

Development of an Integrated Technology for Milk Processing with the Production of Functional Dairy Products and Biotech Products for Food and Pharmaceutical Industry

Kseniya Starovojtova
*Department of food technology
from vegetable raw materials
Kemerovo State University
Kemerovo, Russia*
ORCID: 0000-0002-4012-7570

Lyubov Tereshchuk
*Department of food technology
from vegetable raw materials
Kemerovo State University
Kemerovo, Russia*
terechuk_l@mail.ru

Marina Tarlyun
*Department of food technology
from vegetable raw materials
Kemerovo State University
Kemerovo, Russia*
matarlyu@mts.ru

Irina Dolgolyuk
*Department of food technology
from vegetable raw materials
Kemerovo State University
Kemerovo, Russia*
irinkadolgoluk@mail.ru

Abstract— Investigations described in this article are aimed at developing an integrated technology for processing dairy raw materials for producing functional dairy products, as well as biotech products for food and pharmaceutical industries, with subsequent implementation of results at industry enterprises. Formulas of functional foods based on processed dairy raw materials were developed. Technology and instrumentation were developed for the production of functional milk shakes intended for use in the daily diet as one of the meals in order to eliminate the deficiency of animal proteins, vegetable fats, essential fatty acids and fat-soluble vitamins. The studies conducted allowed us to adjust the technological parameters for the production of dairy products of mass consumer demand in order to add functional properties. Under production conditions, pilot batches of dairy products with desired properties and biological products using secondary dairy raw materials were manufactured.

Keywords—*biotech products, biotransformation, secondary dairy raw materials, import substitution, lactose, casein, whey proteins.*

I. INTRODUCTION

In the current socio-economic situation in the Russian Federation, an important task is to ensure the food security of the country. Measures aimed at increasing the nutritional value of food are considered as effective ones. Topical issues related to the nutrition of the population of Russia are: imbalanced diets in the sense of main nutrients, insufficient content of essential nutrients in the diet, namely, deficiency of animal proteins, vegetable fats, essential fatty acids and fat-soluble vitamins.

The most effective method of preventing the deficiency of essential nutrients in the diets of various population groups is direct enrichment of mass consumption products with vitamins, minerals, essential fatty acids. Such products include milk and dairy products. The share of dairy products in the consumer basket of Russian people is variously estimated at from 20 to 30%. High nutritional value of milk is undeniable due to the presence of vitamins A, D, riboflavin, β -carotene. However, its vitamin composition is not constant and depends on many factors, including season and feed composition of dairy cows. In addition, loss of vitamins during technological processing of

milk, which includes separation, normalization, pasteurization and drying, is significant. Milk skimming also leads to the loss of fat-soluble vitamins A and D, tocopherols and carotenoids. All this indicates the reasonability of additional enrichment of milk and dairy products, in order to achieve constant values of the content of irreplaceable food substances in their composition regardless of the season and method of technological processing of dairy raw materials [1, 2].

Milk being, of course, a valuable product due to the complex multicomponent composition, in its whole form may not be suitable for nutrition of certain groups of adults and children. The most common types of milk intolerance are lactase deficiency, as well as allergies to protein of cow's milk (goat's, sheep's and other types). These forms of milk intolerance are commonly found in childhood but may also be present in adults. Implementation of technologies for the production of milk and lactose-free milk drinks allows solving this problem [3].

The task of obtaining low-allergy dairy products without loss of nutritional value is solved by modifying the protein components of milk using enzymatic hydrolysis (proteolysis). Using hydrolyzed proteins allows achieving the most complete assimilation of short-chain peptides in gastrointestinal tract in comparison with native proteins and amino acids. Obtaining biologically active milk peptides with antihypertensive, antimicrobial, immunostimulating, antifungal and other properties is also of particular interest for food and pharmaceutical industries. At present, the use of hydrolysates is in demand mainly as a component of infant milk formula for preventive and therapeutic purposes, but the demand for them is met mainly with imported products. However, one of the criteria for the country's food security is the level of self-sufficiency in agricultural products. In accordance with the Food Security Doctrine [4], the share of dairy products produced in the country should be at least 90%. However, self-sufficiency in dairy products actually remains at the level of about 80%, due to the lack of domestic dairy products for dietary and therapeutic nutrition, as well as of biological products obtained from dairy raw materials for the needs of agriculture, food industry and pharmaceutical production. Thus, the Russian Federation is import-dependent on specialized dairy products and biotech products

imported from other countries. Therefore, the production of milk and dairy products with desired composition and properties reached with the enrichment with biocorrectors, as well as with the targeted transformation of dairy raw materials, is very pressing.

