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O. Vysotskyi, *E-mail: oleksandrvysotskyi.science@gmail.com*
ORCID: https://orcid.org/0000-0002-4483-9866
O. Kochubei-Litvinenko, Dr. of Technical Sciences, Professor, *E-mail: okolit@email.ua*
ORCID: https://orcid.org/0000-0003-0712-448X, Researcher ID D-7284-2019, Scopus Author ID 57189381380
O. Bilyk, K. of Technical Sciences, Professor, *E-mail: bilyklena@gmail.com*
ORCID: http://orcid.org/0000-0003-3606-1254, Researcher ID M-6190-2018, Scopus Author ID 57189379639
V. Bilokhatniuk,, *E-mail: lsfbqgh@gmail.com*
ORCID: http://orcid.org/ 0009-0008-1116-0241
National University of Food Technologies, 68, Volodymyrska street, Kyiv, 01601, Ukraine
Tel. +38067 3884523

USE OF FERMENTED ACID WHEY ENRICHED WITH MINERAL ELEMENTS IN THE TECHNOLOGY OF RYE-WHEAT BREAD

Abstract

This article investigates the use of fermented acid whey enriched with mineral elements (magnesium, zinc, and manganese) in the technology of rye-wheat bread. Whey obtained through thermal acid coagulation of milk is a valuable resource that can significantly enhance the quality and nutritional value of bakery products. The study analyzes scientific approaches to enriching whey with mineral elements through spark discharge treatment, which creates optimal conditions for cultivating lactic acid bacteria. The primary aim of the study is to examine the fermentation process of whey enriched with mineral elements and its impact on the rheological properties of dough and the quality of finished bakery products. It has been established that spark discharge treatment of whey significantly accelerates the fermentation process, increases acidity, and boosts the growth of lactic acid bacteria. The research shows that using enriched whey allows the fermentation time to be reduced by almost half compared to the control. This is achieved through intensive acid production and biomass growth of lactic acid bacteria. The best results were obtained with whey treated with spark discharges in a conductive layer of zinc, magnesium, and manganese granules. Using fermented whey in the production of rye-wheat bread contributed to increasing the gas-forming capacity of the dough, improving its rheological properties, and increasing the specific volume of finished products. Enriched whey also positively affected the bread's quality by enhancing its porosity, shape stability, and organoleptic properties. It was found that enriching whey with magnesium, zinc, and manganese not only intensifies the fermentation process but also increases the nutritional value of the finished products by enriching them with important microelements. The study demonstrated that using enriched whey reduces dough ball spread, increases its elasticity and resilience, and extends the bread's freshness. The research results confirm the feasibility of using spark discharge enrichment of whey with magnesium, zinc, and manganese to improve the efficiency and quality of bakery production. The proposed technology can be recommended for widespread implementation in production, ensuring high quality and competitiveness of bakery products in the market.

Key words: Whey, Fermentation, Mineral enrichment, Rye-wheat bread, Magnesium, Zinc, Manganese.

Introduction

Numerous works by domestic scientists such as V.I. Drobot, I.A. Reuter, N.O. Chumachenko, V.F. Dotsenko, O.A. Bilyk, T.O. Vasilchenko, and others are devoted to the scientific substantiation of the application of whey in the technology of bakery products. Whey and its processed products not only enrich bakery products but also improve their quality.

The volumes of whey production in Ukraine, calculated based on the production volumes of rennet, fermented, fresh non-fermented cheeses, and casein [1, 2], currently amount to about 900 thousand tons (excluding Crimea and temporarily occupied territories). Therefore, it can be confidently stated that whey is a potential resource reserve not only for dairy processing enterprises but also for the food industry as a whole.

Analysts of the agro-industrial complex noted practically stable production volumes of whey products and an increase in the production of dry whey in the prewar years (2015-2020) [3, 4]. However, the war has also damaged this segment of dairy processing. An AVM expert in June 2023 reported a negative trend in the reduction of whey supplies to external markets.

It should be noted that the industrial processing of valuable secondary whey remains insignificant and amounts to just over 1/3 (34-40%) of the total volume of whey [4]. Domestic producers of various food products began to realize its value and economic attractiveness relatively recently. Factors hindering the intensive processing of whey included technical and technological reasons, namely the lack of economically viable processing technologies and necessary technical equipment, as well as a psychological factor, as for a long period, this by-product of dairy processing was perceived exclusively as production waste. Only starting from the early 2000s, the spread of ecological literacy and the growth of the economic competitiveness of whey products stimulated the emergence and rapid development of the concept that classified whey as valuable food raw material [4].

