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Technique of functional simulation as a tool for providing the required quality of fortified bakery products

ABSTRACT

Relevance. The problem of irrational and unbalanced nutrition is relevant for almost all regions of Russia. There is a need to enrich everyday products with micronutrients that are of particular importance in the diet. Fortified bread and bakery products with specified consumer properties in the diet can be one of such valuable products.

Methods. The methodology of structural analysis and design of systems (Structured Analysis and Design Technique, SADT) is often used in life cycle management of complex high-tech products and has not found wide application in the food industry. The authors substantiate the need to introduce tools for functional and graphical modeling of business processes that implement the SADT methodology in life cycle management to ensure the quality of finished bakery products.

Results. An original generalized functional and logical model of the process "To produce enriched bread (bakery products) with regionally significant micronutrients" has been developed. The analysis of the technology of enriched bakery products, carried out at various levels of decomposition of the process, revealed that the quality of the finished product is significantly influenced by the choice of the technological stage of applying the components of the mixture proposed for the enriching composition. It has been established that preference should be given to organic forms of additives — components of the enriching composition. To preserve the nutritional properties of bakery products, an enriching composition is proposed to be applied to the surface of the finished product. The proposed method has been tested in experimental production conditions. Its manufacturability and controllability of the proposed technical solutions are proved. The approach to functional and graphical modeling of food technologies developed by the authors on the example of bakery products opens up prospects for improving the quality of finished products and can be widely used in food engineering.

Key words: bread, bakery products, pastry, quality assurance, structured analysis and design technique, business process, functional simulation, micronutrients, fortification additives, technologies

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Научная статья

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Методология функционального моделирования как инструмент обеспечения качества обогащенных хлебобулочных изделий

РЕЗЮМЕ

Актуальность. Проблема нерационального и несбалансированного питания актуальна практически для всех регионов России. Существует необходимость обогащения продуктов повседневного спроса микронутриентами, имеющими особое значение в рационе питания. Обогащенный хлеб и хлебобулочные изделия с заданными потребительскими свойствами в рационе питания могут быть одними из таких потребительски значимых продуктов питания.

Методы. Методология структурного анализа и проектирования систем (Structured Analysis and Design Technique, SADT) часто применяется в управлении жизненным циклом сложной наукоемкой продукции, однако в пищевой промышленности она не нашла широкого применения. Авторами обоснована необходимость внедрения инструментов функционально-графического моделирования бизнес-процессов, реализующих методологию SADT при управлении жизненным циклом для обеспечения качества готовых хлебобулочных изделий.

Результаты. Разработана оригинальная обобщенная функционально-логическая модель процесса «Производить обогащенный хлеб (хлебобулочные изделия) регионально значимыми микронутриентами». Анализ технологии обогащенной хлебобулочной продукции, проведенный на различных уровнях декомпозиции процесса, позволил выявить, что на качество готового изделия оказывает существенное влияние выбор технологического этапа нанесения компонентов смеси, предложенной для обогащающей композиции. Установлено, что предпочтение необходимо отдавать органическим формам добавок — компонентам обогащающей композиции. Для сохранения нутрициологических свойств хлебобулочных изделий обогащающую композицию предложено наносить на поверхность готового изделия. Предложенный метод апробирован в условиях экспериментального производства. Доказаны его технологичность и подконтрольность предложенных технических решений. Разработанный авторами на примере хлебобулочных изделий подход к функционально-графическому моделированию технологий пищевых продуктов открывает перспективы повышения качества готовых изделий и может найти достаточно широкое применение в пищевой инженерии.

Ключевые слова: хлеб, хлебобулочные изделия, обеспечение качества, методология структурного анализа и проектирования систем, бизнес-процесс, функциональное моделирование, микронутриенты, обогащающие добавки, технологии

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Introduction/Введение

Organizing a complete, balanced diet for the population is one of the main components of maintaining human health and performance [1–4].

It is on record that a balanced diet allows the body to resist the effects of unfavorable environmental factors, also to significantly reduce the occurrence of chronic non-infectious diseases, including the diseases that affect mental well-being and health of human [5–7].

The problem of insufficient and unbalanced nutrition is relevant for almost all regions of Russia [8, 9].