II. LITERATURE REVIEW

Milk is a source of calcium, phosphorus, magnesium, as well as zinc, cobalt, and iron. In addition, milk contains almost all vitamins. Milk proteins are considered perfectly balanced in terms of content and ratio of essential amino acids. Milk fat is rich in polyunsaturated fatty acids and fat-soluble vitamins that are not found in many other foods. Carbohydrate complex is mainly represented by lactose, a carbohydrate of animal origin, widely used in food and pharmaceutical industries due to its unique properties [5].

However, during the production of dairy products, such as butter, sour cream, cottage cheese and cheese, from 50% to 75% of all milk solids are transferred to skimmed milk, buttermilk and whey which are considered secondary dairy raw materials. Skimmed milk and buttermilk contain almost all milk proteins and carbohydrates, and milk whey contains about 70% carbohydrates, some fractions of caseins (not coagulated by acids and enzymes), as well as soluble whey proteins (lactoglobulins, lactoalbumins, immunoglobulins, lactoferrin, etc.). In addition to proteins and carbohydrates, in the production of desired dairy products, almost all vitamins and minerals, as well as enzymes, hormones, immune bodies and organic acids, are transferred to secondary dairy raw materials [6].

This fact causes the relevance of scientific research aimed at developing new integrated technologies for milk processing with the maximal possible use of secondary dairy raw materials and the manufacturing of products and additives for children's, special, elderly and therapeutic nutrition.

Until now, an integrated approach to the processing of dairy raw materials with manufacturing of several products has not been widely applied in domestic practice. This happened due to both technological complexity of the unit and the insufficient scientific and economic justification of integrated projects. Many academic and industrial institutions of the country are actively engaged in researching the properties of dairy raw materials and their components, but in most enterprises, the processing of dairy raw materials is focused on obtaining separate desired products.

The goal of this research is to develop an integrated technology for the production of milk and dairy products with desired composition and properties for use in food and pharmaceutical industries. To achieve this goal, it was planned to perform a number of scientific and technical tasks.

Key tasks include:

- design of the composition and development of technologies for functional dairy and milk-containing products containing biologically active substances which were obtained from the processing of secondary dairy raw materials;

- development of technology and instrumentation for deep processing of secondary dairy raw materials for manufacturing products and biologically active complexes for food, feed, medical, veterinary, pharmaceutical and cosmetic purposes.

III. RESEARCH METHODOLOGY

Design of ingredient composition and development of the technology of functional food products intended for optimizing the diet and preventing nutritionally dependent diseases were carried out on the basis of previous work on the theoretical justification of the line for creating the functional properties of milk and dairy products [7, 8, 9].

Theoretical studies and part of experimental studies on modeling the ingredient composition of developed functional products were carried out on the basis of laboratories of Technology of Food Products from Plant Raw Materials Department of Kemerovo State University Federal State Budgetary Educational Institution for Higher Education.

Practical studies on the testing of milk processing technology and manufacturing functional ingredients and products were carried out on the basis of a private farm located in the Kemerovo Region; its main profile is the production of butter and cottage cheese.

In the course of work, common and special methods of researching raw materials and finished products were used.

Organoleptic indicators, density, mass fraction of proteins and their fractional composition, mass fraction of lipids and carbohydrates, thermal stability and microbiological purity were determined in raw milk supplied to the enterprise.

Different physical and chemical methods were used for analyzing and assessing the compliance of biologically active substances obtained from dairy raw materials; these included gas chromatography, gas-liquid chromatography, high-performance liquid chromatography, thin-layer chromatography, as well as electrochemical, spectroscopic, and potentiometric methods. For quantitative analysis of organic substances, UV spectroscopy, IR spectroscopy, nuclear magnetic resonance spectroscopy, mass spectrometry, and other methods were used [10].

