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DEVELOPMENT OF THE RECIPE COMPOSITION OF GLUTEN-FREE FLOUR CONFECTIONERY PRODUCTS BASED ON CHICKPEA FLOUR

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The object of this study was gluten-free flour confectionery. In order to improve the structure of the assortment and create products for specialized purposes, the hypothesis was tested that ultra-high-frequency processing can help reduce the microbiological contamination of raw materials and improve the organoleptic characteristics of finished products. For this purpose, recipes for gluten-free flour confectionery products were developed, making it possible to obtain the best values of the specific volume of finished products – custard semi-finished products and gluten-free cupcake. Based on the implementation of second-order rotatable plans, regression models were built, and the resulting response surfaces were transformed to the canonical form. Based on this, it was established that the rational ratios of the components of the cupcake in the formulation are: 80 % flour from ultra-high-frequency processed chickpea flour, 15 % rice, and 5 % amaranth flour. The ratio of components of the custard semi-finished product from ultra-high-frequency processed chickpea flour and corn flour was approximately 50:50 %.

Prototypes of gluten-free flour confectionery products were produced, and the main quality indicators were determined. It was found that when flour from ultra-high-frequency processed chickpeas was introduced into the recipe of a cupcake from rice and amaranth flour, the amount of limiting amino acid lysine increased by 1.08 times compared to unprocessed chickpea flour. In the custard semi-finished product, the amount of the limiting amino acid arginine increased by 1.97 times compared to unprocessed chickpea flour. In general, the biological value of enriched cupcake and custard semi-finished product on average exceeds the control sample by 1.5 times.

In terms of safety, the developed gluten-free flour confectionery products meet the requirements of regulatory documentation

Keywords: leguminous crops, chickpeas, rice, amaranth flour, gluten-free products, optimization of recipes

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1. Introduction

The task of providing gluten-free products for patients with celiac disease has a pronounced social significance and belongs to the global categories that play a significant role in ensuring the quality of life of the country's population. To eliminate it, it is necessary to establish local production of gluten-free products with high quality characteristics through the use of high-quality domestic raw materials. This will lead, on the one hand, to an increase in the quality and competitiveness of products, and on the other, will satisfy the consumer demand of people following a gluten-free diet.

Researchers are increasingly attracted by the problem of intolerance to the cereal protein – gluten. Unlike many other types of allergies, gluten allergy can cause serious disruption to the gastrointestinal tract and harm the body. An extreme manifestation of intolerance is celiac disease [1].

The only treatment for celiac disease is a lifelong gluten-free diet. When following a gluten-free diet, it is necessary to exclude wheat, oats, rye, barley, as well as all products prepared using these cereals [2].

Most gluten-free technologies developed in the world belong to the largest firms in America and Europe. For example, Dr.Schaer, Aproten, GLUTANO FARMO – Italy; GULLON – Spain; Bezglutenex, Balviten, Glutenex – Poland; Maddys – USA; Milupa, Hammermühle, camidaMed – Germany; Taranis – France; Promin, TheBridge – United Kingdom. All their products are protected by patents and have the label "gluten-free" on the packaging. But this category of products is very expensive and not always available for people suffering from celiac disease. The average cost of such products is 5–10 times higher compared to the cost of conventional flour products [3, 4].

Over the past decade, consumer demand for gluten-free products has increased. Consequently, it is necessary to develop local production of such products, as well as export them abroad. The Kazakhstan market is full of gluten-free products of foreign manufacturers with a cost several times higher than the cost of conventional products. Although in Kazakhstan it is possible to cultivate agricultural cereals and develop on their basis a technology for the production of gluten-free products.

Given the variety of grain raw materials grown in Kazakhstan, it is necessary to create a domestic innovative technology for the production of gluten-free products. Therefore, research on the development of gluten-free food products in order to saturate the domestic market and create competitive products that are balanced in chemical composition and with appropriate taste qualities is relevant. Optimal, from this point of view, is the use of raw materials obtained from the products of grain processing to improve the quality, economic indicators of the production of flour confectionery products and give them functional properties. All this makes it relevant to perform work aimed at expanding the range, improving recipes and production technology of flour confectionery products using gluten-free grains.

2. Literature review and problem statement

In the world there are various technologies for the production of gluten-free products, but the fundamental difference between each technology is the different recipe of products and the quality of the raw materials used.

Specialists at the technical research and development center of Finland VTT, research centers in northern Europe, have developed a recipe for gluten-free bread with increased nutritional value based on a mixture consisting of corn flour (30 %) and flour from fermented horse beans (70 %) [4, 5]. However, the disadvantage of this technology is the low volume of crumb and rapid staleness due to the high starch content, as well as low microbiological resistance to the development of potato disease and mold during storage due to the high humidity and low acidity of gluten-free bread.

The Muffin Vitalution has developed gluten-free blends consisting of Spanish sage, flax, almond flour, cinnamon, coconut oil, coconut sugar, eggs, and agave inulin. These gluten-free mixtures are designed to prepare muffins in an ultra-high-frequency oven for feeding people who adhere to the paleo diet [6]. The disadvantage of this technology is the use of various herbal additives in the recipe, which significantly increase the cost of finished products.

For flour confectionery products, flour is a key raw material component. Most of the range of flour confectionery products, which includes cookies, gingerbread, waffles, cakes, pastries, muffins, etc., are made, as a rule, from wheat flour of the highest grade. Therefore, the confectionery industry naturally puts high demands on the quality of flour.

Work [7] developed a technology of gluten-free wafers and a method for their production, containing rice flour, buckwheat flour, sugar, fat component, chicken egg, invert syrup, table salt, baking powder, potato starch, water. This study does not disclose the issues of increasing the nutritional and biological value of the product since the recipe of gluten-free waffles includes rice flour, characterized by a high starch content.

The results of research [8, 9] on the production of gluten-free flour confectionery products based on starch-containing raw materials are reported. However, products produced by this method contain a large amount of carbohydrate, mainly starch, and a low content of vitamins and dietary fiber. The ingredients used do not provide the necessary consumer properties of the products.

A technique for the production of gluten-free cookies is known, where the mixture is prepared by sequential mixing of amaranth flour, whole dry milk, cocoa powder, confectionery fat, caramel powder [10]. The problem of this study is that the recipe used confectionery fat, which is not recommended in therapeutic and prophylactic nutrition, as well as cocoa vela – a hard-to-grind by-product of the production of cocoa powders. In addition, these products do not contain fruit and vegetable and berry components that increase the nutritional value of the product.

The composition for the production of cracker is known, including buckwheat flour, chestnut flour, taken in a ratio with buckwheat flour 1:2, powder from rose hips, yeast, gluten-free egg substitute, pan-salt, refined corn oil, flour corrector in the form of protease, emulsifier, and water [11].