Moreover, the residents of various territories need various micronutrients, while some micronutrients are endemic[1, 2]. Most residents of the Russian Federation territories suffer from iodine, selenium, fluoride and lithium shortage in their diet [6, 7, 10].

Imbalanced diet is an international problem that is especially acute for South African countries. The micronutrients deficiencies are increasing among children and pregnant women in Africa and other developing countries [11, 12]. For instance, fortification of food, including bread, in the South African developing countries is considered as one of the most effective strategies to struggle against micronutrient deficiencies [13, 14].

The insufficient and unbalanced nutrition leads to an imbalance of certain microelements and vitamins in the diet of the population all over the world, which negatively affects health [15–17].

Complex comprehension and finding ways for solution of this problem is an important task for government authorities, medicine, scientific community and the food industry [18, 19].

It is possible to decrease dramatically the negative consequences of insufficient and unbalanced nutrition only with the help of complex approach. This complex approach relates to the stages of the life cycle of the food product, starting with an assessment of the demand for the fortified food products among various consumer groups [20–22].

It is necessary to emphasize that awareness of the importance of micronutrients (trace elements and vitamins) for health has highly increased among the majority of the population [23–25].

That's why some categories of consumers show a steady interest for the assortment of fortified food products that are able to compensate for the deficiency of microelements and vitamins. In addition, consumers have recently developed the increased demand for food products fortified with regionally significant biological elements and vitamins with high digestibility and bioavailability for the body. The value of various types of plant materials, in particular, cereals and beets, has been proven [13, 26, 27].

At the same time, bread and bakery products are increasingly being chosen as an object for fortification [28].

The role of micronutrients (biological elements) is quite convincingly substantiated, for example, in the article [6].

However, the problem of providing their quality, in particular, bioavailability for the body, has not been sufficiently studied and technologically developed and elaborated in relation to technical systems [29, 30].

This fact proves the practical relevance of the fortified food production and opens up great prospects for development of technologies for fortification of various groups of food products [31–33].

Therefore, there is an increasing necessity to apply new methods for the optimal design of business processes [34, 35].

Purpose of the research. Substantiation of necessity and approbation of the technique of functional simulation at the stage of structuring business processes to provide the quality of fortified bakery products.

Object of the research. Business process of production of bread and bakery products, fortified with biological elements and vitamins that are scarce for the regions of residence.

Materials and methods /
Материалы и методы исследования

International requirements of the Codex Alimentarius[3], which form the basis for controlling and monitoring in development of model of a business process for the production of fortified bread (bakery products); structured analysis and design technique (SADT)[2]; tools for graphical simulation of business processes IDEF0, IDEF3, (Integration Definition for Function Modeling) as information support for the life cycle of fortification of bread and bakery products; BPwin (AllFusion Process Modeler) — software product in the sphere of CASE-technologies implementation.

Results and discussion / Результаты и обсуждение

The approach to fortification of bread and bakery products is based on nutritional principles (figure 1), developed by scientists of the Russian Academy of Sciences [36].

The conceptual basis of nutritional principles for development of functional food products is harmonized with the international requirements of the Codex Alimentarius.

We took into consideration that in accordance with the structured analysis and design technique, it is necessary to adhere to the same position, i.e. point of view, in order to ensure a high-quality description of a technical system when formalizing the simulation model and the approach to technical description.

As a basis for choosing the point of view, we took the stated purpose of simulation (Figure 2). Following the classical approach to structural analysis[4], while presenting information on the process we considered the technology of production of fortified bread and bakery products from the point of view of a "quality engineer". The choice of this position — the position of "quality engineer" — is related to necessity to determine the factors that in major affect the quality and food safety of bakery products.

It is generally accepted that quality of a food product must be created and maintained throughout all stages of the product life cycle (PLC). Moreover, the product life cycle shall include all processes, starting from defining the consumers' demand for particular food product and ending with the stage of assessing of these needs satisfaction. The demand for functional groups of food products (fortified with deficient micronutrients) for daily mass consumption is quite convincingly substantiated, including in the works of the authors of the present article [27].

