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# THE PROSPECTS OF USING MILK WHEY ENRICHED WITH Mg AND Mn IN THE TECHNOLOGY OF BAKERY PRODUCTS

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**Abstract.** In this article the technological properties of milk whey, enriched with magnesium and manganese particles by electrical discharge dispersion of metal granules in the medium, and the effect of whey on the technological process and quality of bakery products have been examined. The results of theoretical and experimental studies of the quality of milk whey enriched with Mg and Mn has been presented. The toxicological studies has determined that the enrichment of milk whey with magnesium and manganese particles has not caused potentially harmful factors that could significantly affect the viability of cells of the HEK-293, L-929, PTP lines and their morphological features. The cells of the HEK-293 line were the most vulnerable to the effect of the whey, both untreated and treated by electrical discharge method, due to the low pH of the studied whey samples. The positive influence of enriched whey if applied in the amount of 15% to the mass of flour, on the physical, chemical and sensory qualities of bakery products, particularly the increase specific volume and shelf-life, has been proven. Much attention has been paid to the staling processes, associated with the retrograding and aging of the main biopolymers of bakery products. The relevance of the presented research is in expanding the possibilities of using enriched milk whey for bakery products for the elderly.

**Key words:** milk whey, bio-elemental particles of magnesium and manganese, electrical discharge, biological test-objects in vitro, cell cultures, cytotoxicity, bakery products.

# ПЕРСПЕКТИВИ ВИКОРИСТАННЯ МОЛОЧНОЇ СИРОВАТКИ, ЗБАГАЧЕНОЇ Mg ТА Mn У ТЕХНОЛОГІЇ БУЛОЧНИХ ВИРОБІВ

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**Анотація.** У статті розглянуто технологічні властивості молочної сироватки, збагаченої частинками магнію і мангану, оброблених електроіскровим диспергуванням гранул металів у її середовищі, та вплив сироватки на технологічний процес виробництва булочних виробів і їх якість. Наведено результати теоретичних та експериментальних досліджень якості молочної сироватки, збагаченої Mg і Mn. Комплексом токсикологічних досліджень встановлено, що збагачення молочної сироватки частинками магнію і мангану не викликало потенційно шкідливих чинників, які б могли суттєво вплинути на життєздатність клітин ліній НЕК-293, L–929, PTP та їх морфологічні ознаки. Найбільш вразливими до дії молочної сироватки, як нативної, так й обробленої електроіскровими розрядами, виявилися клітини лінії НЕК–293, що пояснюється низьким pH досліджуваних зразків сироватки. Доведено позитивний вплив використання збагаченої сироватки на фізико-хімічні та органолептичні показники якості булочних виробів за умови внесення її в кількості 15% до маси борошна, а саме: збільшується питомий об'єм і подовжується термін збереження ними свіжості. Велику увагу приділено процесам черствіння, пов'язаним з ретроградацією і старінням основних біополімерів булочних виробів. Актуальність представлених досліджень полягає в розширенні можливості застосування збагаченої молочної сироватки та асортименту булочних виробів для людей похилого віку.

**Ключові слова:** молочна сироватка, часточки біоелементів магнію та мангану, електроіскрове оброблення, біологічні тест-об'єкти in vitro, культури клітин, цитотоксичність, булочні вироби, черствіння.


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## Introduction. Formulation of the problem

Bakery products are considered a constant and necessary part of human diet. The research done by domestic and foreign scientists has established that it is impossible to meet the nutritional requirements of human organism by following the usual diet [1,2]. Traditional varieties of bakery products are of high energy value, but they do not have a balanced chemical composition. World practice shows that this problem can be solved, provided that the concept of improving the dietary rations is followed by using functional ingredients in the technology of bakery products.

Nowadays, one of the relevant problems of the bakery industry is expanding the range of bakery products for the elderly. The experience of scientists and practitioners suggests that one of the ways to solve it is by adding natural biocorrectors that will improve the

nutritional value of bakery products. One of such products may be milk whey enriched with particles of magnesium and manganese by electrical discharge dispersion of metal granules in the medium [3].