Work [12] developed a confectionery mixture containing buckwheat flour, starch, powdered sugar, confectionery fat, milk powder, flour from sunflower seed kernels, flour from pumpkin seed kernels. The mixture is pre-fried at a temperature of 170–220 °C, obtaining a confectionery mixture that tastes like a mixture of fried almonds, hazelnuts, and peanuts. The disadvantage of this study is that the products developed according to the developed recipe have a specific buckwheat taste and increased fragility.

In many technologies, it is possible to replace wheat flour of the highest grade only partially with secondary types of flour. This is flour obtained from other cereals or legumes. For example, amaranth, buckwheat, rice, corn, soybean, pea, chickpea, lentil, etc.

Flour proteins from leguminous crops are represented mainly by globulins and a small amount of albumin, a low content of glutamic acid and proline. They are characterized by a high content of arginine, lysine, and aspartic acid. A distinctive feature of the albumins present in the composition is the high content of methionine, lysine, isoleucine, threonine, and tryptophan.

Leguminous crops differ significantly in their technological characteristics from the grain of traditional grain crops, the technology of industrial processing of which into flour has been worked out in detail for many years, it is necessary to search for ways to improve its processing.

When using leguminous crops in the development of technology, it is very important to take into account their properties, which differ from other cereals. Leguminous crops differ significantly in their characteristics from the grain of traditional grain crops, the technology of industrial processing of which into flour has been worked out in detail for many years. In addition, legumes are a source of anti-alimentary compounds that prevent the absorption of essential nutrients [13].

The process of flour production consists of two stages – preparatory and direct grinding (grinding) of grain. To reduce energy costs for its implementation and increase the yield of flour, it is proposed to carry out preliminary heat treatment of cereals, which helps reduce the strength of raw materials [14].

Based on all of the above, the use of ultra-high-frequency processing for leguminous crops is of interest.

In the study, cereals were subjected to heat treatment with ultra-high-frequency fields, which leads to changes in the structure of starch, contributing to an increase in its sorption activity. Studies have shown that when processed with a field power in the range of 400–600 W, the organoleptic characteristics of the grain improved. It is also proved that irradiation in ultrahigh-frequency fields reduces the contamination of microorganisms and, consequently, increases the shelf life of finished products [15].

In studies, flour from leguminous crops is proposed as a gluten-free flour for dietary nutrition of patients with celiac disease.

Chickpea flour is a flour that is obtained from the Bengal variety of Asian peas. Chickpeas differ from other legumes by a higher content of most mineral elements, the vitamin composition is close to soybeans. It contains selenium (28.51 mg) necessary for the human body, which is necessary to stabilize the process of hematopoiesis, prevent osteoporosis. In addition, chickpeas are a good source of vitamin$_{B2}$ (0.51 mg/100 g), B6 (0.56 mg/100 g) and nicotinic acid (2.25 mg/100 g) [16].

The addition of chickpea flour increases the taste and biological value of products. Depending on the variety, the protein content ranges from 20 to 30 %. Fats are in the range of 4–7 %, carbohydrates – 47–50 %. Energy value is due to high calorie content (360 kcal) [17, 18]. However, chickpea flour has a specific leguminous taste and smell, which affects the quality of finished flour confectionery.

Currently, the only treatment for celiac disease is a lifelong gluten-free diet. When following a gluten-free diet, it is necessary to exclude wheat, oats, rye, barley, as well as all products prepared using these cereals [19].

Cereal proteins are divided into glutenins, which are biologically active proteins, and prolamins. The name “prolamin” reflects the characteristics of the amino acid composition of the protein, namely the high content of proline and glutamine, which determine the toxicity of gliadin, secalin, hordein, and avenin for patients with celiac disease, prolamins of rice, chickpeas, buckwheat, corn and amaranth contain less glutamine and proline, which makes it possible to use these crops in the diet for celiac disease [2, 20].

Hydrocolloids such as guar, xanthan gum and others are most often used as structure-forming agents of gluten-free products, which increase the specific volume, softness and slow down the staleness of flour products [21]. Hydrocolloids cover starch granules and delay water absorption. One solution to replace wheat protein is leguminous mixtures, which form the structure of gluten-free dough for flour confectionery. Almost all types of unconventional raw materials (chickpea, rice, and amaranth) have functional properties, such as moisture absorption – the ability of raw materials to absorb moisture, fat absorption – the ability to adsorb fat, foaming and gelling ability. Using the functional properties of non-traditional raw materials, it becomes possible not only to improve the quality of confectionery products but also to obtain products with predetermined properties.

The formation of the structure of gluten-free confectionery products depends on the content of the protein fraction of the raw material gliadin and glutenin.

Thus, one of the promising areas of scientific research is the development of highly efficient technologies for the production of gluten-free products, using Kazakhstani leguminous raw materials. As a result of such studies, products based on non-traditional types of raw materials will be characterized by increased nutritional and biological value. This is due to the fact that non-traditional types of flour provide a balance of amino acid composition, dietary fiber, vitamins, macro- and microelements without the use of hydrocolloids to form the structure of gluten-free products.

Despite the fact that the range of flour confectionery products is very diverse, one of the important tasks facing the confectionery industry is the development of new types of products in order to improve the structure of the assortment, the creation of products for specialized purposes. The solution to this problem is facilitated by the use of non-traditional, gluten-free raw materials in the formulation in order to improve the structural and mechanical properties of the dough and increase the shelf life of finished products.

3. The aim and objectives of the study

The purpose of the research is to develop a technology of gluten-free flour confectionery products based on chickpea flour with increased nutritional and biological value.

To accomplish the aim, the following tasks have been set:

– to determine the optimal ratio of recipe components of gluten-free flour confectionery products and offer technological schemes for the production of cupcake and custard semi-finished products;

– to investigate the nutritional and biological value of gluten-free flour confectionery products;

– to determine the effect of ultra-high-frequency processed chickpea flour on microbiological indicators and shelf life of gluten-free flour confectionery.

4. Materials and methods of research

4. 1. The object and hypothesis of research

In Kazakhstan, various grains and legumes are grown in sufficient volume, which can be an excellent raw material for obtaining gluten-free products. The object of research was flour confectionery muffins and custard semi-finished products. In the recipe of muffins and custard semi-finished products, processed chickpea flour was used.

The hypothesis of the study assumed that ultra-high-frequency processing could help reduce the microbiological contamination of raw materials and improve the organoleptic characteristics of finished products.

4. 2. Methods of research of quality indicators of gluten-free flour confectionery products

Assessment of the nutritional value of gluten-free flour confectionery products was carried out according to standard research methods:

– the mass fraction of fat was determined by the Soxhlet method;

– mass fraction of protein – according to the Kjeldahl method, using an automated combustion furnace and a distillation apparatus;

– mass fraction of carbohydrates – iodometric titration.