Marketing and design, as interrelated activities, play a significant role in the stages of the product life cycle (PLC). Moreover, the design stage shall be aimed at developing a preliminary design (including information support) in

[1] Naumova N.L., Rebezov M.B., Varganova E.Ya. Functional products. Supply and demand. Chelyabinsk. 2012. ISBN: 978-5-696-04229-9
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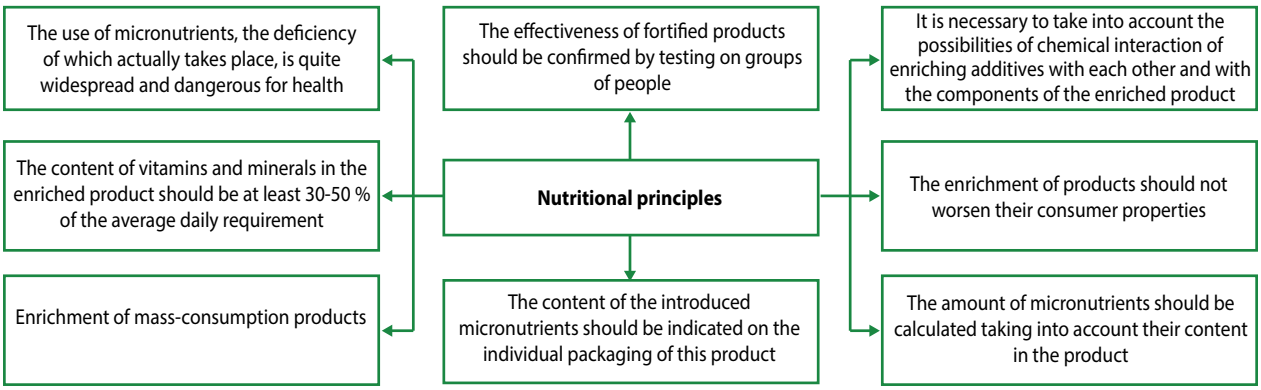
[3] URL: https://www.fao.org/fao-who-codexalimentarius/about-codex/en
[4] Mark D.A., McGowan K.L. Methodology of structured analysis and design. 1993; 240.

Fig. 1. Nutritional principles of food fortification (summary) adopted as main controls



accordance with the documented technical requirements that ensure optimal costs. We took advantage of the SADT at early stages of the process of the system development ("system life cycle", i. e. SLC), so this article focuses on the food design stage.

Currently, SADT is successfully applied to a wide range of engineering tasks. This methodology received wide support in a sphere of national standardization within the framework of the standardization concept for the management of life cycle in the complex science-intensive products [37]. That proves the versatility of our approach. However, this technique has not been widely used to ensure the quality of fortified bakery products. This fact predetermined the approbation of the technique of functional simulation for this group of food products, widely represented in the mass market.

Based on the adopted position, we substantiated the direction for choosing the goal of the functional simulation model (Figure 2). The chosen aim shall be considered as achieved when the simulation process comes to its end; in particular, when the task "Production of bread (bakery products) fortified with deficient micronutrients" is implemented.

To understand, analyze and make decisions about the necessity to reengineer or replace the existing system, or to design a new system, we tested the concept of tools for graphical modeling of business processes IDEF0 (Integration Definition for Function Modeling) as information support for the life cycle of bread and bakery products. Meanwhile we took into account that the IDEF0 standard is a subset of SADT.

The previous author's researches[5] conducted on the example of development of the technology of beer and beer-based beverages showed "the promising nature of functional analysis of the product life cycle, performed in the BPWin software environment". We took into consideration that the program supports three functional simulation techniques (IDEF0, IDEF3, DFD). This combination made it possible to clarify some stages of the business process under analysis.

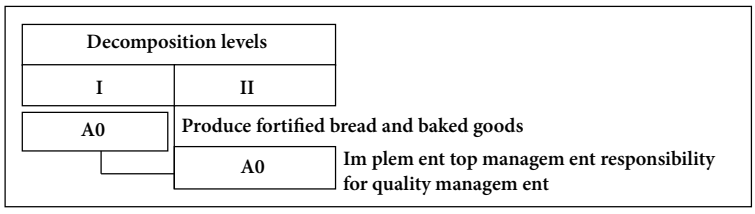
The position we choose, is aimed at achieving the required quality and food safety of bread and bakery products. This position predetermined the nature of research in order to optimize the technological process. Using the IDEF0 functional simulation method, we created a tree of functional blocks (Figure 3).