Due to affordable prices and easy use, bakery products are the main food products that provide nutrients to the population, especially the elderly [4]. Fundamental studies of the quality and technological properties of milk whey enriched with Mg and Mn, in conjunction with its cytotoxic effect and the development of technology of using milk whey in bakery products for the elderly, will enable the formation of basic conceptual regulations for improving the nutritional value of bakery products.

Many scientists work on the development of technologies of baked goods with high nutritional value, made with non-traditional raw materials, such as the flour of various cereals, milk products, vegetable and fruit powders, bran, flaxseed flour and other ingredients [5,6].

One of the types of non-traditional raw materials is natural milk whey, which activates the microflora of liquid yeast, yeast suspension, liquid dough; intensifies the dough-making process; increases the nutritional value of bakery products made from straight or prefermented dough; allows to save flour [7]. However, the addition of only natural whey cannot solve the problem of improving the quality of bread, mineral content in particular is not substantially improved [8].

Therefore, using milk whey enriched with Mg and Mn in the development of technology of bakery products for the elderly is justified and relevant.

## Analysis of recent research and publications

Improved nutritional value of bakery products is especially needed for the elderly, since with age biosynthesis and the activity of digestive enzymes decrease, which weakens the processes of digesting nutrients. It is therefore necessary to provide the body with minerals, particularly Mg and Mn. Magnesium is essential for carbohydrate, protein, lipid and phosphorous metabolism. Additionally, it reduces agitation in nerve cells, relaxes the heart muscle and thus controls the functions of all organs and systems, such as nervous, cardiovascular, bone, muscle systems, etc. [9–11].

Another essential chemical element is manganese. It is necessary for the proper development of cells, good assimilation of thiamine, biotin, iron and copper, which are necessary for hematopoiesis. Manganese is required for the normal structure of bones, the formation of thyroxin (the main thyroid hormone), it helps with feebleness, improves muscle reflexes and memory, reduces nervous irritability [12].

From the literature analysis, one can conclude that biometals are essential in the diet of the elderly, so there is a need for using them for the enrichment of food products [13].

The problem of using micronutrients in the technology of bakery products is selecting their physical and chemical forms [12]. According to the scientific approaches and principles of enriching food products with micronutrients, they should be characterized by high bioavailability and digestibility. Therefore, in bakery technology, it is advisable to use raw materials that have naturally high or enriched content of valuable micronutrients. Adding whey enriched with minerals to the bakery products holds promise in this direction. In the National University of Food Technologies (Ukraine) together with researchers from the National University of Life and Environmental Sciences (Ukraine), an electrophysical method of microelement enrichment of milk whey, by magnesium and manganese in particular, has been developed. The use of milk whey enriched with Mg and Mn in the technology of bakery products increases the bioavailability of these metals, since they function in the human organism in this form [3].

According to the literature analysis, the digestive process of the elderly deteriorates in 90 % of cases, therefore, it is recommended that they consume bakery products of yesterday's baking [14,15].

Taking into account the above, we propose the technology of bakery products for the elderly, containing milk whey enriched with Mg and Mn.

**This work was aimed** at establishing the safety of the milk whey, enriched with magnesium and manganese particles by the electrical discharge dispersion of metal granules in the medium, by an alternative in vitro method using cell test objects and the possibility of using such whey in the technology of bakery products for the elderly.

In order to achieve this goal, the following tasks were set:

1) toxicological study of the safety of milk whey, enriched with Mg and Mn by electrical discharge dispersion of the granules of the corresponding metals;

2) determining the possibility of enriching milk whey with magnesium and manganese;

3) investigating chemical composition, physical and chemical properties of milk whey enriched with Mg and Mn;

4) investigating the effect of using milk whey enriched with Mg and Mn on the quality of bakery products.

## Research materials and methods

The object of research is milk whey left after making sour milk cheese, which is enriched with particles of magnesium and manganese as a result of electrical discharge treatment in a discharge chamber with a conductive layer of granules of the corresponding metals. Milk whey left after making sour milk cheese with protein particles removed and a loaf “Niva” were used as control samples.