Whey and its processed products are widely used in the dairy, meat, confectionery, and bakery industries, in the production of food concentrates, children's, sports, and gerodietic nutrition products, and others [4, 5]. There is a demand for whey products both in countries with stable economies to meet the needs of middle-class consumers who engage in sports and care about their health and in developing countries to meet nutritional needs.

Thus, Ukraine has a large raw material resource that should be directed towards the production of mass-consumption food products that are in demand on both domestic and external markets, as well as special-purpose products. In this context, bakery products are a promising group of food items that will serve as a stable "consumer" of whey as a food ingredient in the formulation of special and gerodietic products.

Literary review

Natural whey in bread and bakery technologies plays the role of an activator of the microflora of liquid yeast, yeast suspension, liquid starter, and an intensifier of dough preparation. Additionally, the use of whey enhances the nutritional activity and value of bread products in sponge and accelerated dough methods, allowing for flour savings [6].

Whey is used in the recipes of rye-wheat bread. It is important to ensure high dough acidity to reduce enzyme activity, enhance the swelling of proteins, pentosans, and flour shell particles [7, 8]. This role can be performed by acidic whey as a natural acidifier. It should be noted that increasing the titrated acidity of whey to 160-180 °T will contribute to the stabilization of the dough preparation process and obtaining high-quality finished products.

It is known that achieving the required titrated acidity (170±10 °T) can take up to 48 hours and, as a result, the duration of the technological cycle will increase. This will impact the economic indicators of production. This fact supports the relevance of finding ways to intensify the technological process of producing acidic whey as a food ingredient for rye-wheat bakery recipes.

Technological approaches that provide for the intensification of acidic whey fermentation are generally limited to the use of various organic acids, food additives, and are extremely limited. In contrast, improving the technology by creating favorable conditions for the growth of lactic acid microflora in the fermented environment deserves attention. This can be achieved by enriching whey with biologically valuable mineral elements, which will serve as a nutrient medium for microorganisms and promote the growth of lactic acid bacteria biomass, thereby intensifying acid production in the system.

This approach is promising because, along with the intensification of whey fermentation, it will also enrich bakery products with mineral elements.

Whey contains a whole set of macro- and microelements [9, 10], but the amounts of zinc, magnesium, and manganese are insufficient to ensure the vital activity of microbial cells and their growth.

Microbial cells require a significant amount of macro- and microelements: carbon, nitrogen, oxygen, hydrogen, phosphorus, sulfur, potassium, calcium, magnesium, zinc, manganese, sodium, chlorine, molybdenum, selenium, and others [11]. Zn, Mg, and Mn can be considered as factors for the intensification of fermentation because they participate in the construction of living cell components, promote energy metabolism and protein synthesis of microbial cells, activate and stabilize enzyme activity [12, 13], and improve the fermentation activity of brewer's yeast [14, 15].

They can be regarded as growth factors for lactobacilli and yeasts. For example, in [16], it was shown that enriching Lactobacillus rhamnosus and Lactococcus lactis strains with magnesium ions using pulsed electric fields had no negative effect on the structural and mechanical properties of dairy products. Moreover, a positive impact on the adhesive properties of the product and the viability of microorganisms was observed even after freezing.

In [14], a positive effect on the viability and fermentation activity of brewer's yeast was described due to electron-ion treatment conducted in the flow during yeast loading into the fermentation apparatus. It was proven that this treatment reduces the number of non-viable cells by 26-40% and accelerates wort fermentation by an average of 2 days.

It was shown that adding nanoaquachelates of zinc, with a zinc concentration of 0.10 mg/dm³ obtained by spark discharge, increases the fermentation activity of brewer's yeast [15]. At the final stage of fermentation, the amount of CO2 released was 14% higher than in the control. At the same time, the amount of fermented extract in young beer decreased by 15% compared to the control, and the main fermentation process was shortened by 1-2 days, depending on the initial wort concentration.

The above confirms the feasibility of enriching whey with magnesium, manganese, and zinc to accelerate its fermentation. A promising direction in this area is the inclusion of spark discharge enrichment of raw materials with technologically valuable mineral elements into the technological scheme for producing fermented acidic whey [17].