Determination of the amino acid composition of the protein was carried out by high-performance liquid chromatography on the KnauerSmartline 5000 chromatograph using reverse phase chromatography on the Diasphere-110 column. Photometric detection at λ=248 nM. Injection volume – 20 μl. Quantitative calculation of the amino acid content was carried out according to the ratio of the areas of the peaks of the standard and the sample.

The content of vitamins (B_1 thiamine chloride, B_2 riboflavin, B_3 pantothenic acid, B_5 nicotinic acid, B_6 pyridoxine, B_9 folic acid, C ascorbic acid) was determined by electrophoresis "Kapel 105".

On the high-performance liquid chromatograph "Agilent-1200" (USA), diode-matrix, fluorescent and refractometric detectors determined the content of aflatoxin- B_1, amino acids, carbohydrates, fat-soluble vitamins.

With the help of the atomic absorption spectrometer "KVANT-Z.ETA", elemental analysis of liquid samples of various origin and composition was carried out at the level of concentrations measured in μg/l-ng/l. The device is used for quantitative determination: 1 – Cu Copper, 2 – Al Aluminum, 3 – Zn Zinc, 4 – Pb Lead, 5 – Cr Chromium, 6 – Ni Nickel, 7 – Cd Cadmium, 8 – As Arsenic, 9 – Sn Tin.

Microbiological contamination of products was determined according to the following methodology. Samples of finished flour confectionery products were taken for seeding, washed with a cotton swab into a test tube with 10 ml of sterile physiological solution. Cultivation of microorganisms was carried out according to GOST 26670-91. The determination of colony-forming units (CFU) was carried out according to GOST 10444.15-94, the determination of yeast and molds – according to GOST 10444.12-2013. Determination of the number of mesophilic aerobic and facultative-anaerobic microorganisms was carried out in accordance with the requirements of GOST 10444.15-94 [22], the number of bacteria of the Escherichia coli group – in accordance with the requirements of GOST 31747-2012 [23] the number of mycelial fungi and yeast – in accordance with the requirements of GOST 10444.12-88 [23–25].

4. 3. Construction of mathematical models

To form the recipes of flour confectionery products from gluten-free types of flour, it was planned to solve several problems. These include the development of the basic form of the product and the formation of its consumer properties with a modified chemical composition. The changes are associated with the goal of increasing the nutritional value due to gluten-free raw materials, organoleptic and physicochemical compatibility of the component composition. In the production of flour confectionery products, it is known that the physicochemical properties of the flour used have a direct impact on the quality of the final product. For example, the starch and protein content significantly affects the rheology of the test [26].

Therefore, at the first stage of the experiment, samples of muffins and custard semi-finished products prepared from various types of flour were examined: chickpeas, rice, corn, and amaranth. Samples were prepared using the traditional technology of cupcakes and custard semi-finished products with a complete replacement of wheat flour of the highest grade, adapted for all types of flour used. As a control sample, a recipe for a cupcake and a custard semi-finished product from wheat flour of the highest grade was taken.

As a mathematical model, the regression equation was taken in the normalized k^3 factor space of k input variables, for two output variables: the specific volume of the finished product – the custard semi-finished product (Y_1, cm^3/g) and the specific volume of the finished product – gluten-free cake (Y_2, cm^3/g). Accordingly, the following were chosen as input variables:

– for the study of Y_1: the mass of chickpea flour (C, g), the mass of corn flour (M, g), the mass of chicken eggs (E, g);

– for the study of Y_2: the mass of chickpea flour (C, g), the mass of rice flour (R, g), the mass of amaranth flour (A, g).

Normalization of input variables was carried out according to the typical formula [27], which translates the natural values of input variables into a dimensionless range [–1; +1]. The conversion from normalized to natural values was carried out taking into account the range of variation on the basis of a typical equation [28, 29].

The structure of the regression equation takes the form of a polynomial of the second power:

$$Y_j = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1^2 + a_5x_2^2 + a_6x_3^2 + \\ + a_7x_1x_2 + a_8x_2x_3 + a_9x_1x_3,\ j = 1, 2, \qquad (1)$$

where x_i are the input variables in the normalized form, a_i are the coefficients to be determined, and j is the number of the output variable.

The presence of conditions for conducting an active experiment made it possible to choose for the implementation of either a rotatable plan or an orthogonal plan of a complete factor experiment [30] followed by the calculation of coefficients in a simple way [31, 32], justified by the orthogonality of the plan.

The obtained regression equations were described by response surfaces, which were analyzed by their canonical transformation, followed by comparison and evaluation of the signs of the values of the eigenvalues of the symmetric matrix $A=(a_{il})$ of order $n=2$ after the transformation of equation (1) [33]. The transformation I implied fixing the variable x_1 at three levels: $x_1=-1$; $x_1=0$; $x_1=+1$, and the construction of response surfaces for each case in order to determine the behavior of optimal solutions when changing the variable x_1 common to the two regression equations. The choice of three levels was dictated by the possibility of implementing a D-optimal plan on a segment [30], which makes it possible to determine the value of the optimum with the greatest accuracy.

The elements of matrix A are formed from the coefficients before the nonlinear terms of the regression equation converted to the two-dimensional form $Y_j=f(x_2, x_3)$:

$$Y_j = a_0 + 2b'x + x'Ax, \qquad (2)$$

where $x = \begin{pmatrix} x_2 \\ x_3 \end{pmatrix}$ is the matrix of input variables after the transformation of equation (1) to two-dimensional form, x' is the transposed matrix of input variables, b' is the transposed matrix of coefficients before the linear terms of the equation:

$$2b = \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} a_2 + a_7x_1 \\ a_3 + a_9x_1 \end{pmatrix},\ A = \begin{pmatrix} a_5 & \frac{1}{2}a_8 \\ \frac{1}{2}a_8 & a_6 \end{pmatrix}.$$

The nature of the response surface was determined on the basis of the following conditions:

– $\lambda_1<0$, $\lambda_2<0$, $|\lambda_1| \neq |\lambda_2|$ – ellipsoid [34], in cross-section Y=const ellipses, extremum point – maximum;

– λ_1<0, λ_2>0, $|\lambda_1| \neq |\lambda_2|$ – hyperbolic paraboloid [35], in the cross-section Y=const of hyperbola, the extremum point is the saddle point;

– λ_1>0, λ_2<0, $|\lambda_1| \neq |\lambda_2|$ – hyperbolic paraboloid, in cross-section Y=const of hyperbola, extremum point – saddle point;

– λ_1>0, λ_2>0, $|\lambda_1| \neq |\lambda_2|$ – ellipsoid, in cross-section 3Y=const ellipses, extremum point – minimum.