The laboratory unit, used for treatment, consists of a generator of discharge pulses (pulse rate is 0,2–2,0 kHz, inductance of the discharge circuit is 1 μH); a discharge chamber with a magnesium or manganese electrode system and a conductive layer of granules of the corresponding metals; control unit; measuring and auxiliary devices. A capacitor with a capacity of 100 μF was used as a power storage device [6]. Treatment parameters are as follows: the size of the discharge chamber is 300 $cm^3$; exposition time is 60 s; the temperature of milk whey is (20±2)°C.

In the Laboratory of Analytical Chemistry and Monitoring of Toxic Substances at the Institute of Labor Medicine of the National Academy of Medical Sciences of Ukraine, the content of metallic elements in whey samples was determined by the method of inductively coupled plasma atomic emission spectrometry on the Optima 210 DV device (Perkin Elmer, USA).

Particle size was determined using the particle dispersion analyzer Malvern Instruments Ltd. (UK), pH was measured on pH-meter I-160 M; oxidation-reducing potential was measured on pH-meter with platinum electrodes EB-74.

The study of the cytotoxic effect of milk whey enriched with magnesium and manganese as a result of electrical discharge treatment was carried out in the Laboratory of Industrial Toxicology and Occupational Health, using the chemical substances of the Institute of Labor Medicine of the Academy of Medical Sciences of Ukraine and cell cultures of the HEK-293 (human embryonic kidney cells), L-929 (mouse fibroblast cells) and PTP (piglet testicular cells) lines obtained from the Bank of Cell Lines of Zabolotny Institute of Microbiology and Virology of the National Academy of Sciences of Ukraine.

Cells used in the experiment were cultured in RPMI 1640 medium (SIGMA, USA) containing 4 mmol/$dm^3$ of L-glutamine, 10% of calf embryonic serum (SIGMA, USA), 40 μg/$cm^3$ of gentamicin in humidified atmosphere with 5 % $CO_2$ at a temperature of 37°C. The nutrient medium was changed every two days. The cells were reset with the Versen solution provided that the cells formed a solid monolayer (4–5 days of growth).

The cytotoxic activity was studied using generally accepted tests: a test of mitochondrial activity (MTT assay) and a sulfodoamine-B staining test (SR B-test) [10,11]. MTT assay determines the functioning of mitochondria by the dehydrogenase activity that forms crystals with tetrazolium salts [16]. Cells were planted on 96-well plates at a concentration of $1\times10^5$/$cm^3$ in the amount of 100 μl per well in a complete nutrient medium. After 24 hours, experimental samples of whey were added in natural concentration followed by sequential dilution (1:2). After 24 hours of culture, colorant MTT (3-[4,5-dimethylthiazole-2-yl]-2,5-diphenyltetrazolium bromide; Thiazolyl blue) (SIGMA, USA) was introduced into the medium in the amount of 10 μl per well at a concentration of 5 mg/$cm^3$ for three hours The plate was then centrifuged (1500 rpm for 5 min), the supernatant was removed and 50 μl of DMSO (dimethyl sulfoxide, SERVA) was added to each well to dissolve the formazan crystals. After 30 minutes of incubation at room temperature, the optical density of the contents of the wells at a wavelength of 540 nm was measured using a multi-beam spectrophotometer Sunrise Tecan (Austria). Wells with cells in a nutrient medium, to which the test whey was not added, were used as control.

For laboratory baking, straight dough was prepared with the moisture content of 43%. The dough was mixed in a two-speed dough machine. Milk whey was added during the dough mixing. The dough was shaped by hand and proved at temperature (35±2)°C and relative humidity (75±2)%. The products were baked in the oven at a temperature of 220–240°C.

The quality of baking products was determined by physical and chemical (specific volume, shape stability, structural and mechanical properties of the crumb) and sensory parameters (appearance, surface condition of the crust, porosity structure, taste, smell) [17]. The effect of additives on the freshness of the products was studied by measuring the structural and mechanical properties of crumb. Total deformation of the crumb was measured after 72 hours of storage on a penetrometer AP 4/1. Complex quality index was determined by the quality score of bakery products [17]. Nutritional value was calculated using the program "Optima" [18]. The results of experimental studies were statistically analyzed using standard Microsoft Office software packages.