There is insufficient information on the course of fermentation of whey enriched with zinc, magnesium, and manganese due to spark discharge dispersion of conductive metal granules to intensify the process of producing acidic whey for its subsequent use as a food ingredient for rye-wheat products. Therefore, this direction of scientific research is relevant.

Formulation of the problem.

1. Study of the process of fermenting whey enriched with mineral elements through spark discharge treatment;

2. Study of the impact of fermented acidic whey enriched with magnesium, manganese, and zinc on the rheological properties of dough and the quality of rye-wheat bread.

Materials and methods

The object of the research was the process of fermenting whey and the technology of rye-wheat bread made using fermented acidic whey enriched with mineral elements.

The whey, obtained through thermal acid coagulation of milk, was subjected to fermentation since it is considered the most favorable medium for cultivating lactic acid bacteria. Before fermentation, the whey was purified from sedimented protein particles and then treated in an experimental spark discharge installation, developed by scientists from the National University of Life and Environmental Sciences of Ukraine [18], according to one of the following options:

1. With a conductive layer of manganese granules

(hereafter – sample 1).

2. With a conductive layer of magnesium granules (hereafter – sample 2).

3. With a conductive layer of zinc granules (hereafter – sample 3).

4. Sequentially in three spark discharge chambers with a conductive layer of zinc granules in one, magnesium in the second, and manganese in the third (hereafter – sample 4).

The duration of spark discharge treatment in the spark discharge chambers was varied from 30 to 120 seconds.

The treated whey was then pasteurized at a temperature of (78±2) °C, cooled to a temperature of (37±1)°C, and inoculated with pure cultures of Lactobacillus acidophilus. The choice of these starter cultures is justified by their high acid production level (acid production threshold over 300 °T), which is significant when processing whey with a high pH level due to the accumulation of metal particles. Moreover, this culture is an active antagonist against foreign microbiota and can ensure the safety of the finished product. Fermentation was carried out at a temperature of (37±1) °C for 36 hours.

The control was fermented whey produced without the use of spark discharge treatment of the raw material (hereafter – control).

To determine the impact of spark discharge treatment on the acid-producing properties of Lbc. acidophilus, the titrated acidity of whey was measured every 6 hours during fermentation at a temperature of (37±1) °C.

To study the impact of the obtained fermented whey enriched with mineral elements on the indicators of the technological process, biochemical, physicochemical changes in the dough, and the quality indicators of bread from a mixture of rye and wheat flour, the control was "Special" bread: rye flour – 30 kg, premium wheat flour – 70 kg, pressed baker's yeast – 0.7 kg, table salt – 1.8 kg. The dough was prepared on a thick starter with a moisture content of 48%. The dough was kneaded in a two-speed dough mixer. The whey was dosed at 15% of the flour mass. Dough pieces were formed manually. Proofing was carried out at a temperature of (35±2) °C and relative humidity of (75±2) % until ready. The products were baked in a shelf oven at a temperature of 240-260 °C.

The quality of the dough was evaluated by physicochemical and rheological indicators after kneading and after the completion of dough fermentation according to generally accepted methods [19]. The quality of the bread was determined by physicochemical (specific volume, porosity, shape stability, structural and mechanical properties of the crumb) and organoleptic indicators (appearance, crust surface condition, crumb structure, taste, smell).

The impact of additives on the shelf life of the products was studied by changes in the structural and mechanical properties of the crumb. The overall, resilient, and elastic deformation was determined after 4, 24, and 48 hours of storage using the AP 4/1 penetrometer. The comprehensive quality indicator was determined by a point evaluation of the quality of bakery products [19].

Statistical processing of the research results was carried out using Microsoft Excel XP software.

Results of the study and their discussion

It was established that all experimental samples exhibited a natural gradual increase in titrated acidity during the fermentation of whey inoculated with pure cultures of Lactobacillus acidophilus.

However, it should be noted that in the samples enriched with valuable mineral elements (Zn, Mg, Mn) due to spark discharge treatment for 30-60 seconds, the increase in titrated acidity (ΔT) over time was more intense. Thus, after 24 hours of fermentation, in experimental sample No. 1, ΔT ranged from 140 to 169 ºT depending on the duration of treatment; in sample No. 2 – from 122 to 136 ºT, in sample No. 3 – from 145 to 175ºT, and in sample No. 4 – from 140 to 171 ºT. In contrast, in the control under the same fermentation time, titrated acidity increased only to 110 ºT.

