis has been put forward that utilizing buttermilk as a dairy base for low-lactose yogurt production, under conditions of directed regulation of functional and technological properties, will make it possible to obtain a new product with high nutritional and biological value.

Scientists at the State University of Trade and Economics proposed a technology for low-lactose yogurt based on buttermilk[21]. Based on experimental studies, the need to normalize buttermilk by dry matter content was determined. It has been proven that using dry milk protein concentrate for buttermilk normalization in an amount of 2.5...8.5% helps improve the organoleptic properties of the product, prevents syneresis, enables obtaining a product with a stable consistency, and increases the yield of the finished product.

The authors studied the process of lactose hydrolysis in dairy mixtures based on buttermilk with an increased content of dry matter[22, 23]. It was established experimentally that to achieve a lactose hydrolysis efficiency within 70...75% in dairy mixtures with a dry matter content of 14% and 15%, the

[20] Гніцевич В. Кінетика ферментолізу лактози молочної сироватки / В. Гніцевич, Н. Чикун, Ю. Гончар. *Товари і ринки*. 2017. № 2. С. 97–104.

[21] Юдіна Т., Серенко А. Технологія низьколактозних молочних сумішей для йогуртів. *Міжнар. наук.-практ. журн. «Товари і ринки»*. 2022. № 3 (43). С. 108–116. https://doi.org/10.31617/2.2022(43)09.

[22] Yang J., Rainville P., Liu K., & Pointer B. Determination of lactose in low-lactose and lactose-free dairy products using LC-MS. *Journal of Food Composition and Analysis*. 2021. No. 100. P. 1038–1057.

[23] Мінорова А. Підбір та дослідження ефективності заквашувальних препаратів з підвищеною β-галактозидазною активністю / Мінорова А., Романчук І., Даниленко С., Рудакова Т., Крушельницька Н., Потемська О., Наріжний С. Підбір та дослідження ефективності заквашувальних препаратів з підвищеною β-галактозидазною активністю. *Продовольчі ресурси*. 2022. Том 10. № 19. С. 88–98.

most rational process duration parameters are 120...150 min when adding an enzyme preparation dose of 0.03%, and 90...120 min when adding a dose of 0.05%. At the same time, it should be noted that increasing the process duration to 180...240 min is inappropriate for the following reasons: first, it leads to a decrease in hydrolysis rates, which is caused by a decrease in lactose content and an increase in the concentration of its hydrolysis products-glucose and galactose, which act as inhibitors of β-galactosidase GODO-YNL2; second, it leads to an increase in energy costs, which is undesirable[24].

Thus, based on the aggregate of conducted experimental studies, rational parameters for the lactose hydrolysis process in dairy mixtures with an increased dry matter content for low-lactose yogurt production were determined: enzyme preparation dose – 0.03...0.05%, hydrolysis temperature – 40 ± 2 °C, duration – 90...150 min[25].

In the production of fermented milk drinks, particularly yogurts, an important technological stage is the use of starter cultures and the fermentation of the dairy base. It is the fermentation process that ensures the formation of the structural-mechanical properties of the fermented milk clot and the characteristic organoleptic indicators of the finished product. The efficiency of fermentation directly depends on the concentration of the starter culture, temperature, and duration of the process.

The aim of this work is to optimize the technological parameters of fermenting buttermilk-based dairy mixtures with an increased dry matter content and hydrolyzed lactose.

The following were selected as the subject of research: buttermilk obtained by cream-churning in butter makers; dry milk protein concentrate; dry demineralized dairy whey; dairy mixtures normalized by dry matter content; yeast-derived lactase enzyme preparation "GODO-YNL2" (manufacturer Shusei Company Limited, Japan); direct vat set starter cultures for yogurt production YC-X11 (Chr. Hansen, Denmark); and food systems modeling low-lactose yogurts in their composition.