Based on the widely-known nutritional principles of food fortification (Figure 1), which we accepted as the main control actions, we ran an analysis of input information flows about the properties of finished (fortified) bread. Among the control information taken into consideration, we also took into account the modern standards, requirements and achievements in the sphere of nutritional science and technology of food fortification (Figure 4). This approach is consistent with the chosen point of view of the "quality engineer" and the technique of functional simulation.

Fig. 2. Determination of the aim and point of view regarding the model of the process of fortified bread and bakery products production

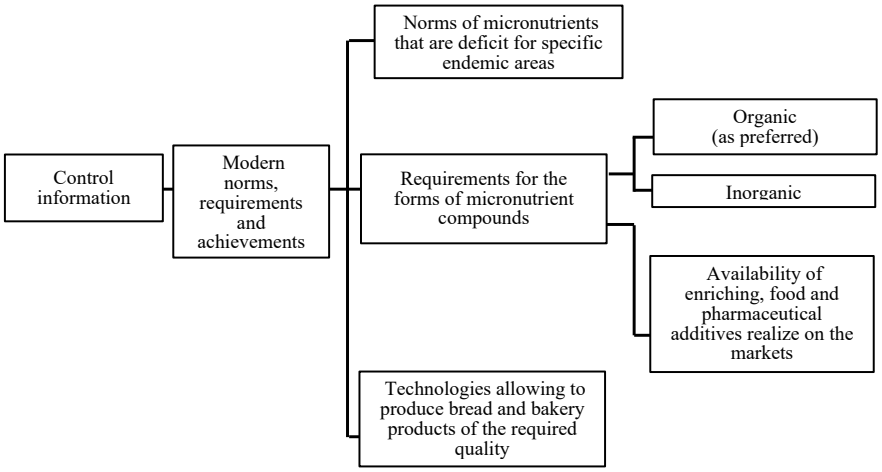
Questions	Aim
1. What affects the quality and safety of fortified bread and bakery products?	1. To structure the main stages of the production process, influencing the formation of the quality and safety of fortified bread and BAKERY PRODUCTS. 2. Simulate information flows accompanying the production of fortified bread and BAKERY PRODUCTS. 3. To create a model "As it should be" for the process of production of fortified bread and CBI, which should be achieved by the real process "As it is" at a specific bakery enterprise.
2. How to meet the consumer's requirements?	
3. At what point do quality standards affect the production of fortified bread and bakery products?	
4. What ensures the functioning of the QMS?	
5. What resources are needed to produce fortified bread and bakery products?	
6. What raw materials and what input data are required for the production of fortified bread and bakery products?	
7. What stages and what parameters of the quality of fortified bread and bakery products is it necessary to control?	
8. Is it possible to expand the range of quality and safety indicators?	
9. Is it possible to meet customer's requirements within the existing technological process?	
10. What methods and means of control are needed to expand the range of quality indicators?	
Point of view: quality engineer. Only from this point of view it is possible to show the factors that affect the quality and safety of fortified bread and bakery products, as well as to simulate information flows that accompany the production of fortified bread and bakery products.	

Fig. 3. The tree of the main functional blocks of the process "Production of fortified bread and bakery products with deficient micronutrients" in BPWin environment (for a particular product)



[5] Tretyak L.N. Technology of production of beer with given properties: monograph. 2012; 463.

Fig. 4. Control information taken into account during identification of the input information flows



During the subsequent decomposition of stages of fortification of finished (plain basic) bread or bakery products (Figures 5–7), we took into account that the IDEF0 technique is standardized and independent. It gives an adequate and fairly complete overview of a complex system which the life cycle of food products belongs to.