This article describes the results of research on the development of a technology of instant milk shake for functional use designed to eliminate the deficiency of animal proteins, essential fatty acids and fat-soluble vitamins. Most of the ingredients that make up the product were obtained during processing of secondary dairy raw materials; biologically active substances obtained from the processing of plant materials were also used [11].

IV. RESULTS

As a result of theoretical studies, a formula of functional milkshake was developed which consists of secondary dairy raw materials and ingredients obtained during its comprehensive processing.

Instant granular product is a dried microemulsion obtained from dairy components (pre-condensed skimmed milk, sodium caseinate, whey protein concentrate and lactose) and fat phase consisting of the composition of three vegetable oils with balanced fatty acid content (sunflower, soya and linseed oil in a ratio of 50:30:20), as well as with additional enrichment with biologically active substances of plant origin. This product is characterized by high content of milk proteins [11].

The choice of specific vegetable oils and their percentage in fat phase is due to the goal of increasing the biological effectiveness of finished product, since it is such a

composition that has a ratio of ω -6: ω -3 polyunsaturated fatty acids at the level of (4:1) what corresponds to the requirements for the products with functional purpose [2, 17].

Sodium caseinate in shake composition performs both technological functions, improving product consistency, and helps to increase nutritional value. Whey proteins were also included in product formula, as they are considered as the most complete, due to the presence of all the essential amino acids in quantities and ratios that correspond to the norms of human physiological needs [12]. Plant phospholipids mixed with lactose are also included in the formula. These ingredients also have a dual function. Due to its surface activity and hydrophilic properties, the mixture of lecithin with lactose, when interacting with fat phase of the product, forms adsorption layers on the surface of the powder particles, thereby reducing surface tension at the water-powder interface and preventing the agglomeration of fat globules what contributes to product instantiation. [13.18].

In addition, plant phospholipids are indispensable nutrients, average daily need for which is set at 5 g/day.

Product formula also includes components with beneficial effect proved by numerous studies: oil extract of carotenoids and tocopherols obtained in the course of processing sea buckthorn fruits by the method of three-stage percolation. Physical and chemical characteristics of the obtained oil extract are given in Table 1.

TABLE I. PHYSICAL AND CHEMICAL PARAMETERS OF THE OIL EXTRACT OF CAROTINOIDS AND TOCOPHEROLS

Quality parameter	Value
Density at 20°C, g/cm ³	0.920
Refractive index	1.471
Iodine value, mg iodine	91.1
Thiocyanogen value, mg iodine	78.5
Acid value, mg KOH/g	4.6
Content of:	
carotenoids, mg/100 g	206.7
vitamin E, mg/100 g	130.6

In addition to enrichment with vitamins, this extract improves the organoleptic characteristics of the finished product giving it a pleasant light yellow color.

Ingredient composition of the product was designed taking into account the norms of human physiological needs in basic nutrients. Nutritional and energy value of the product is shown in Table 2.

TABLE II. NUTRITIONAL AND ENERGY VALUE OF MILK SHAKE

Nutritional value parameter	Value	
	Per 100 g of powder product	Per serving of powder product (30 g)
Energy value, kcal/kJ	481.7/2015	144.5/604.6
Proteins, g	50	15
Fats, g	27.3	8.2
SFA	2.7	0.8
MUFA	14	4.2
PUFA	10.6	3.2
Omega 6	8.48	2.5
Omega 3	2.12	0.6
Phospholipids, g	6	2
Carbohydrates, g	14	5.4
Vitamins		
Vitamin A, µg	260	78
Beta-carotene, mg	4	1.2
Vitamin E, mg of toc. eq.	8.3	2.5
Vitamin D, µg	1.8	0.54
Vitamin K, µg	2.2	0.7
Minerals		
Calcium, mg	830	250
Phosphorus, mg	770	231
Magnesium, mg	90	27
Potassium, mg	1300	390
Iron, mg	1.5	0.45
Zinc, mg	3	0.9

One serving of the product covers 20% of daily requirement of proteins, polyunsaturated fatty acids and fat-soluble vitamins.