2. Substantiation of Technological Parameters for the Production of Low-Lactose Yogurts Based on Buttermilk

The fermentation process is one of the key stages in yogurt production, as it is during fermentation that the main quality characteristics of the finished

[24] Моісеєва Л. О. Розроблення технології низьколактозного кисломолочного продукту : дис. …. канд. техн. наук: 03.00.20. Інститут продовольчих ресурсів НААН України. 2021. 183 с.

[25] Юдіна Т., Серенко А. Технологія низьколактозних молочних сумішей для йогуртів. *Міжнар. наук.-практ. журн. «Товари і ринки»*. 2022. № 3 (43). С. 108–116. https://doi.org/10.31617/2.2022(43)09.

product are formed. At this stage, the fermented milk clot forms, and the structural-mechanical properties as well as the characteristic taste and aroma of the yogurt are established. A decisive role in the course of fermentation processes is played by the type of starter culture, its concentration, temperature, and duration, under the influence of which complex biochemical transformations of dairy raw material components take place.

Based on an analysis of the starter culture market and the legacy of works by domestic and foreign scientists, the direct vat set starter culture for yogurt YC-X11 (manufacturer Chr. Hansen, Denmark) was selected for the production of low-lactose fermented milk drinks[26].

The fermentation parameters recommended by the manufacturer using the direct vat set starter culture YC-X11 are defined for whole milk as the starting raw material in yogurt production. Therefore, in order to substantiate the operating conditions of the starter culture in a different dairy system, the effect of its added dose on the quality indicators of low-lactose yogurt based on buttermilk was studied.

The fermentation of buttermilk-based dairy mixtures with a dry matter content of 14.1% and 15.3% was carried out in a thermostat at a temperature of 40 ± 2 °C. The fermentation duration was 30...300 min, with a sampling interval of 30 min.

The effectiveness of the starter culture was evaluated by the physicochemical and organoleptic indicators of the formed fermented milk clots, taking into account that according to DSTU 4343:2004[27], the standardized titratable acidity for yogurts is 80...140 °T.

In order to determine the optimal fermentation parameters of buttermilk with an increased dry matter content and hydrolyzed lactose, under which the product acquires appropriate physicochemical and structural-mechanical indicators, a process optimization was carried out.The experiment was planned according to an orthogonal symmetric Box-Behnken design. Experimental factors were selected at the upper ("+") and lower ("–") levels based on the results of preliminary studies. A full three-factor experiment with variation levels of –1; 0; +1 was utilized. The fermentation process of buttermilk-based dairy mixtures is characterized by the following parameters: x_1 – dose of the starter culture, mg; x_2 – fermentation duration, t·60s; x_3 – fermentation temperature, °C.The response functions adopted were: Y_1 – titratable acidity, °T; Y_2 – effective viscosity, mPa·s.

[26] Заквашувальні препарати для кисломолочних напоїв. Режим доступу: https://www.chr-hansen.com/en/food-cultures-and-enzymes/fresh-dairy/our-products-fresh-dairy.

[27] ДСТУ 4343:2004. Йогурти. Загальні технічні умови. Київ, 2005. 16 с.

Based on the results of the experiments, mathematical dependencies were obtained that describe the influence of the starter culture dose, duration, and fermentation temperature on the formation of the fermented milk clot in yogurt production. The adequacy of the developed mathematical models was checked using Fisher's criterion at a 5% significance level, and the significance of the coefficients was verified using Student's t-test.

Table 1 presents the conditions for conducting the full three-factor experiment to optimize the fermentation process of buttermilk with an increased dry matter content and hydrolyzed lactose.

Table 1

Levels and ranges of experimental factors

Levels	Factors		
	Fermentation starter dose, mg	**Fermentation duration, t·60s**	**Fermentation temperature, °C**
	x_1	x_2	x_3
Main ($x_{i\,0}$)	2,7	195	40
Variation range ($\Delta\, x_i$)	0,1	15	5
Lower ($x_{i\,min}$)	2,6	180	35
Upper ($x_{i\,max}$)	2,8	210	45

The research results (Figs. 1–3) indicate that the formation of a fermented milk clot with target organoleptic properties and a standardized titratable acidity within 80...140 °T is achieved under the following rational parameters: for a dairy mixture with a dry matter (DM) content of 14.1% – starter culture dose of 2.6...2.8 mg/100 g; process duration – 210...240 min; for a dairy mixture with a DM content of 15.3% – starter culture dose of 2.6...2.8 mg/100 g; process duration – 180...210 min.