The determination of n eigenvalues λ_i was carried out by solving the characteristic equation

$$\begin{vmatrix} a_{11}-\lambda & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22}-\lambda & \dots & a_{2n} \\ . & . & . & . \\ a_{n1} & a_{n2} & \dots & a_{nn}-\lambda \end{vmatrix} = \\ =(-\lambda)^n + P_1\lambda^{n-1} + \dots P_n = 0. \qquad (3)$$

Reducing the dimensionality of the regression equation followed by canonical transformation of the response surface is convenient in practical terms. This is due to the fact that this approach makes it possible to see the behavior of the output variable in the stationary region when displaced from it. That is, one can see how, if the value of one of the input variables is fixed at several levels, it is necessary to change the values of other input variables in order to obtain the best values of the output variable. Of particular importance is such a task for automated dosing systems of formulation components, solving the technological problem of optimal dosing in loading systems [32].

Tables 1, 2 give the variation intervals and normalized values of input variables affecting the specific volume of finished products – the composition of the custard semi-finished product from gluten-free raw materials and gluten-free muffins. There are also values of the leverage of stellar dots α.

Table 1

Variation intervals and normalization of input variables for the study of the specific volume of finished products – custard semi-finished product

Factors		Variation levels					Variation intervals
Designations in natural form	Notation in normalized form	–1,68	–1	0	+1	+1,68	
C, g	x_1	61.59	65	70	75	78.41	5
M, g	x_2	66.59	70	75	80	83.41	5
E, g	x_3	106.4	120	160	200	213.6	40

Table 2

Variation intervals and normalization of input variables for the study of the specific volume of finished products – gluten-free cupcakes

Factors		Variation levels					Variation intervals
Designations in natural form	Notation in normalized form	–1,68	–1	0	+1	+1,68	
C, g	x_1	71.59	75	80	85	88.41	5
R, g	x_2	14.59	15	20	25	28.41	5
A, g	x_3	2.66	3	4	5	5.34	1

5. Results of the development of gluten-free flour confectionery technology

5. 1. Results of optimization of the recipe composition of gluten-free confectionery products and technological schemes of production

Table 3 shows a rotatable plan and the results of experimental studies of gluten-free custard semi-finished products.

Table 3

Results of experimental studies of gluten-free custard semi-finished products

No.	Encoded values			Natural Values			Experimental values of the specific volume of finished products – custard semi-finished product
	x_1	x_2	x_3	C, g	M, g	E, g	Y_1, cm^3/g
1	–	–	–	65	70	120	7
2	–	–	+	65	70	200	7.5
3	–	+	–	65	80	120	9.5
4	–	+	+	65	80	200	10
5	+	–	–	75	70	120	10.5
6	+	–	+	75	70	200	10
7	+	+	–	75	80	120	9.5
8	+	+	+	75	80	200	7
9	–1.68	0	0	61.59	75	160	10
10	+1.68	0	0	78.41	75	160	7.5
11	0	–1.68	0	70	66.59	160	8.5
12	0	+1.68	0	70	83.41	160	9
13	0	0	–1.68	70	75	104.6	8
14	0	0	+1.68	70	75	213.6	7.5
15	0	0	0	70	75	160	9.5
16	0	0	0	70	75	160	9.5
17	0	0	0	70	75	160	10
18	0	0	0	70	75	160	10
19	0	0	0	70	75	160	9.5
20	0	0	0	70	75	160	10

The regression equation for calculating the specific volume of finished products – custard semi-finished products – is as follows:

$$Y_1 = 9.732 - 0.088x_1 + 0.135x_2 - 0.208x_3 - \\ -0.239x_1^2 - 0.239x_2^2 - 0.594x_3^2 - \\ -1.125x_1x_2 - 0.25x_2x_3 - 0.5x_1x_3. \qquad (4)$$

Proceeding from (4), the solution to equation (3) produced the following eigenvalues of the matrix A: λ_1=–0.63346 and λ_2=– 0.19983. Consequently, the response surface is an ellipsoid (Fig. 1), and the equation in canonical form is represented as follows:

$$Y_1 + 0.63346\xi_1^2 + 0.19983\xi_2^2 = \begin{cases} 11.856 \text{ if } x_1 = -1, \\ 10.343 \text{ if } x_1 = 0, \\ 11.001 \text{ if } x_1 = +1, \end{cases} \qquad (5)$$

where ξ_1, ξ_2 are the new coordinates of the factor space of the input variables after the canonical transformation of the response surface in x_2–x_3 coordinates.

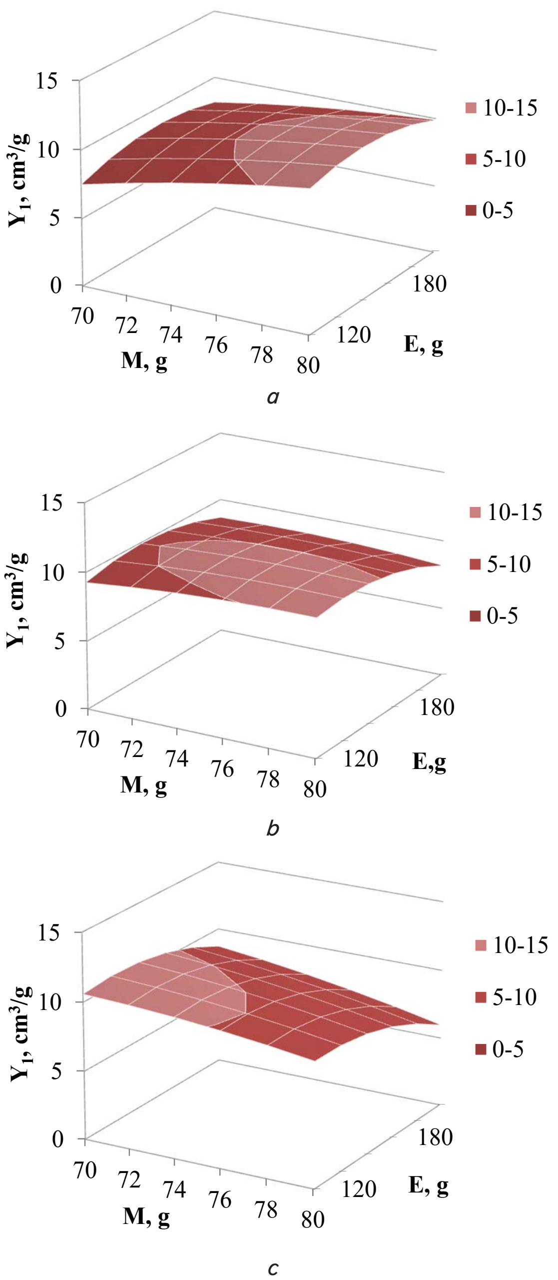

Fig. 1. Response surface describing the values of the specific volume of the finished product – custard semi-finished product in the space of factors "M – E": *a* – *C*=65 g, *b* – *C*=70 g, *c* – *C*=75 g

Table 4 shows a rotatable plan and the results of experimental studies of gluten-free muffins.