To optimize the technological parameters of obtaining developed product and the products of secondary dairy raw materials processing, practical studies were conducted under production conditions.

The objects of practical research on the processing of secondary dairy raw materials were skimmed milk in the amount of 400 kg obtained in the course of producing 20 kg of butter, as well as milk whey in the amount of 90 kg obtained in the course of producing 10 kg of cottage cheese.

Quality parameters for secondary dairy raw materials used for production of experimental batches of whey proteins, sodium caseinate and lactose are shown in Table 3.

TABLE III. DRY SUBSTANCES OF SECONDARY DAIRY RAW MATERIALS

Parameter	Value	
	Skimmed milk	Milk whey
Proteins,%	3.4	0.9
Lipids (milk fat),%	0.05	0.2
Lactose,%	4.8	4.7
Minerals, %	0.7	0.6
Total	8.95	6.4

Whey protein concentrate and lactose intended for inclusion in the composition of milk shake were obtained from whey using experimental unit for ultrafiltration [6, 15, 16]. Ultrafiltration is a type of low-pressure membrane filtration that separates colloidal particles with size in the range of 1-10 nm. Casein, whey proteins, large fat molecules fall into this range. At the first stage, the ultrafiltrate was thickened until solids content reached about 30%. Then, to separate whey proteins, condensed ultrafiltrate was heated to 59°C. Subsequently, whey proteins were separated and sent for further processing (drying), and the rest condensed ultrafiltrate was subjected to electro dialysis desalination at

50°C, then it was concentrated until solids content reached 55% and also sent to spray drying. Lactose content in the finished product was 92%.

Sodium caseinate was obtained in two stages. At the first stage, edible casein was obtained from skimmed milk by precipitation of pre-prepared fermented whey. The resulting clot was washed with water, crushed and dried to a moisture content of not more than 15%. At the second stage, a 15% sodium hydroxide solution was sprayed onto crushed dry casein with constant stirring, maintaining solids content at 78-80%, pH of mixture in the range of 6.2-6.9, and the temperature of mixture in the range of 60-70°C. Then the mixture was dried until a moisture content of not more than 8% was reached. Solubility index, protein, fat, carbohydrate and moisture content were determined in obtained sodium caseinate. Quality parameters of sodium caseinate obtained by this method are shown in Table. 4.

TABLE IV. SODIUM CASEINATE QUALITY RESEARCH RESULTS

Parameter	Value
Consistency	Dry fine powder
Taste and smell	Lactic
Color	Creamy white
Moisture content, %	6
Mass fraction of fat,%	2
Mass fraction of protein,%	85
Mass fraction of carbohydrates,%	1
pH	6.3
Solubility index, cm ³ of wet precipitation	0.2

This table shows that the resulting product has good solubility and can be used as a source of protein in the production of designed shake and other functional foods.

Tests conducted under production conditions made it possible to develop a technology and substantiate the technological conditions for the production of instant milk shake.

Technology for the production of functional instant dairy product

At the first stage, before condensation, skimmed milk is subjected to heat treatment, which ends with direct steam treatment (at 140°C) in a heater and subsequent cooling in a self-evaporator. At the same time, a solution of edible sodium caseinate, a solution of whey proteins, and a mixture of lecithin with lactose are prepared in different containers

equipped with a steam jacket and stirrer suitable for mixing highly viscous products. Then solutions of sodium caseinate and whey proteins are heated to 80°C and mixed with skimmed milk.

After heat treatment, a mixture of skimmed milk with a solution of sodium caseinate and whey proteins is concentrated in a vacuum evaporator to achieve 45-50% solids.

The next step is preparing crude emulsion from a mixture of vegetable oils heated to 50°C and condensed mixture of skimmed milk with sodium caseinate in a container equipped with a steam jacket and paddle mixer. After stirring the mixture for half an hour at the temperature of 55°C, the resulting crude emulsion is sent for two-stage homogenization at the temperature of 72°C and pressure: P1 = 8-10 MPa, P2 = 2-3 MPa. At the same stage, an oil extract containing tocopherols and carotenoids is added to the product.