It was noted that with an extension of the treatment duration to 120 seconds, fermentation occurred more slowly, which can be explained by the increase in the number of metal particles in the micron range and, as a result, the shift of the pH in the whey towards the alkaline side.

The highest acid-forming activity of the lactic acid microorganisms Lbc. acidophilus was observed in whey treated in a discharge chamber with a conductive layer of Mn or Zn granules for 60 seconds, and in whey enriched with Mg, Mn, and Zn. It is worth noting the synergistic effect of zinc, magnesium, and manganese on the intensity of fermentation, which is due to the increase in important nutritional micro- and macroelements for the construction of living cell components of lactobacilli in a form accessible for absorption and constructive metabolism.

The obtained data are consistent with the results presented in works [12, 13, 20] and indicate the positive effect of enriching the fermentation medium with zinc, magnesium, and manganese on the intensification of biotechnological processes.

It should be noted that the fermentation of whey enriched only with magnesium occurred somewhat more slowly compared to experimental samples No. 1, No. 3, and No. 4. It can be assumed that the amount of Mg obtained during treatment for 30-60 seconds is insufficient for the full nutrition of lactobacilli, while with an increase in treatment time, although its amount increases, the pH of the medium and the number of microparticles, inaccessible for full absorption by microbial cells, also increase, negatively affecting the fermentation process.

It was found that the appropriate acidity (170±10°T) is achieved by whey enriched with zinc and/or magnesium and/or manganese within 12-18 hours, whereas the control takes 30 hours of fermentation.

The results of fermentation intensification are confirmed by studies of the number of lactobacilli in the experimental samples of fermented whey (Table 1).

Therefore, the results of the conducted studies on the increase in acidity and the number of lactobacilli in the experimental samples of whey confirmed the possibility of reducing the fermentation duration by almost half as a result of its treatment before fermentation with spark discharges in a discharge chamber with a conductive layer of manganese or zinc granules for 60 seconds or sequential treatment in three spark discharge chambers

Table 1 – Change in the number of lactobacilli during the fermentation of whey treated with spark discharges under different parameters (duration, material of the electrodes of the discharge chamber)

Experimental Sample	Number of Lactobacilli, CFU/g, at Fermentation Duration, hours	
	12	24
Control	$(1±0,05)·10^6$	$(1±0,05)·10^7$
Sample No. 1 (treatment duration, seconds): 30	$(8±0,4)·10^6$	$(3±0,1)·10^7$
60	$(4±0,2)·10^7$	$(5±0,2)·10^8$
90	$(1±0,05)·10^7$	$(7±0,3)·10^7$
120	$(3±0,05)·10^6$	$(1±0,05)·10^7$
Sample No. 2 (treatment duration, seconds): 30 c	$(3±0,1)·10^6$	$(1±0,05)·10^7$
60	$(1±0,05)·10^7$	$(7±0,3)·10^7$
90	$(7±0,3)·10^6$	$(2±0,1)·10^7$
120	$(1±0,05)·10^6$	$(6±0,3)·10^6$
Sample No. 3 (treatment duration, seconds): 30 c	$(2±0,1)·10^7$	$(5±0,2)·10^7$
60	$(8±0,3)·10^7$	$(2±0,1)·10^8$
90	$(6±0,05)·10^6$	$(9±0,3)·10^6$
120	$(2±0,05)·10^6$	$(3±0,3)·10^6$
Sample No. 4 (treatment duration, seconds): 30(Zn) +30 (Mg) + 30 (Mn)	(1±0,3)·108	(5±0,3)·108
60 (Zn) +60 (Mg) + 60 (Mn)	(5±0,2)·106	(9±0,4)·106

with a conductive layer of manganese, magnesium, and zinc granules for 30 seconds each.

Given the feasibility of enriching bakery products with a complex of mineral substances, the impact of whey enriched with Mg, Mn, and Zn on the parameters of its fermentation process was investigated.

At the next stage, the impact of fermented whey enriched with Mg, Mn, and Zn on the technological process and quality of rye-wheat bread was studied. For this purpose, trial laboratory baking was conducted where the dough was prepared on a thick starter according to the recipe for "Special" bread (this bread served as the control). Fermented whey and fermented whey enriched with Mg, Mn, and Zn were dosed at 15% of the flour mass, according to literature sources [21, 22]. The quality of the dough and bread was evaluated by physicochemical, organoleptic indicators, and a comprehensive quality indicator. The results are presented in Table 3 and Figure1.