## Results of the research and their discussion

The results of physical and chemical research and dispersion analysis of milk whey samples before and after electric discharge treatment are presented in table 1.

Studies have shown a decrease in the oxidation/reduction potential in processed whey (an increase of anti-oxidant properties), which may indicate both the benefit of the process of $M\leftrightarrow Mn^{n+}$ +ne and the possible complexation between metal ions and milk whey bioligands, which, in turn, leads to an increase of the biological availability of magnesium and manganese in processed whey.

The dispersion analysis of the samples showed that the average size of whey powder particles before and after treatment was not significantly different. However, since the toxicity of the system may depend on the size of the metal particles dispersed in whey [16], the average hydrodynamic diameter of magnesium and manganese particles in colloidal solutions, obtained by electrical discharge dispersion of the corresponding metal granules in the aqueous medium with similar treatment parameters to whey, was additionally determined. It was determined that colloidal

solutions of magnesium and manganese had particles in nano (about 30 nm) and micro range (from 100 nm to 10 μm). The average particle size in the colloidal solution of magnesium and manganese was 118±5 nm and 270±11 nm respectively.

**Table 1 – Characteristics of milk whey samples**

| Sample | pH | Titrated acidity, °T | Average particle size, nm | Mg content, mg/kg | Mn content, mg/kg |
|---|---|---|---|---|---|
| Milk whey left after making sour milk cheese (control) | 4.40 ± 0.2 | 82 | 562 ± 23 | 59.8 ± 0.59 | 0.015 ± 0.002 |
| Milk whey treated in a discharge chamber with a layer of conductive granules of magnesium between the electrodes of the corresponding metal | 4.75 ± 0.2 | 75 | 560 ± 13 | 170 ± 5.08 | 0.018 ± 0.001 |
| Milk whey treated in a discharge chamber with a layer of conductive granules of manganese between the electrodes of the corresponding metal | 5.10 ± 0.2 | 68 | 536 ± 39 | 58.4±0.05 | 0.069 ± 0.003 |

Investigation of toxic properties of milk whey enriched with particles of magnesium and manganese has allowed to establish that, in relation to HEK-293 cells, the largest cytotoxic activity was shown, in fact, by milk whey itself (24.3% of live cells). In samples enriched with magnesium and manganese, the number of living cells was slightly higher – 26.4% and 26.8%, respectively (Table 2). This cytotoxic effect is due to low pH of whey (see Table 1), which contributed to the reduction of viable cells due to their lysis. It was noted that decreasing whey concentration in the incubation medium 8 and more times (and, consequently, increasing the pH of the medium to the level of normal cell functioning) contributed to the normal cell growth. The cytotoxic activity of milk whey enriched with Mg and Mn particles was approximately the same as in the milk whey before treatment. Thus, when using dilution ratio of 1:4, the number of live cells was 55.4% (whey with Mg) and 49.3% (whey with Mn), and in dilutions of 8 and more, normal cell activity was observed similar to that of normal whey. The number of live cells ranged from 82 to 94.6% compared to the control sample.

**Table 2 – Estimation of cytotoxic effect of milk whey enriched with Mg and Mn particles on cell culture of the HEK-293 line (MTT assay)**

| Dilution ratio (times) | Amount of living cells, % | | |
|---|---|---|---|
| | Milk whey | Milk whey, enriched with Mg | Milk whey, enriched with Mn |
| 2 | 24.30 | 26.40 | 26.80 |
| 4 | 57.30 | 55.40 | 49.30 |
| 8 | 84.00 | 83.50 | 82.20 |
| 16 | 85.10 | 84.20 | 86.60 |
| 32 | 89.50 | 88.10 | 90.10 |
| 64 | 91.10 | 92.80 | 94.20 |
| 128 | 93.5 | 93.75 | 94.60 |

Studies performed on the cells of the L-929 line showed that the samples of milk whey enriched with magnesium and manganese particles stimulated proliferation, which contributed to an increase in the number of living cells (more than 100% in control) (Table 3). While milk whey, according to MTT assay, reduced the vitality of L-929 cells to 77% in dilutions of 1:2, 1:4, 1:32 and 1:64, with other concentrations the amount living cells was 80–90.5%.