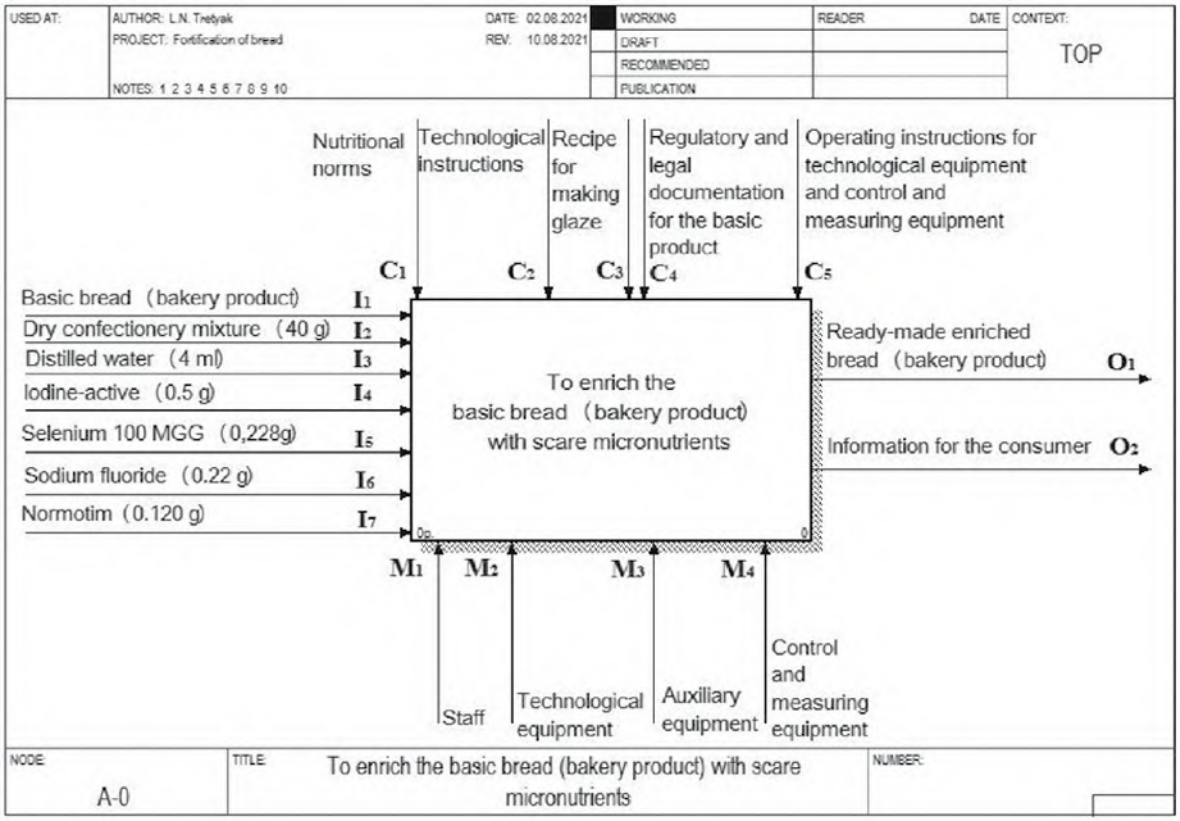
During development and construction of metamodel (context diagram) of the process (Figure 5), we identified and structured the material (raw material) and regulatory and legislative flows, that fill the boundary arrows of the function "To fortify bread with deficient micronutrients". It is necessary to emphasize that the context diagram (Figure 5) is aimed at implementation of the model aim, which, in its turn, is related to the point of view of the "quality engineer" (Figure 2).

According to technique IDEF0, the function block is designed to convert inputs (Input I1-I7) to outputs (Output O1-O2) with appropriate control actions (Control C1-C5) that restrict or provide the conditions for conversions.

An adequate and sufficient set of informational inputs (on the left in the Figure 4) and outputs (on the right in the Figure 4) was defined at the stage of interviewing experts, engaged in the subject business process of the food fortification. For detailed analysis of the factors affecting the quality of fortified bakery products, we used our earlier results of the correlation "quality-to-factors" taken from the causal diagram of Issikawa.