The regression equation for calculating the specific volume of finished products – gluten-free muffins – is as follows:

$$Y_2 = 19.43 + 1.016x_1 + 0.893x_2 + 1.159x_3 - \\ -0.587x_1^2 - 0.587x_2^2 - 0.41x_3^2 - \\ -1.063x_1x_2 - 1.688x_2x_3 - 1.438x_1x_3. \quad (6)$$

Based on (5), the solution to equation (3) produced the following eigenvalues of the matrix *A*: λ 1=–1.34661 and λ_2=0.350266. Therefore, the response surface is a hyperbolic paraboloid (Fig. 2), and the canonical equation is represented as follows:

$$Y_2 + 1.34661\xi_1^2 - 0.350266\xi_2^2 = \begin{cases} 20.106 \text{ if } x_1 = -1, \\ 20.429 \text{ if } x_1 = 0, \\ 20.535 \text{ if } x_1 = +1, \end{cases} \quad (7)$$

Table 4

Results of experimental studies of gluten-free muffins

No.	Encoded values			Natural Values			Experimental values of the specific volume of finished products – gluten-free muffins
	x_1	x_2	Y_1, cm³/g	*C*, g	*R*, g	*A*, g	Y_2, cm³/g
1	–	–	–	75	15	3	17
2	–	–	+	75	15	5	17.5
3	–	+	–	75	25	3	19.5
4	–	+	+	75	25	5	20
5	+	–	–	85	15	3	20.5
6	+	–	+	85	15	5	20
7	+	+	–	85	25	3	19
8	+	+	+	85	25	5	17
9	–1.68	0	0	71.59	20	4	19
10	+1.68	0	0	88.41	20	4	17.5
11	0	–1.68	0	80	14.59	4	18.5
12	0	+1.68	0	80	28.41	4	19
13	0	0	– 1.68	80	20	2.66	18
14	0	0	+1.68	80	20	5.34	17.5
15	0	0	0	80	20	4	19.5
16	0	0	0	80	20	4	20
17	0	0	0	80	20	4	20
18	0	0	0	80	20	4	20
19	0	0	0	80	20	4	19.5
20	0	0	0	80	20	4	19

The high water absorption capacity of chickpea flour dough leads to greater moisture loss during baking, which suggests that the semi-finished product for a cake from this type of flour will be very dry [36]. To avoid this, in the future, more chicken eggs or other type of flour had to be added to this dough in an amount of at least a third to the mass of all flour used. The closest to the dough of wheat flour in terms of water absorption was the dough for rice flour muffins. The value of this indicator was slightly higher for the dough from amaranth flour, therefore, in order to, in the future, achieve the value of water absorption of the dough from wheat flour in this sample, it will be necessary to create a mixture. Indicators of the stability of the samples are shown in Fig. 3.

Rice flour dough had a low water absorption and stability index compared to chickpea and amaranth flour dough. High water absorption capacity slows down the staling process, prolongs the shelf life of products, makes their appearance more attractive to consumers.

In the formation of the gel-like pseudoplastic structure of the dough for the cake, a protein complex of chickpea flour was used.

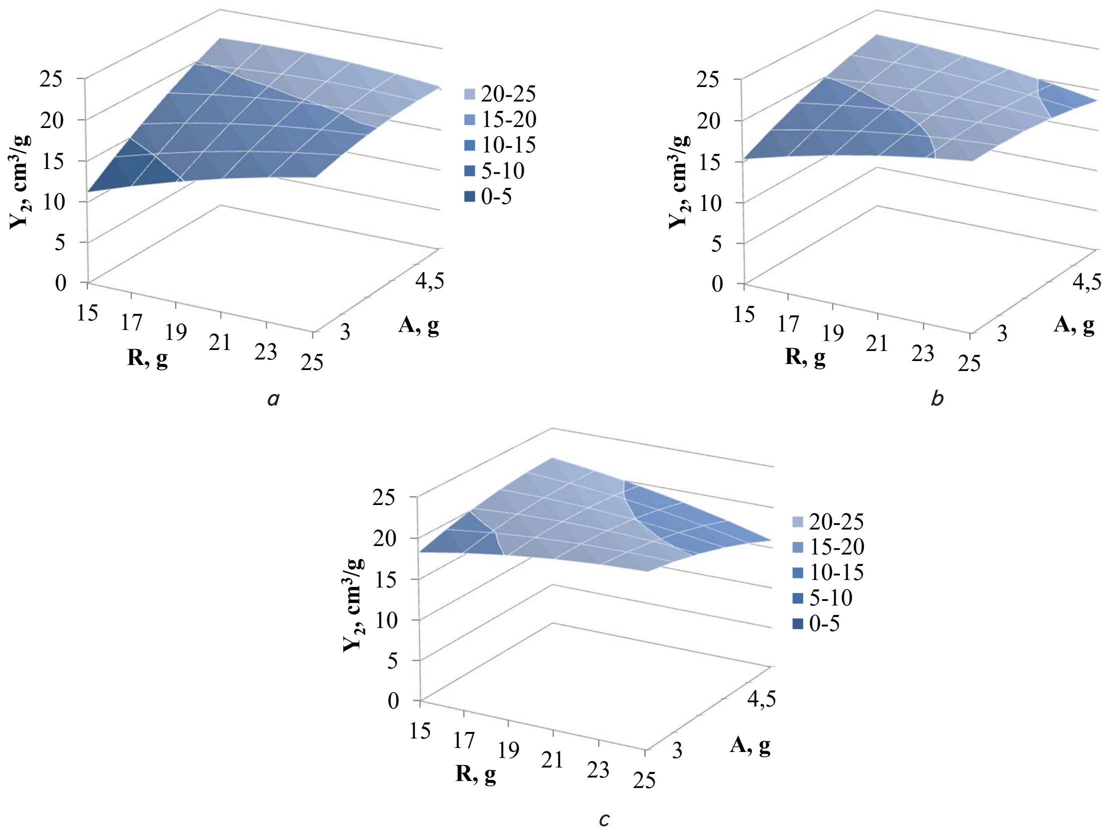

Fig. 2. Response surface describing the values of the specific volume of finished products – gluten-free cupcakes in the space of factors "R – A": *a* – *C*=75 g, *b* – *C*=80 g, *c* – *C*=85 g