Adding milk whey with magnesium particles diluted more than 32 times to the cells of the L-929 line did not cause an increase in the number of live cells compared to the control sample. As with normal whey, the percentage of living cells was 85–95%. Analyzing this data, we can conclude that only a certain concentration of magnesium particles stimulates proliferation.

The addition of milk whey with dilution ration 1:2 to piglet testicular cells (cells of the PTP line) caused the death of 41.8 % of cells. Subsequent dilution of whey (8–64 times) did not significantly affect their viability (Table 4).

**Table 3 – Viability of cells of the L-929 line under the effect of whey, enriched with particles of magnesium and manganese (MTT assay)**

| Dilution ratio (times) | Amount of living cells, % | | |
|---|---|---|---|
| | Milk whey | Milk whey, enriched with Mg | Milk whey, enriched with Mn |
| 2 | 74.91 | 178.37 | 110.53 |
| 4 | 73.22 | 124.10 | 115.05 |
| 8 | 80.28 | 116.47 | 141.63 |
| 16 | 90.46 | 102.61 | 147.00 |
| 32 | 72.93 | 85.37 | 123.25 |
| 64 | 77.17 | 92.44 | 118.73 |
| 128 | 85.09 | 91.02 | 125.23 |
| 256 | 94.98 | 95.27 | 126.64 |

**Table 4 – Viability of cells of the PTP line under the effect of whey, enriched with particles of magnesium and manganese (MTT assay)**

| Dilution ratio (times) | Amount of living cells, % | | |
|---|---|---|---|
| | Milk whey | Milk whey, enriched with Mg | Milk whey, enriched with Mn |
| 2 | 58.19 | 94.26 | 69.08 |
| 4 | 75.22 | 94.31 | 76.49 |
| 8 | 89.82 | 98.58 | 87.28 |
| 16 | 91.19 | 107.17 | 107.48 |
| 32 | 93.52 | 108.23 | 111.40 |
| 64 | 100.71 | 117.62 | 165.35 |

No cytotoxic effect of whey enriched with magnesium particles was noted; the number of live cells in samples with 2-8 dilution ranged from 94 to 98.5%. Dilution of more than 16 that leveled the effect of pH caused an increase in the number of live cells (up to 107.2–117.6%) compared to control.

The samples of milk whey with manganese particles in the first three dilutions had an insignificant toxic effect, while the number of live cells was in the range of 69.1–87.3%, as with the normal whey (Table 4). Subsequent dilution caused an increase in the number of living cells.

**Table 5 – Effect of whey, enriched with magnesium and manganese, on dough and bread quality**

| Quality indices | Loaf "Niva" | | | |
|---|---|---|---|---|
| | control (without additives) | with natural whey | with whey enriched with | |
| | | | Mg | Mn |
| *Dough* | | | | |
| Moisture content, % | 43.0 | | | |
| Titrated acidity, °: | | | | |
| in the beginning | 1.0 | 1.5 | 1.5 | 1.5 |
| in the end | 1.5 | 2.0 | 1.0 | 1.0 |
| Duration of fermentation, min | 60 | | | |
| Duration of proving, min | 50 | | | |
| Specific volume of the dough, $cm^3$ | 126 | 132 | 136 | 136 |
| Dough spreading, mm | 105 | 100 | 100 | 100 |
| Gas production during fermentation and proving $cm^3/100g$ | 296 | 312 | 318 | 322 |
| *Finished product* | | | | |
| Porosity, % | 74 | 76 | 82 | 82 |
| Acidity, ° | 1.5 | 2.0 | 2.0 | 2.0 |

Thus, the enrichment of milk whey with magnesium and manganese particles by electrical discharge dispersion of the granules of the corresponding metals in its medium did not cause potentially harmful factors that could significantly affect the vitality of the cells of the body, therefore this whey can be used in the bakery products technology.

Further research focused on the possibility of using processed whey in the technology of bakery products. To this end, baking test was carried out.