It was established that the addition of fermented whey and fermented whey enriched with magnesium, manganese, and zinc increased the acidity of the dough compared to the control, which was observed throughout the fermentation period. It was found that the use of all

Table 2 – Impact of whey enriched with Mg, Mn, and Zn on the parameters of the fermentation process

Indicator	Indicator value	Comparative value relative to control
	Control	Experimental sample
Fermentation duration to reach acidity (170±10 °T), hours	32±0,5	– 2,0 times
Number of lactobacilli, CFU/g, during fermentation, hours		
12	(1±0,05)·10	$+(1·10^2)$
24	(1±0,05)·10	$+(5·10^1)$
Mg content in fermented whey, mg/kg	96,3±4,8	+ 2,0 times
Mn content in fermented whey, μg/kg	2,8±0,1	+ 3,0 times
Zn content in fermented whey, μg/kg	285±10,2	+1,5 times

Note: "+" indicates an increase in the indicator; "–" indicates a decrease in the indicator; "~" indicates no significant change.

studied whey samples intensified fermentation, as evidenced by the greater accumulation of carbon dioxide, both during fermentation and proofing. This is due to the enrichment of the dough with nutrients necessary for yeast activity. The activation of yeast in the dough with fermented whey leads to a reduction in proofing time. The addition of fermented whey and fermented whey enriched with magnesium, manganese, and zinc reduces the spread of the dough ball, presumably due to the effect of lactic acid on the protein-protease complex.

The study of the quality of finished products showed that due to the increase in gas production, specific dough volume, and improvement in the elasticity of the gluten framework with the addition of fermented whey and fermented whey enriched with magnesium, manganese, and zinc, the specific volume of bread increases. Thus, in bread with fermented whey and fermented whey enriched with magnesium, manganese, and zinc, this indicator increased by 7.9% and 11.5%, respectively, compared to the control (Figure 1).

It was established that the addition of fermented whey and fermented whey enriched with magnesium, manganese, and zinc improves the shape stability of the products, making this product suitable for both hearth and pan baking. The research results showed that the highest comprehensive quality indicator was achieved in bread with fermented whey enriched with magnesium, manganese, and zinc.

From literature sources, it is known that the use of whey extends the freshness of bakery products. Therefore, it was appropriate to study the impact of fermented whey and fermented whey enriched with magnesium,

Table 3 – Impact of fermented whey enriched with magnesium, manganese, and zinc on the quality of dough and bread.

Quality Indicators of Bread	Bread		
	Control (without additives)	Fermented whey	Fermented whey enriched with Mg, Mn, Zn
Dough			
Moisture content, %	48,0		
Titrated acidity, degrees:			
Initial	5,2	6,8	6,7
Final	7,0	9,4	9,4
Fermentation duration, min	90		
Proofing duration, min.	50	40	35
Specific volume of dough, cm^3	120	132	144
Dough ball spread, mm	102	92	96
Gas production during fermentation and proofing, cm^3/100g	1136	1320	1456
Finished products			
Specific volume, cm^3/100g	226	244	252
Porosity, %	64,0	68,	71,0
Acidity, degrees	6,4	8,2	8,0
Shape stability	0,36	0,40	0,42
Comprehensive quality indicator	89,0	93,2	95,3

1 2 3

Fig. 1 – Impact of additives on bread quality: 1 – control, 2 – with fermented whey, 3 – with fermented whey enriched with magnesium, manganese, and zinc.

Table 4. Impact of fermented whey enriched with magnesium, manganese, and zinc on the staling process

Quality Indicators of Bread	Bread		
	Control (without additives)	Fermented whey	Control (without additives)
Crumbiness of crumb, %			
after 4 hours	1,2	1,0	1,2
after 72 hours	3,2	2,7	2,6
Change in crumb deformation during storage, instrument units			
4 hours			
Total	58	70	75
Plastic	42	48	51
Elastic	16	22	24
72 hours			
Total	23	29	33
Plastic	17	20	23
Elastic	6	9	10
Freshness, %			
4 hours	100	100	100
72 hours	39,7	41,4	44,0

manganese, and zinc on the preservation of freshness in bakery products. The staling process was judged by the overall deformation of the crumb and crumbiness (Table 4).

The degree of staleness was concluded based on the determination of crumbiness of the crumb after 72 hours of storage. As the data shows, in bread with fermented whey enriched with magnesium, manganese, and zinc, this indicator decreased by 26.0% and 31%, respectively, compared to the control after 72 hours of storage. This is facilitated by the additional protein and lactose content of the whey. The obtained data is confirmed by the degree of freshness preservation.