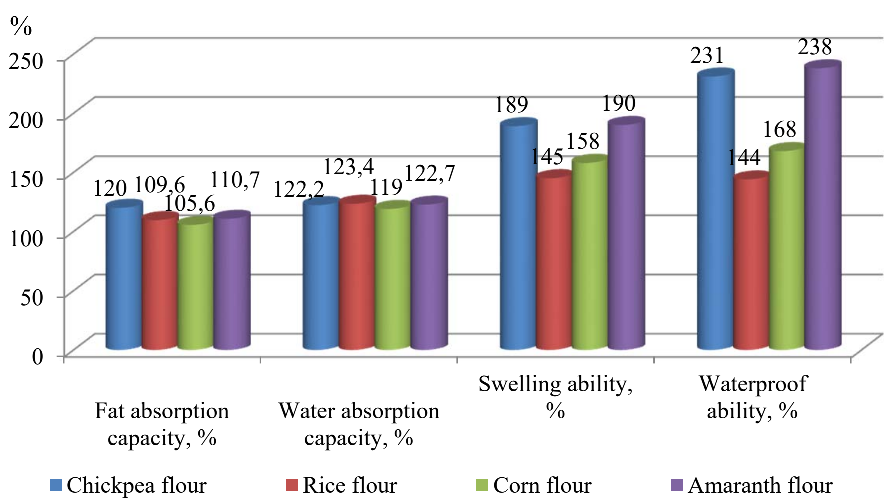

Fig. 3. Water-binding capacity of flour

In the course of experimental studies, variants of cupcake samples consisting of the following flour ratios were taken:

– Sample No. 1 – wheat flour muffins;

– Sample No. 2 – muffins made of 100 % unprocessed chickpea flour;

– Sample No. 3 – 100 % from flour of ultra-high-frequency processed chickpeas of the "Miras 07" variety;

– Sample No. 4 – muffins from processed chickpea, rice, and amaranth flour – 85:10:5;

– Sample No. 5 – muffins made of processed chickpea, rice, and amaranth flour – 80:15:5;

– Sample No. 6 – muffins of processed chickpea, rice, and amaranth flour – 70:20:10.

As a control sample, muffins made of wheat flour, processed and unprocessed chickpea flour were taken. The main organoleptic indicators of cupcakes are taste and smell. When tasting, sample No. 2 had an unpleasant legume taste and smell, and sample No. 3 had a lighter legume taste compared to sample No. 2. To improve the taste and smell, compositions of rice and amaranth flour were chosen.

Samples of a cake from gluten-free flour, produced according to the proposed recipes, were evaluated using a score scale of organoleptic assessment of the quality of gluten-free muffins. The results of the tasting evaluation of a gluten-free cake are shown in Fig. 4.

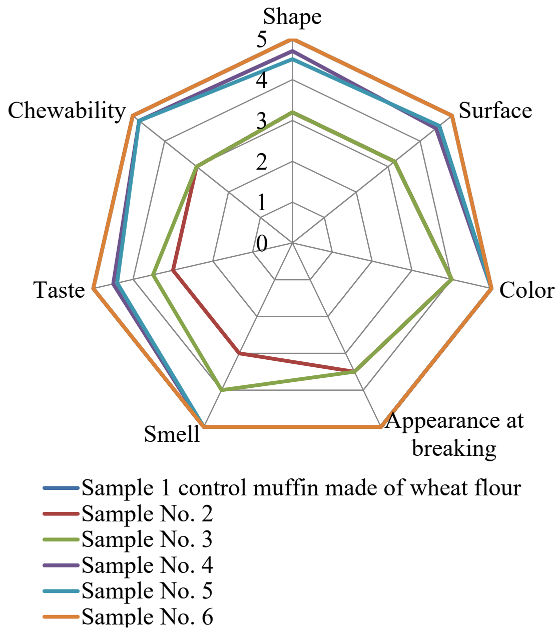

Fig. 4. Profilogram of organoleptic parameters of muffins from gluten-free mixture (chickpea, rice, and amaranth flour)

A feature of the composition of samples No. 4–6 is that as an improvement in rheological and organoleptic properties, rice and amaranth flour were added in the amount of rice 10–20 %, amaranth 5–10 %. According to the results of organoleptic evaluation, it can be argued that the shape and surface of the samples under study differed significantly from the control sample. With the increase in the amount of chickpea flour, the color of the products changed from light yellow to dark yellow. At the fracture – to a yellow-cream color. An increase in the introduced processed chickpea flour positively changed the taste of the muffins. The organoleptic evaluation of cupcakes according to the point system showed that the most points were received by muffins from ultra-high-frequency processed chickpea flour No. 5 – 4.77 points and cupcakes from mixture No. 4 – 4.63 points. Cupcakes from the mixture sample No. 2 received a minimum number of points – 3.73 points.

The use of flour from ultra-high-frequency processed chickpeas can improve the organoleptic characteristics of confectionery.

As a result of tasting, sample No. 5 was chosen as the best option. 80 % of ultra-high-frequency processed chickpea flour is added to its composition. In addition, rice and amaranth flour are added to improve the consistency of the dough in a ratio of 15 %:5 %.

Chickpea flour in its composition contains a large amount of protein, which potentially increases the biological value of the cake.

Further, studies were carried out to determine the structural and mechanical indicators of cupcake samples given in Table 5.

Structural and mechanical indicators, depending on the type and ratios of flour mixtures, differed significantly. The indicator of the specific volume with a decrease in the dosage of chickpea flour gradually increases since the recipe of cakes includes rice and amaranth flour. Rice flour contains a large amount of amylose, which gives muffins a porous crumb texture, and amaranth flour gives elastic-elastic characteristics due to the large amount of starch, protein, and fiber.

On the basis of experimental studies, a technological scheme for the production of gluten-free cupcakes has been developed (Fig. 5).

The optimal dosage in the cupcake recipe can be considered 80 % chickpea flour, 15 % rice flour, 5 % amaranth flour.

Further, studies of organoleptic evaluation of finished custard semi-finished products according to the proposed recipes were carried out.

Variants of samples of custard semi-finished product consist of the following flour ratios:

– No. 1 – custard semi-finished product from wheat flour;

– No. 2 – custard semi-finished product from 100 % unprocessed chickpea flour;

– No. 3 – custard semi-finished product from 100 % from flour of ultra-high-frequency processed chickpeas of the "Miras 07" variety;

– No. 4 – custard semi-finished product from processed chickpea and corn flour 80:20;

– No. 5 – custard semi-finished product from processed chickpea and corn flour 60:40;

– No. 6 – custard semi-finished product from processed chickpea and corn flour – 50:50).