When lower doses of the starter culture are added, a decrease in the intensity of clot formation and an increase in fermentation duration occur, which leads to unnecessary energy expenditures that are undesirable. Adding a starter culture dose of 3 mg/100 g does not significantly affect the change in indicators characterizing the quality of the developed product, but it increases its production cost.

It is known that the strains of lactic acid bacteria in the YC-X11 starter culture are chemoorganotrophic microorganisms[28, 29]. This means they obtain energy by

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[28] Delorme, C. Safety assessment of dairy microorganisms: Streptococcus thermophilus. *International Journal of Food Microbiology.* 2008. Vol. 126. P. 274–277.

[29] Han X., Yang Z., Jing X., Yu P., Zhang Y., Yi H. et al. Improvement of the texture of yogurt by use of exopolysaccharide producing lactic acid bacteria. *Biomed. Res. Int.* 2016. 2016:7945675. DOI: 10.1155/2016/794.

oxidizing organic substances. In our case, lactic acid bacteria oxidize lactose, converting it into glucose and galactose. Glucose and galactose serve as substrates for the synthesis of lactic acid. Temperature affects the activity of dairy bacteria and their metabolic rate. At higher temperatures, the enzymes involved in the metabolism of dairy bacteria work faster, producing more lactic acid per unit of time, and, as a consequence, the process of fermented milk clot formation accelerates.

Therefore, considering the above, the next series of experiments investigated the effect of fermentation temperature on starter culture activity in dairy mixtures with an increased dry matter content (Figs. 2, 3).

The study was conducted by varying the temperature within the range of 15...55 °C, with an added starter culture dose of 2.6...2.8 mg, and a process duration of 210 min.

The obtained results proved that the starter culture exhibits the highest efficiency in the temperature range of 40...45 °C. At lower temperatures, the process of fermentation and clot formation occurs more slowly, which is explained by the low activity of the lactic acid bacteria Lactobacillus bulgaricus and Streptococcus thermophilus at the specified temperatures. When the temperature is increased above 45 °C, a decrease in starter culture efficiency is observed due to the inactivation of lactic acid bacteria under the action of high temperatures.

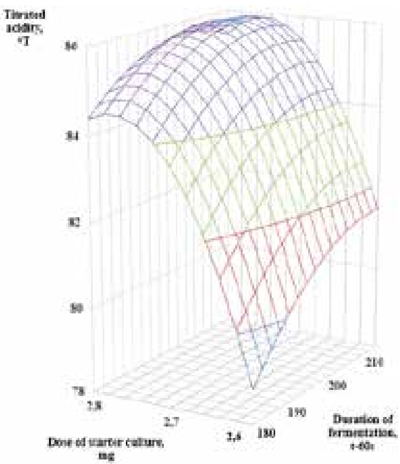

Fig. 1. Dependence of titratable acidity on the starter culture dose and fermentation duration at a temperature of 40 °C

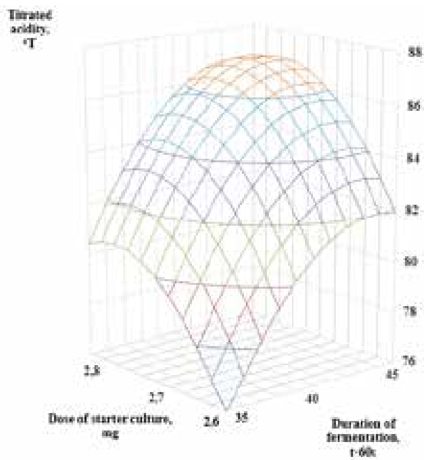

Fig. 2. Dependence of titratable acidity on the starter culture dose and fermentation temperature at a duration of 195·60s

Figs. 4–6 present the results of studying the effect of the starter culture dose and fermentation duration of dairy mixtures with different dry matter contents on the rheological properties of low-lactose yogurt.