Straight dough was prepared according to the formula of loaf "Niva" (which served as control product), milk whey left after making sour milk cheese, whey enriched with Mg particles and whey enriched with Mn particles, was dosed in quantities of 15 % to the mass of flour. The evaluation of the quality of dough and bread was carried out according to the physical, chemical, sensory parameters and complex quality index. The results are presented in table 5 and fig. 1

It has been established that adding natural whey and whey enriched with Mn and Mg particles separately increased the acidity of dough and loaf. It has been determined that using all examined samples of whey increased gas production, specific volume and rheological properties of the dough, which led to an increase of the specific volume of bread. Thus, in a loaf with whey enriched with magnesium and manganese, this indicator increased by 7.0% and 6% respectively compared to control (Fig. 1a).

Adding whey strengthens the gluten frame which positively affects the shape stability of bakery products (Fig. 1b). Adding processed whey did not cause changes to traditional sensory qualities of wheat bread.

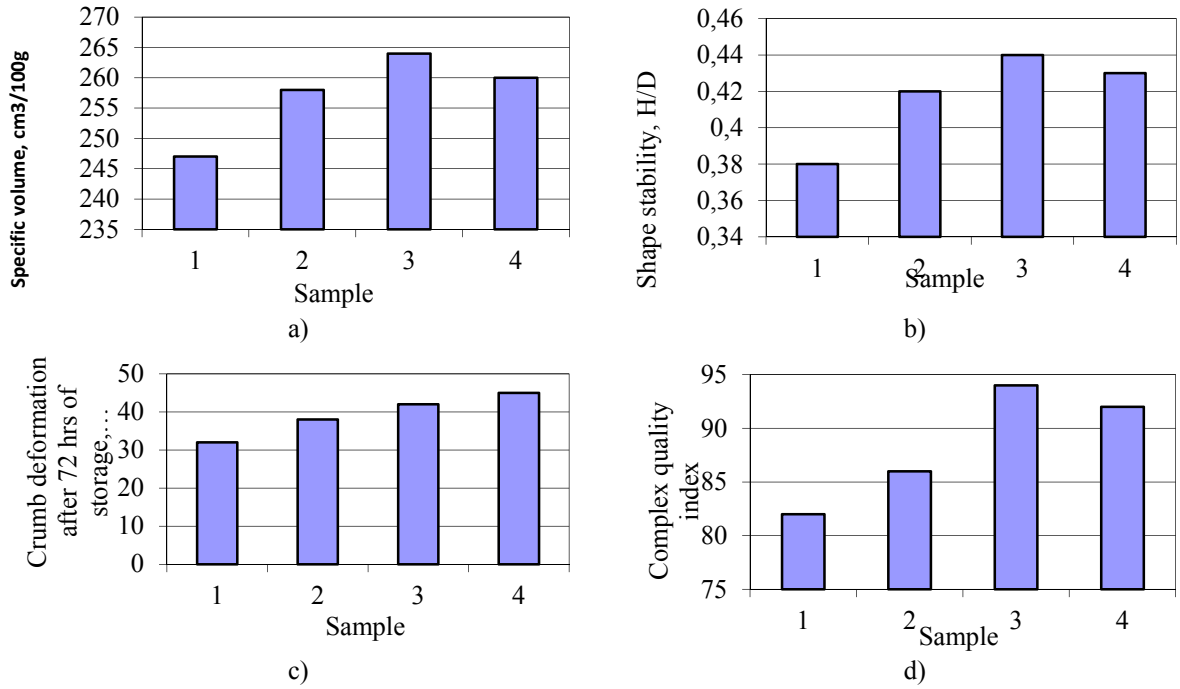
Staling is a problem of baking industry, connected to the decrease of consumer properties of bakery products and additional costs of the processing of stale bread; therefore it was advisable to study the effect of enriched whey on preserving the freshness of bakery products.

The degree of staling was determined by the total deformation of the crumb after 72 hours of storage. A comparative analysis of freshness of the studied samples showed a positive effect of adding whey (Fig. 1c). According to the data, adding whey to the dough almost doubled the total deformation of the crumb (Fig. 1c).

The results of research have shown that bread with whey enriched with biogenic magnesium particles had the highest complex quality index (Fig. 1d).