The organoleptic evaluation of the custard semi-finished product (Fig. 5) showed that the highest number of points was received by sample No. 6 (4.94 points) compared to the control sample. The custard semi-finished product with a high content of corn flour had a pronounced taste and aroma. Custard semi-finished product No. 3 (3.48 points) from 100 % of processed chickpea flour when baking the semi-finished product spread, did not hold its shape, hollow semi-finished product was not formed. An increase in the dosage of the introduced chickpea flour led to a deterioration in the quality of the custard semi-finished product, the organoleptic parameters and the specific volume of the semi-finished product decreased by 1.0 %, compared with the control sample.

Table 5

Quality indicators of cupcakes with different flour ratios

Name of indicators	The value of the indicators of muffins made from chickpea and rice flour, amaranth with their ratio, %					
	1	2	3	4	5	6
	100 % wheat flour	100 % Chickpea flour	100 % ultrahigh frequency processing Chickpea flour	Chickpea, rice, and amaranth flour – 85:10:5;	Chickpea, rice, and amaranth flour – 80:15:5;	Chickpea, rice, and amaranth flour– 70:20:10)
Structural and mechanical indicators						
Specific volume, cm/100 g	239	240	247	249	250	250
Elasticity, %	44.9	61.1	50.4	49.3	48.7	49.0
Elasticity, %	50.1	40.8	44.9	45.2	53.9	53.6
Plasticity, %	4.0	3.1	4.3	4.4	6.3	6.4
Wettability, %	160.0	155.0	160.6	176	179.7	179

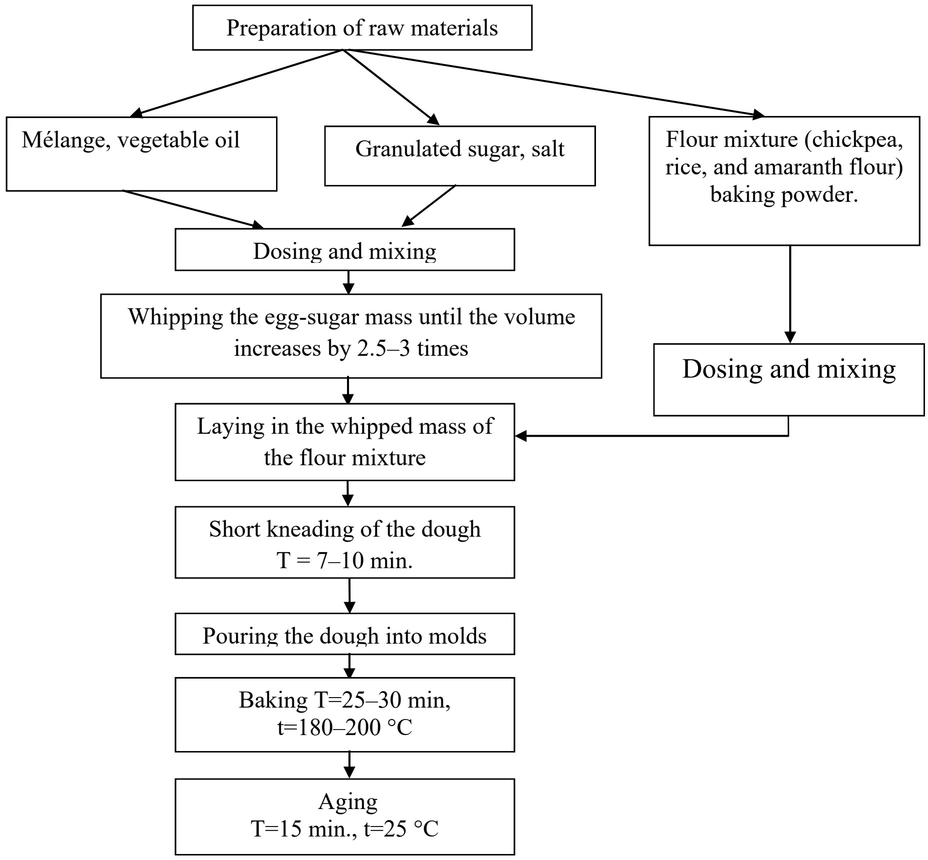

Fig. 5. Technological scheme of muffin production

Sample No. 6 had a regular shape, without lumps, and with the formation of a cavity inside the semi-finished product. The taste of the custard semi-finished product improved with the increase in corn flour. Since, in corn flour, it is contained in a large amount of protein fractions – glutenin. Glutenin gives gluten elasticity, which helps to get a volumetric, hollow custard semi-finished product when baking.

Table 6 gives the quality indicators of the custard semi-finished product at different ratios of chickpea and corn flour.

Samples from chickpea and corn flour had the highest humidity at their dosage of 50 %. The lowest alkalinity – custard semi-finished products with chickpea flour and corn flour at a dosage of 60 and 40 %, respectively. Samples from 80 % of the processed chickpeas during baking, the dough spread, did not hold its shape, and did not form a hollow chamber.

A technological scheme for the production of gluten-free custard semi-finished products has been developed (Fig. 7).

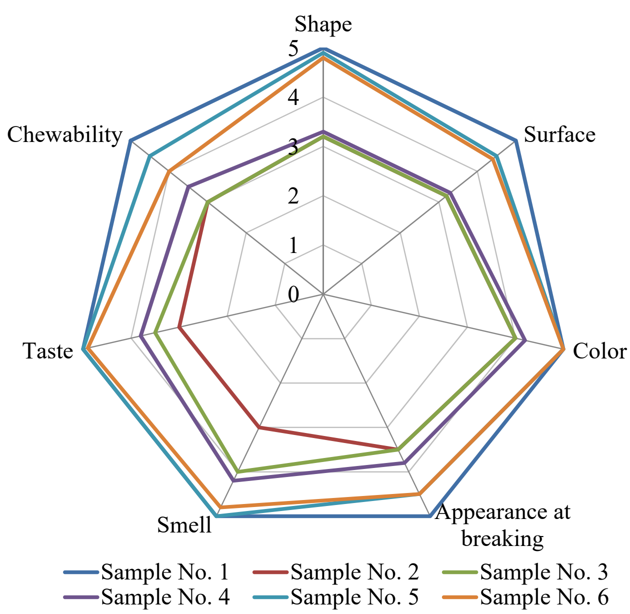

Fig. 6. Profilogram of organoleptic parameters of custard semi-finished products from gluten-free mixtures (chickpea, corn flour)

As a result of experimental studies, taking into account the qualitative indicators of gluten-free products, a recipe for a cake and a custard semi3finished product was developed, given in Table 7.