Control actions (C_1–C_5) are represented by a set of norms and requirements: C_1 — nutritional standards (MR 2.3.1.1915-04 "Recommended levels of consumption of food and biologically active substances, MR 2.3.1.2432-08" Norms of physiological requirements for energy and nutrients for various groups of the population of the Russian Federation"). As noted above, the national standards are harmonized with the international standards[6]; C_2 — technological instructions for plain basic bread and fortified bread (bakery products); C_3 — recipe of fortifying icing (fortifying composition); C_4 — regulatory and legal documentation for the basic product (GOST R 58233-2018[7]; MR 2.3.2.2571-10 "Food fortification with vitamin and

Fig. 5. Generalized functional-logical model of the process "Production of bread (bakery products) fortified with deficient micronutrients"



[6] Commission Directive 2008/100/EC of 28 October 2008 amending Council Directive 90/496/EEC on nutrition labelling for foodstuffs as regards recommended daily allowances, energy conversion factors and definitions (Text with EEA relevance). — URL: https://eur-lex.europa.eu/eli/dir/2008/100/oj

[7] GOST R 58233-2018 Bread from wheat flour. Technical conditions.

mineral complexes of mass market varieties of bakery products produced according to national standards"[8]); C_5 — manuals for the operation of the main and auxiliary technological, as well as control and measuring equipment.

To achieve the aims (Figure 2) and solve the tasks for production of food with required quality, the business process (Figure 4) must be provided with the mechanisms (Mechanisms: M1–M4) listed below: M_1 — personnel, who implements technological procedures for fortification of bread (bakery products); M_2 — technological equipment; M_3 — auxiliary equipment; M_4 — control and measuring equipment necessary for the fortification of bread (bakery products).

Conceptually, those executive mechanisms (resources) are designed to implement transformations (Input — Output) in accordance with the factors that affect the quality and safety of the fortified bakery products. In our opinion, it is the quality criteria of the final product (fortified bread and bakery products) that shall be decisive throughout the chain of correlation between the requirements for the technological process, the base product, and the fortifying additives.

Technological lines shall be provided with dispensers for bulk mixtures, convective cooling lines for plain basic bread and fortified bread, and for bakery products also (the core equipment). The auxiliary equipment must include measuring instruments, scales: analytical (for example, scale of brand "*Ohaus Pioneer*"), laboratory scales (*ACOM JW-1-300*), and other technological appliances.

Requirements for control and measuring equipment, included into the technical basis of metrological functions, must meet the criteria set forth by the authors earlier [38, 39].

The preliminary expert analysis and the method of functional simulation, applied together with the technique of graphical structural analysis, revealed the following sub-processes (Figure 6): 1) calculation of micronutrients dosage rate; 2) mixing the basic mixture (confectionery mixture as the base of the icing) and the fortifying additives to obtain the fortifying mixture (composition); 3) mixing the fortification mixture with water; 4) application of the fortification mixture (icing) on the finished bread (baked goods).

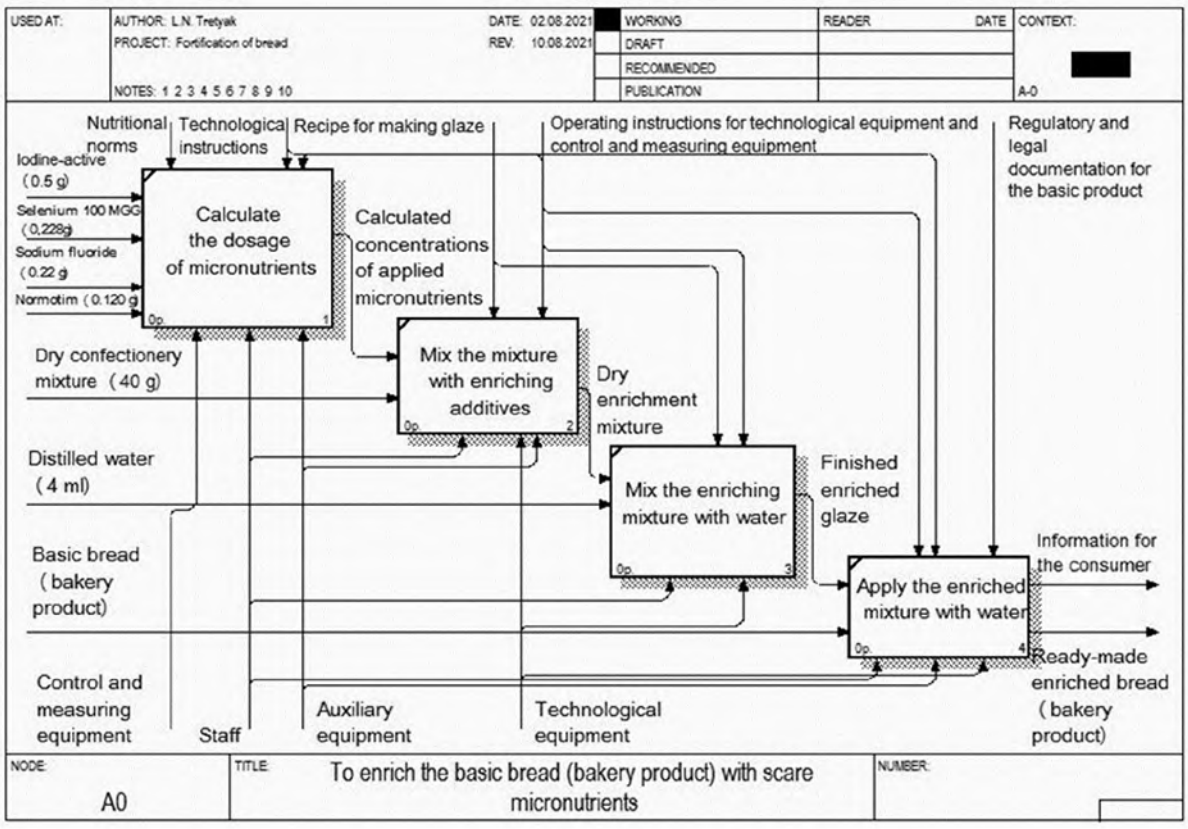
During the decomposition of the generalized functional-logical model (Figure 4), some peculiar features of the functions of sub-processes are established: all blocks (sub-processes) are characterized by a connection of the "output-input" type. This link establishes the working sequence per each of the sub-processes, since the output of one function serves as input to the next function.