To achieve the goals of this work, it was necessary to calculate the nutritional value of wheat bread for the elderly in comparison with bread from high grade wheat flour. The evaluation was carried out by calculating their chemical composition using the "Optima" program [18].

The calculations used the daily rate of bread consumption (277 g) provided by the "consumer basket", approved by the Cabinet of Ministers of Ukraine and the norms of physiological requirements of the population in main nutrients and energy.




*Bread sample*: 1 – control without additives; 2 – with natural whey; 3, 4 – with whey, enriched with magnesium and manganese respectively

**Fig. 1. Effect of whey, enriched with magnesium and manganese, on bread quality:**
a) specific volume; b) shape stability; c) staling after 72 hours; d) complex quality index

The results of calculations, presented in the table 3, show that milk whey and whey enriched with magnesium and manganese, when added in the amount of 15% to the mass of flour, increase the content of calcium by 46.2, potassium by 10, iron by 34.6%. Using whey enriched with magnesium increases its content in finished products by 14.3% and using whey enriched with manganese increases its content by 0.077 mg.

**Table 6 – Chemical composition of the 100 g of loaf "Niva"**

| Nutrients, % | Control (without additives) | Product with milk whey | | |
|---|---|---|---|---|
| | | natural | enriched with Mg | enriched with Mn |
| Proteins | 7.905 | 8.048 | 8.048 | 8.048 |
| Fats | 2.402 | 2.408 | 2.408 | 2.408 |
| Carbohydrates | 55.200 | 55.206 | 55.206 | 55.206 |
| Minerals, mg: | | | | |
| calcium | 17.710 | 25.900 | 25.900 | 25.900 |
| phosphorous | 69.300 | 69.500 | 69.500 | 69.500 |
| potassium | 98.860 | 109.000 | 109.000 | 109.000 |
| manganese | 26.550 | 26.600 | 26.600 | 26.626 |
| magnesium | 12.860 | 13.400 | 14.700 | 13.400 |
| iron | 0.973 | 1.310 | 1.310 | 1.310 |
| Vitamins, mg: | | | | |
| thiamine ($B_1$) | 0.135 | 0.140 | 0.140 | 0.140 |
| riboflavin ($B_2$) | 0.038 | 0.050 | 0.050 | 0.050 |
| niacin (PP) | 1.033 | 1.031 | 1.031 | 1.031 |
| Energy density, kcal | 260.1 | 261.0 | 261.0 | 261.0 |

The coverage of the average daily requirements of the human body in biologically important substances by consuming 277 g of the loaf enriched with milk whey is presented in table 7. As shown in table 7, bakery products with milk whey enriched with Mg or Mn increase the coverage of the requirements in calcium, phosphorus, potassium, magnesium, manganese, iron.

**Table 7 – Coverage of daily nutrient requirements by consuming 277 g of the loaf**

| Nutrients | Average daily requirement [19] | Content in 277 g of the loaf | | | | Coverage of daily requirements by consuming 277 g of the loaf, % | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | control (without additives) | with milk whey | | | control (without additives) | with milk whey | | |
| | | | natural | enriched with Mg | enriched with Mn | | natural | enriched with Mg | enriched with Mn |
| Proteins, g | 61 | 21.9 | 22.3 | 22.3 | 22.3 | 35.9 | 36.6 | 36.6 | 36.6 |
| Fats, g | 65 | 6.65 | 6.67 | 6.67 | 6.67 | 10.2 | 10.3 | 10.3 | 10.3 |
| Starch, g | 280 | 152.9 | 152.9 | 152.9 | 152.9 | 54.6 | 54.6 | 54.6 | 54.6 |
| Minerals, mg: | | | | | | | | | |
| calcium | 800 | 49.1 | 71.7 | 71.7 | 71.7 | 6.1 | 8.9 | 8.9 | 8.9 |
| phosphorous | 1200 | 192.0 | 193.6 | 193.6 | 193.6 | 16.0 | 16.1 | 16.1 | 16.1 |
| potassium | 3750 | 273.8 | 301.9 | 301.9 | 301.9 | 7.3 | 8.05 | 8.05 | 8.05 |
| manganese | 10 | 73.5 | 73.7 | 73.7 | 73.8 | 735 | 737 | 737 | 738 |
| magnesium | 400 | 35.6 | 37.1 | 40.7 | 37.1 | 8.9 | 9.3 | 10.2 | 9.3 |
| iron | 15 | 2.7 | 3.6 | 3.6 | 3.6 | 18 | 24 | 24 | 24 |
| Vitamins, mg: | | | | | | | | | |
| thiamine ($B_1$) | 1.2 | 0.37 | 0.39 | 0.39 | 0.39 | 30.8 | 32.5 | 32.5 | 32.5 |
| riboflavin ($B_2$) | 1.4 | 0.11 | 0.14 | 0.14 | 0.14 | 7.9 | 10.0 | 10.0 | 10.0 |
| niacin (PP) | 2.2 | 2.86 | 2.86 | 2.86 | 2. 86 | 130 | 130 | 130 | 130 |
| Energy density, kcal | 1570 | 720.5 | 723.0 | 723.0 | 723.0 | 45.9 | 46.1 | 46.1 | 46.1 |