To dry the product, it a multi-stage spray dryer is proposed, combining the technology of fluidized bed spray drying with a three-stage drying (Fig. 1).

At the first stage, the emulsion is sprayed through a set of spray units in drying chamber. High-speed vertical air flow provides instant evaporation of moisture and prevents particles of the dried product from sticking to the walls of drying chamber. Powder particles are immediately directed to fluidized bed embedded in the bottom of drying chamber for the second stage of drying process. Then the product is fed to a vibrofluidizing device for final drying and cooling. At the stage preceding powder drying in a vibro fluidizer, a mixture of lecithin and lactose is introduced in the product. Wet powder layer vibrates on air distribution plate. Vibration effect in combination with the upward and forward flow of drying air through the perforated plate creates optimal conditions for processing and transporting the powder. Due to vibration, it is possible to work with layers of fluidized powder with the size of less than 200 mm.

Drying air comes from the upper part of chamber what provides good secondary agglomeration when small particles in the drying air collide with the product sprayed from spray units. Exhaust air passes through a bag filter which separates the remaining particles contained in the air. Fine fractions coming from the bag filter are returned to the drying chamber in a static fluidized bed.

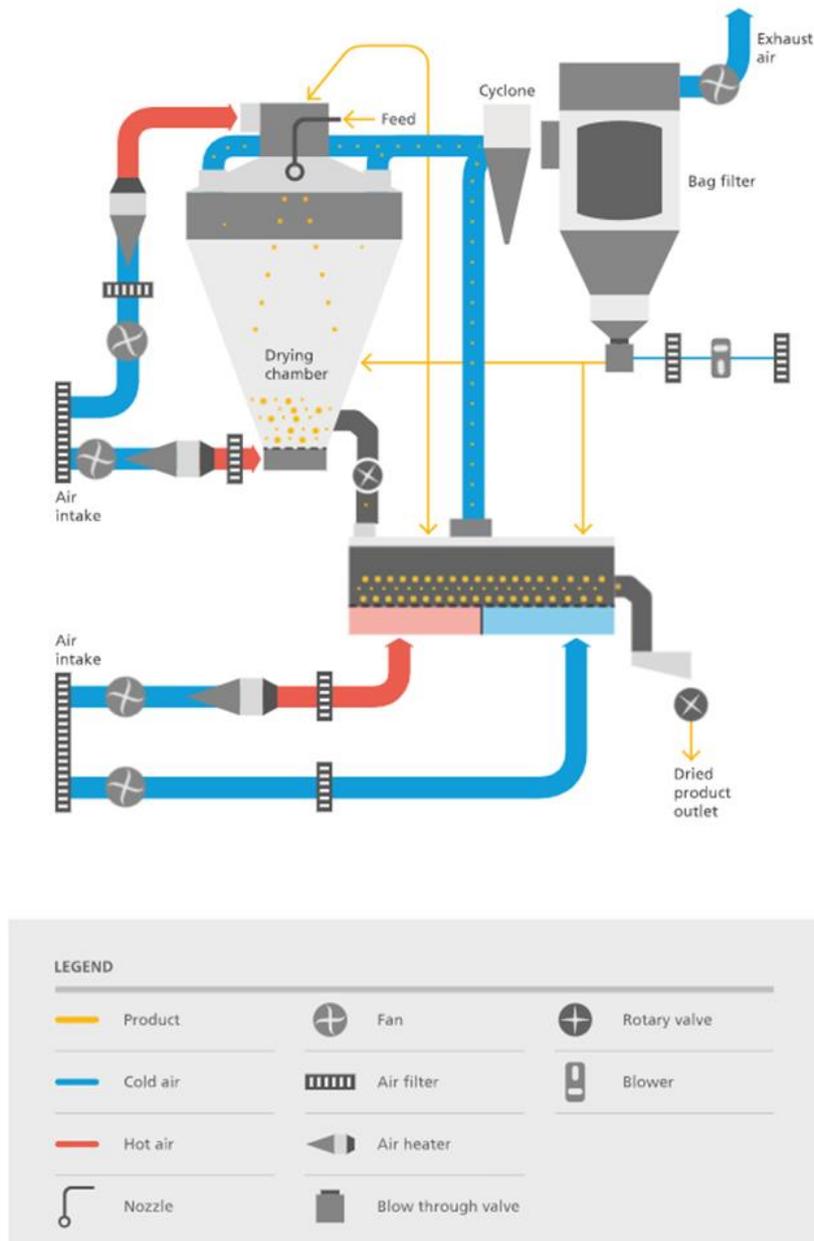


Fig. 1. Process flow diagram for the production of functional instant milk shake

After the creating of prototypes of functional instant milkshake, organoleptic and physical and chemical parameters of the finished product were found. Results are shown in Table 5

TABLE V. QUALITY PARAMETERS OF FINISHED PRODUCT

Parameter	Value
Consistency	Dry powder consisting of agglomerated particles
Taste and smell	Sweet, lactic with a touch of pasteurization
Color	Light yellow
Moisture content, %	4
Mass fraction of fat,%	27.3
Mass fraction of protein,%	50
Mass fraction of carbohydrates,%	14
Mass fraction of phospholipids,%	6
Mass fraction of carotenoids, mg/100 g	4
Mass fraction of tocopherols	8.3
Acidity, °T	20
Solubility index, cm ³ of wet precipitation	0.2