The analysis of the technology of fortified bakery products at various levels of its decomposition, made it possible to identify the main issues: selection of the stage of fortification and the method of mixing the components — the micronutrients carriers.

The applying of fortifying additives complex — carriers of deficient micronutrients — is suggested at the final technological stage: it's feasible to apply it on the surface of the finished product in the form of fortified icing. This method has several advantages. The main advantage is the preservation of the properties of the fortification elements. Preference is given to organic forms of fortifying additives: they are the safest and more accessible for digestion by the consumer's body.

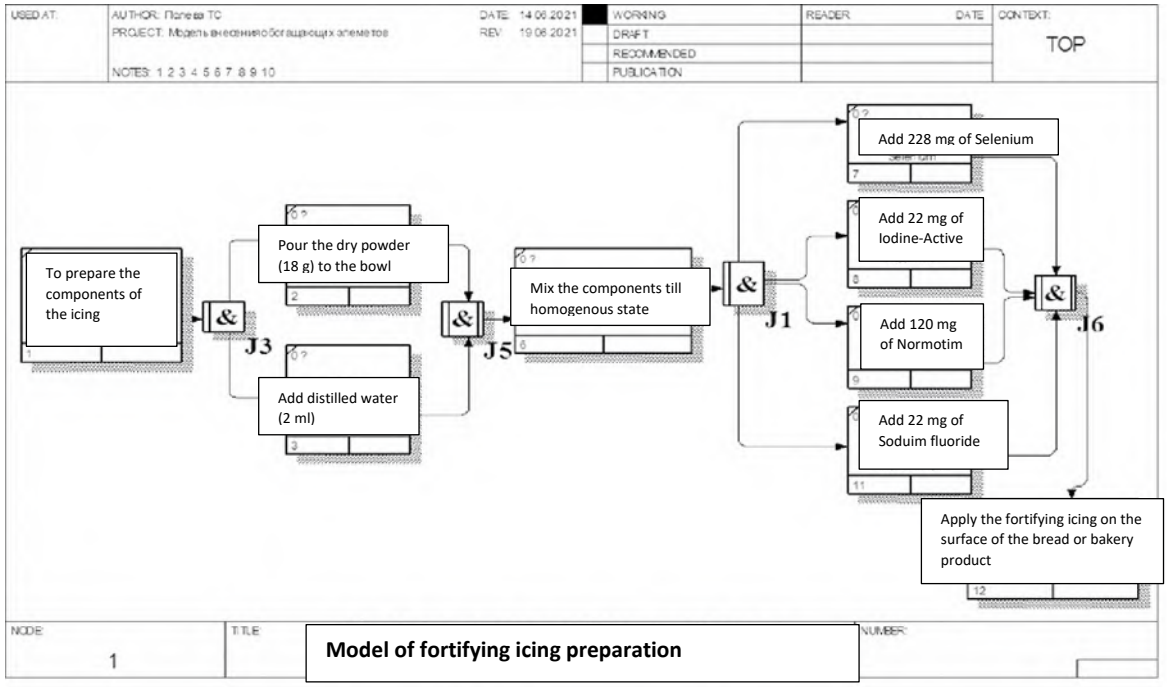
Previously obtained expert knowledge about the subject area of the business process "Fortification of bread with deficient micronutrients" was used to build a separate model in IDEF3 notation. The process "Model of the fortified icing preparation" (Figure 7), depicted by a diagram in the