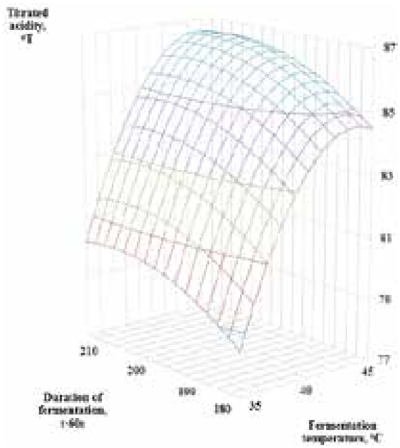

Fig. 3. Dependence of titratable acidity on the duration and fermentation temperature at a starter culture dose of 2.7 mg

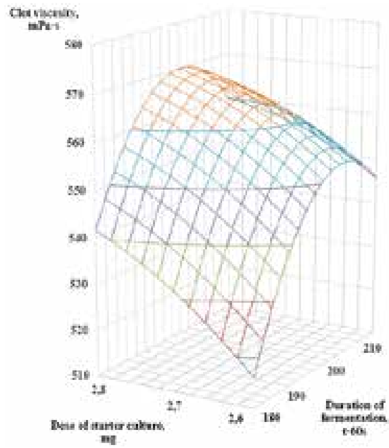

Fig. 4. Dependence of viscosity on the starter culture dose and fermentation duration at a temperature of 40 °C

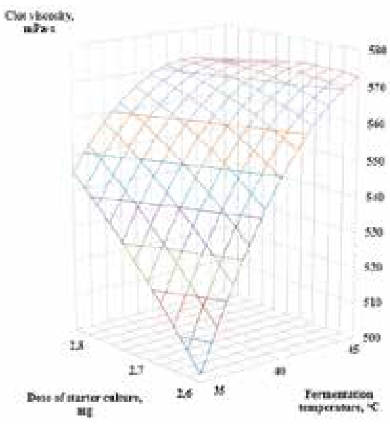

Fig. 5. Dependence of viscosity on the starter culture dose and fermentation temperature at a duration of 195·60s

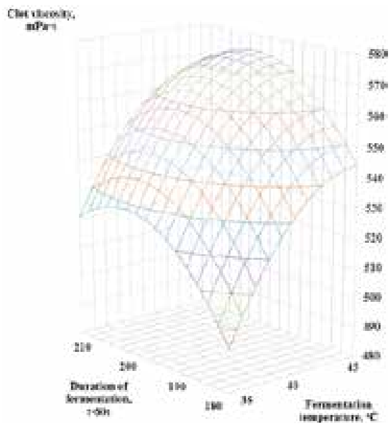

Fig. 6. Dependence of viscosity on the duration and fermentation temperature at a starter culture dose of 2.7 mg

The presented results (Figs. 4–6) proved that with an increase in fermentation duration, an increase in the viscosity of the test samples occurs. This is explained by the fact that dairy mixture components, such as proteins and lactose, participate in the formation of the fermented milk clot. Lactic acid bacteria included in the starter culture convert lactose into glucose and galactose, which serve as a substrate for biochemical reactions that result in the formation of lactic acid. Lactic acid leads to the coagulation of proteins, followed by the formation of a fermented milk clot[30].

Thus, when adding starter culture doses of 2.6...2.8 mg/100g and a fermentation duration of 180...210 min, the viscosity of the finished product for a dairy mixture with a dry matter content of 14.1% was 523...559 mPa·s, and for a dairy mixture with a dry matter content of 15.3% – 560...564 mPa·s, respectively. The resulting low-lactose yogurt is characterized by a stable structure and a semi-liquid consistency. This correlates well with data from previous researchers regarding the rheological properties of drinking yogurts[31].