New functional dairy product can be recommended for the daily diet of all groups of a healthy population. Its instant form and convenient packaging (it is possible to pack it in portioned sachets for use on the road) and in cans for home use allows preparing the product on the way, at school, in university, in gym, dissolving it in 200 mL of room temperature water.

V. CONCLUSIONS

Implementation of the proposed technology will create new competitive balanced consumer dairy products and preventive products for specialized and rehabilitation nutrition, as well as biotech products with desired functional properties. Application of modification methods for dairy raw materials will provide the opportunity to intentionally change its structure and to obtain products and preparations with new physical and chemical or structural and functional properties that contribute to increasing the yield and preservation of finished products, creating new functional products.

Within the framework of conducted research, a comprehensive flexible technology for processing dairy raw materials with the production of functional food products and biotech products was developed, technological parameters were tested under production conditions and pilot batches of dairy products with desired properties and of biological products were developed in order to expand the range and to increase the competitiveness of domestic healthy food products.

Proposed approach and technologies make it possible to completely process valuable secondary dairy raw materials implementing the principles of environmentally friendly production and resource saving, and have high economic efficiency. Design of secondary dairy raw materials utilization workshops at dairy plants allows obtaining both composite functional dairy products and derivatives of secondary dairy raw materials (casein and whey protein concentrates, lactulose, glucose-galactose syrups, etc.)

Studies aimed at the development of cost-effective separate food ingredients and multicomponent products based on functional dairy raw materials, including these for sport, elderly, therapeutic and preventive nutrition, is a promising direction in the development of food science and should be continued and aimed at implementation of results into industrial production.