Fig. 6. Decomposition of the process "Fortification of bread with deficient micronutrients"



[8] URL: https://docs.cntd.ru/document/1200078426

Fig. 7. Diagram of the process "Model of the fortified icing preparation" in IDEF3 notation



IDEF3 notation, is decomposed to clarify the main business process. The diagram represents the main organizational unit of description in IDEF3. The construction of a diagram (Figure 5) allowed us to simulate a situation when processes (actions) are run in a certain sequence and interdependence, as well as to describe the objects involved together in one process.

The results of the conducted patent research (author's matrices of patent search) showed that this method has signs of scientific novelty of the proposed patent solution. It is suggested to cook the fortifying icing on the basis of the dry confectionery mixture "Alter-Icing".

The following pharmaceutical preparations were chosen as micronutrients carriers: "Iodine-active" — as a source of iodine, "Sodium fluoride" — as a source of sodium, "Selenium 100 MGG" — as a source of selenium, "Normotim" — as a source of lithium. It is proposed to apply these pharmaceutical preparations, after their mixing, on the surface of the finished product in the form of fortified icing, in accordance with the original recipe.

Conclusions/Выводы

It is possible to ascertain that the consumers' interest for the functional food products has increased. In particular it can be referred to the food fortified with micronutrients which are deficient for endemic territories (regions). The proven fact of enhancing consumers' preferences for functional food involves the search for tools for providing and managing the quality of functional food products at various stages of their life cycle. The authors propose to assure the due quality of fortified bakery products by structured analysis and design technique.

The tree of the main functional blocks of the process "Production of bread and bakery products fortified with deficient micronutrients" developed by the authors in the BPWin software environment and its subsequent decomposition were performed to implement the point of view of the "quality engineer". The accepted position of "quality engineer" allowed us to determine the factors that primarily affect achieving the due quality and safety of bread and bakery products.

Control actions are represented by a set of modern nutritional norms and requirements for the quality and safety of plain basic bread and fortified bread (bakery products).

Preliminary expert analysis, application of cause-effect diagrams and the technique of graphical structural analysis made it possible to determine the optimal number of sub-processes of the business process under consideration. The obtained result was used in decomposition of the main business process "Production of bread and bakery products fortified with deficient micronutrients".

The obtained expert knowledge and analysis of the stages of the fortified bakery products technology were used for decomposition of the process "Model of the fortified icing preparation", performed in the IDEF3 notation.

Clarification of the main business process allowed revealing the most significant technology issues: the choice of the stage of applying the fortifying composition, the method of the fortified icing mixing and applying on the base food product.

It is proposed to apply the complex of fortifying additives — the carriers of deficient micronutrients (micronutrients and vitamins) — at the final technological stage: to apply the fortifying mixture on the surface of the ready-to-consume food product in the form of fortifying icing.

The approach proposed by the authors for simulation of the fortified bakery products technology, based on the structured analysis and design technique, can play a key role in providing the due quality of food product, and in optimization of technological processes at the early stages of the product life cycle, which is crucial in food engineering.

Все авторы несут ответственность за работу и представленные данные.
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All authors bear responsibility for the work and presented data.
All authors made an equal contribution to the work.
The authors were equally involved in writing the manuscript and bear the equal responsibility for plagiarism.
The authors declare no conflict of interest.

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