During the further course of the fermentation process for 210...240 min, an insignificant change in viscosity indicators is observed in the test samples, while the consistency of the yogurt remains uniform, semi-liquid, and without whey separation.

For the mathematical substantiation of the optimal process parameters of fermentation, a method for solving compromise problems of multi-objective optimization using the conjugate gradient method was used. To solve the formulated problem, we used the "Solver" add-in of the MS Excel package.

The method consists of choosing a target function limited to a set value and describing constraints from a system of equations. In the calculations, a relative error of $1 \cdot 10^{-6}$ and a permissible deviation of 5% were assumed. Optimization was performed by the conjugate gradient method. During the calculation, the following results were obtained:

	Variables			**Objective function**	
Name	X_1	X_2	X_3	$Y_1(X_1,X_2,X_3)$	
Value	2,625	206,0000626	39,60075575	561,7332159	→ max
Constraints					
$Y_2(X_1,X_2,X_3)$ =	82,608	>=	80		
$Y_2(X_1,X_2,X_3)$ =	82,608	<=	140		
X_1=	2,625	>=	0		
X_2=	206,000	>=	0		
X_3=	39,601	>=	0		

[30] Кулігін М. Л. Дослідження впливу регуляторів консистенції на якість та реологічні властивості йогурту. *Вісник Херсонського національного технічного університету*. 2020. №. 2 (73). С. 41–47.

[31] Геліх А. О., Даниленко С. Г., Крижська Т. А., Семерня О. В. Оптимізація реологічних показників структури йогурта із додаванням ізоляту білка насіння коноплі. *Продовольчі ресурси*. 2022. № 18. С. 51–60.

Consequently, through a multi-factor experiment, it was proven that the formation of a stable fermented milk clot with a standardized titratable acidity within 80...140 °T occurs under the following parameters: starter culture dose – 2.6 mg/100g, process duration – 210 min, temperature 40 ± 2 °C.

CONCLUSIONS

Based on the conducted research, it was established that during the fermentation of buttermilk with an increased dry matter content, obtaining a stable fermented milk clot with target organoleptic properties and a standardized titratable acidity within 80...140 °T is achieved at an introduced starter culture dose of 2.6...2.8 mg/100g.

The effect of temperature on the buttermilk fermentation process with an increased dry matter content was investigated. It was found that the highest efficiency of the starter culture is observed at a temperature of 40...45 °C. Under lower temperature regimes, the process of fermentation and clot formation proceeds more slowly, which is due to the insufficient activity of the lactic acid bacteria Lactobacillus bulgaricus and Streptococcus thermophilus. Raising the temperature above 45 °C leads to a decrease in the effectiveness of the starter culture due to the partial inactivation of lactic acid bacteria under the influence of high temperatures.

The regularities of the influence of technological fermentation parameters on the formation of the fermented milk clot of low-lactose yogurt were established. It has been proven that the optimal parameters for the fermentation process of buttermilk with an increased dry matter content and hydrolyzed lactose are: starter culture dose – 2.6 mg/100 g, process duration – 210 min, temperature 40 ± 2 °C.

SUMMARY

The work investigates the process of buttermilk fermentation in the technology of low-lactose yogurt, and determines the optimal parameters of the fermentation process.

The conditions for conducting a full three-factor experiment are proposed. The effect of temperature on the fermentation process of buttermilk with a high content of dry matter is studied. It is established that the highest efficiency of the fermentation preparation is observed at a temperature of 40…45 °C.

The patterns of the influence of technological fermentation parameters on the formation of a sour milk clot of low-lactose yogurt are established. It is proven that the optimal parameters of the fermentation process of buttermilk with a high content of dry matter and hydrolyzed lactose are: the dose of

the fermentation preparation is 2.6 mg/100 g, the duration of the process is 210 min., the temperature is 40 ± 2 °C.

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