REFERENCES

- [1] G. Golubeva, L. V. Spravochnik, *Tekhnologa molochnogo proizvodstva. Tekhnologiya i retseptury. Tom 9. Konservirovanie i sushka moloka* [Directory technologist milk production. The technology and formulation. Volume 9. Cohn-Serving and drying of milk]. St. Petersburg: GIOR Publ., 2005. (in russ.)
- [2] L. V. Tereshchuk, K. V. Starovoytova, *Theoretical And Practical Aspects Of Creation Of Dairy-Fat Products*. Kemerovo, 2015. (in russ.)
- [3] L.V. Tereshchuk, K. V. Starovoytova, I. V. Dolgolyuk, and M. A. Tarlyun, "Vegetable Oils as Functional Ingredients of Emulsion Products," *Maslozhirovaya promyshlennost'* (Oil and fat industry), No. 2, pp. 20-23, 2015. (in russ.)
- [4] Food Security Doctrine of the Russian Federation. <http://kremlin.ru/acts/bank/30563>
- [5] L. V. Tereshchuk, K. V. Starovoytova, and O. A. Ivashina, "Dairy components as factor of creation of structure of spread," *Syrodellie i maslodellie* (Cheesemaking and butter making), No. 2, pp. 50-51, 2015. (in russ.)
- [6] A. E. Stefankin, "Research on constructive and technological parameters of membrane apparatus for cottage cheese whey concentration," *Food Processing: Techniques and Technology*, Vol. 42, No. 3, pp. 133–139, 2016. (in russ.)
- [7] A. K. Pabby, S. S.H. Rizvi, and A. M. Sastre Requena, *Handbook of Membrane Separations: Chemical, Pharmaceutical, Food, and Biotechnological Applications*. CRC Press, 2008.
- [8] E. S.Nechaeva, D. M. Popov, "Issledovanie dispersnogo sostava pyli i fakela raspyla zhidkosti v rotornom raspylitel'nom pyleulovitele [Research disperse composition of dust and the spray liquid in the rotary races, spray-dust collector]," *Tekhnika i tekhnologiya pishchevykh proizvodstv* [Food Processing: Techniques and Technology], No. 2, pp. 93–96, 2013. (in russ.)
- [9] D. M. Popov and L. V. Tereshchuk, "Deodorization of raw milk in a rotary spray apparatus," *Food Processing: Techniques and Technology*, Vol. 42, No. 3, pp. 125–132, 2016. (in russ.)
- [10] A. S. Mamontov, K. V. Starovoytova, L. V. Tereshchuk, and M. A. Tarlyun, "Main quality criteria for milk-and-fat emulsion products," *Food Processing: Techniques and Technology*, Vol. 43, No. 4, pp. 36-42, 2016. (in russ.)
- [11] G. L. Hasenhuettl and R. W. Hartel, *Food Emulsifiers and Their Applications: Second Edition*. New York: Springer New York, 2008. <https://doi.org/10.1007/978-0-387-75284-6>
- [12] A. M. Helmenstine, *Emulsifier Definition - Emulsifying Agent*. ThoughtCo. <https://www.thoughtco.com/definition-of-emulsifier-or-emulsifying-agent-605085>
- [13] I. A. Evdokimov, D. N. Volodin, V. A. Misyura, M. S. Zolotorev, and M. I. Shramko, "Functional fermented milk desserts based on acid whey," *Foods and Raw Materials*, Vol. 3, No. 2, pp. 40-48, 2015. <https://doi.org/10.12737/13116>
- [14] T. T. Phan, T. T. Le, P. Van der Meer, and K. Dewettinck, "Comparison of emulsifying properties of milk fat globule membrane materials isolated from different dairy by-products. *Journal of Dairy Science*," Vol. 97, No. 8, pp. 4799-4810, 2014. <https://doi.org/10.3168/jds.2014-8030>
- [15] I. Buyanova, S. Lupinskaya, I. Smirnova, and I. Maseeva, "Innovative Solutions in Processing of Milk Whey on the Base of Ecological and Economic Principles," *IOP Conference Series: Earth and Environmental Science*, Vol. 224, 012007, 2019. <https://doi.org/10.1088/1755-1315/224/1/012007>
- [16] C. Vega and Y. H. Roos, "Invited review: Spray-dried dairy and dairy-like emulsions-Compositional considerations," *Journal of Dairy Science*, Vol. 89, No. 2, pp. 383-401. 2006. [https://doi.org/10.3168/jds.S0022-0302\(06\)72103-8](https://doi.org/10.3168/jds.S0022-0302(06)72103-8)
- [17] L. V. Tereshchuk and M. S. Umanskiy, *Molochno-zhirovye kompozitsii: aspekty konstruirovaniya i ispol'zovaniya* [Milk-Fat Compositions: Aspects Of The Design And Use]. Kemerovo: KemIFST Publ., 2006. (in russ.)
- [18] K. V. Starovoytova and L. V. Tereshchuk, *Teoriya i praktika primeneniya poverkhnostno-aktivnykh veshchestv v proizvodstve pishchevykh emul'siy* [Theory And Practice Of Application Of Surfactants In The Production Of Food Emulsions]. Kemerovo: KemIFST Publ., 2016.