Thus, adding milk whey enriched with magnesium or manganese to the dough not only improves the physical properties of the dough and the quality of bakery products, but also substantially increases their nutritional value due to the increase of mineral content.

**Approbation of research results.** The technology of the loaf "Dzerovyi" has been developed and presented to the tasting at LLC "Dva mlyna", where it received favorable reviews and high praise.

## Conclusions

As a result of the conducted research, the following conclusions were drawn:

1. Toxicological studies have shown that enriching milk whey with magnesium and manganese particles by electrical discharge dispersion of the granules of the corresponding metals in the medium did not

cause potentially harmful factors that could significantly affect the viability of the cells of HEK-293 (human embryonic kidney cells), L-929 (mouse fibroblast cells) and PTP (piglet testicular cells) lines.

2. The possibility of enriching milk whey with magnesium and manganese by electrical discharge synthesis of biometals has been proven.

3. The increase of magnesium and manganese content in processed whey has been established. Physical and chemical properties of processed whey did not undergo significant changes.

4. Adding milk whey enriched with magnesium or manganese to the bread in the amount of 15% to the mass of flour improved the product quality, such as shape stability and shelf-life, confirmed by the highest value of the complex quality index, and increased the mineral content.

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# ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ МОЛОЧНОЙ СЫВОРОТКИ, ОБОГАЩЕННОЙ Mg И Mn В ТЕХНОЛОГИИ БУЛОЧНЫХ ИЗДЕЛИЙ


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**Аннотация.** В статье рассмотрены технологические свойства молочной сыворотки, обогащенной частицами магния и марганца в результате электроискрового диспергирования гранул металлов в ее среде и влияние сыворотки на технологический процесс производства булочных изделий и их качество. Приведены результаты теоретических и экспериментальных исследований качества молочной сыворотки, обогащенной Mg и Mn. Комплексом токсикологических исследований установлено, что обогащение молочной сыворотки частицами магния и марганца не вызывало потенциально вредных факторов, которые могли бы существенно повлиять на жизнеспособность клеток линий НЭК–293, L–929, PTP и их морфологические признаки. Наиболее уязвимыми к действию молочной сыворотки, как натив-

ной, так и обработанной электроискровыми разрядами, оказались клетки линии НЕК–293, что объясняется низким pH исследуемых образцов сыворотки. Доказано положительное влияние обогащенной сыворотки на физико-химические и органолептические показатели качества булочных изделий при внесении ее в количестве 15% к массе муки, а именно: увеличивается удельный объем и удлиняется срок сохранения изделиями свежести. Большое внимание уделено процессам черствения, связанным с ретроградацией и старением основных биополимеров булочных изделий. Актуальность представленных исследований заключается в расширении возможности применения обогащенной молочной сыворотки в ассортименте булочных изделий для пожилых людей.

**Ключевые слова:** молочная сыворотка, частицы биоэлементов магния и марганца, электроискровая обработка, биологические тест-объекты in vitro, культуры клеток, цитотоксичность, булочные изделия.

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