The scientifically established technological aspects of whey fermentation intensification due to the use of spark discharge mineral enrichment formed the basis for technological recommendations for improving the method of producing acidic whey as a food ingredient for rye-wheat bakery products.

Conclusions

It has been proven that the fermentation duration is nearly halved as a result of enriching whey with magnesium, manganese, and zinc, which is due to the increase in essential micro- and macroelements for the nutrition of lactobacilli cells.

The proposed technology of fermented acidic whey as a food ingredient for rye-wheat bakery products, compared to the existing technology, offers the following advantages: it halves the production cycle time for the ingredient; increases the utilization rate of technological equipment; does not require significant space for the installation of the technological complex for spark discharge treatment and reduces the need for tanks (fermenters) due to the reduced fermentation time; accelerates the technological process of producing bakery products from a mixture of rye and wheat flour.

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О. Висоцький, здобувач ОНС «Доктор філософії», E-mail: oleksandrvysotskyi.science@gmail.com
О. Кочубей-Литвиненко, д-р техн. наук, професор, *E-mail: okolit@email.ua,*
О. Білик, канд. техн. наук, професор, *E-mail: bilyklena@gmail.com,*
В. Білохатнюк, *E-mail: lsfbqgh@gmail.com*
Національний університет харчових технологій, Володимирська, 68, м. Київ, 01601, Україна,

ВИКОРИСТАННЯ СИРОВАТКИ КИСЛОЇ ФЕРМЕНТОВАНОЇ, ЗБАГАЧЕНОЇ МІНЕРАЛЬНИМИ ЕЛЕМЕНТАМИ, В ТЕХНОЛОГІЇ ЖИТНЬО-ПШЕНИЧНОГО ХЛІБА

Анотація

В даній статті досліджено використання кислої ферментованої молочної сироватки, збагаченої мінеральними елементами (магнієм, цинком та манганом), у технології житньо-пшеничного хліба. Молочна сироватка, отримана шляхом термокислотного зсідання молока, є цінним ресурсом, який може значно підвищити якість і харчову цінність хлібобулочних виробів. У роботі проаналізовано наукові підходи до збагачення молочної сироватки мінеральними елементами шляхом електроіскрового оброблення, що створює оптимальні умови для культивування молочнокислих бактерій. Основною метою дослідження є вивчення процесу ферментування сироватки молочної збагаченої мінеральними елементами та її вплив на реологічні властивості тіста і якість готових хлібобулочних виробів. Встановлено, що електроіскрове оброблення сироватки сприяє значному прискоренню процесу ферментації, підвищенню кислотності та зростанню кількості молочнокислих бактерій. Дослідження показали, що застосування збагаченої сироватки дозволяє скоротити час ферментації майже у два рази порівняно з контролем. Це досягається за рахунок інтенсивного кислотоутворення та зростання біомаси молочнокислих бактерій. Найкращі результати були отримані при використанні сироватки, обробленої електроіскровими розрядами зі струмопровідним шаром гранул цинку, магнію і мангану. Використання ферментованої сироватки у виробництві житньо-пшеничного хліба сприяло підвищенню газоутворюючої здатності тіста, покращенню його реологічних властивостей та збільшенню питомого об’єму готових виробів. Збагачена сироватка також позитивно вплинула на якість хліба, покращуючи його пористість, формостійкість та органолептичні властивості. Виявлено, що збагачення сироватки магнієм, цинком і манганом не тільки сприяє інтенсифікації ферментаційного процесу, але й підвищує харчову цінність готових виробів, збагачуючи їх важливими мікроелементами. Дослідження показали, що використання збагаченої сироватки дозволяє знизити розпливання кульки тіста, підвищити його еластичність і пружність, а також подовжити свіжість хліба. Результати досліджень підтверджують доцільність використання електроіскрового збагачення молочної сироватки магнієм, цинком і манганом для підвищення ефективності та якості виробництва хлібобулочних виробів. Запропонована технологія може бути рекомендована для широкого впровадження у виробництво, забезпечуючи високу якість та конкурентоспроможність хлібобулочних виробів на ринку.

Ключові слова: молочна сироватка, ферментація, збагачення мінеральними елементами, житньо-пшеничний хліб, магній, цинк, манган

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