Table 6

Quality indicators of custard semi-finished products with different flour ratios

Name of indicators	The value of indicators of custard semi-finished products prepared from chickpea and corn flour with their ratio, %					
	1	2	3	4	5	6
	100 % wheat flour	100 % ChickC pea flour	100 % ultrahigh frequency processing Chickpea flour	Chickpea and corn flour –80:20	Chickpea and corn flour – 60:40	Chickpea and corn flour – 50:50
Physicochemical parameters						
Humidity, %	31	29	30	31	32	33
Mass fraction of fat, %	78	79	80	75	74	75
Alkalinity, %	65.9	61.1	50.4	49.3	48.7	48.8
Wettability, %	30.1	35.8	38.9	35.2	33.9	34.0
Density, %	4.0	3.1	10.7	15.5	17.4	17.6
Porosity, %	50.0	45.6	45.7	49.3	54.0	54.5

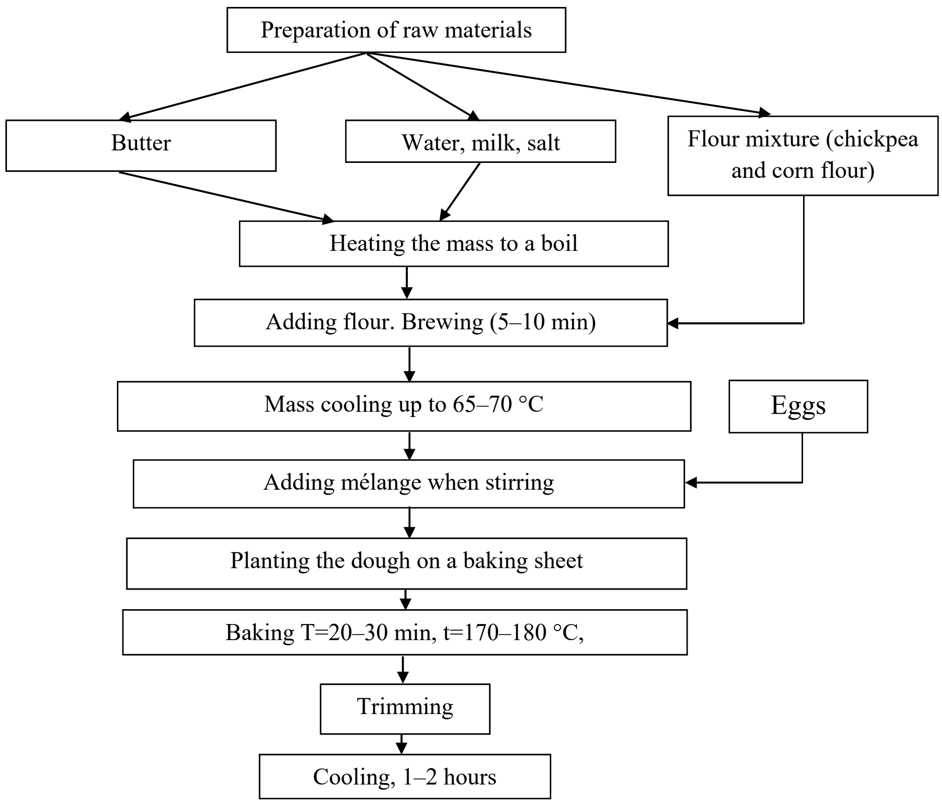

Fig. 7. Technological scheme of production of custard semi-finished product

Table 7

Recipes of developed gluten-free flour confectionery products

Name of raw materials and materials	Consumption per 100 kg of flour	
	Gluten-free cupcakes	*Gluten-free custard semi-finished product*
1	2	3
Chickpea flour	40	10
Fig flour	7.5	–
Amaranth flour	2.5	–
Corn flour	–	10
Mélange	15.3	34
Vegetable oil	12	–
Butter	–	10.9
Milk	–	19
Sugar	22	–

Continuation of Table 7

1	2	3
Salt	0.3	0.1
Baking powder	0.4	–
Water	–	16
Total	100	100

5. 2. Investigation of food and biological value of gluten-free flour confectionery products

The nutritional value (Table 8), amino acid (Fig. 8, 9) and vitamin composition (Table 9) of gluten-free muffins and custard semi-finished products were investigated in comparison with the control option.

Based on the data in Fig. 8, it was found that when flour from ultra-high-frequency processed chickpea flour was introduced into the cupcake recipe, the amount of the limiting amino acid lysine increased by 1.08 times compared to unprocessed chickpea flour. In general, the biological value of an enriched cake on average exceeds the control sample by 1.5 times.

Based on the data in Fig. 9, it was found that when processed chickpea flour was introduced into the formulation of a custard semi-finished product, the amount of the limiting amino acid arginine increased by 1.97 times compared to unprocessed chickpea flour.

Further, studies were conducted to determine the nutritional value of the developed flour confectionery products in comparison with control (Table 8).

Table 8 shows that the content of the mass fraction of protein in the developed flour confectionery products increased by almost 1.3 times. The high protein index in muffins and custard semi-finished products in comparison with the control option is due to the fact that the composition of the flour mixture includes processed chickpea flour. The content of the mass fraction of fat in the developed products exceeds by 1.2 times compared to the control version due to the use of chickpea in flour formulations. In terms of energy value, gluten-free muffins and custard semi-finished products are less caloric compared to the control sample.

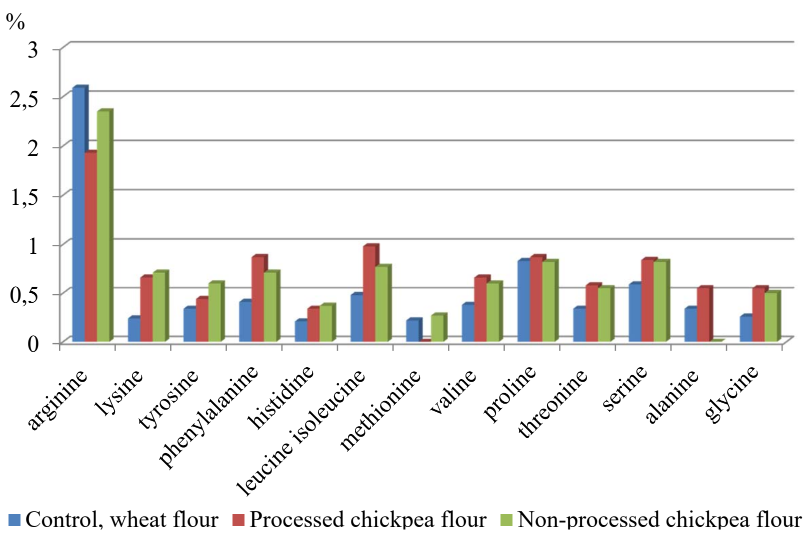

Fig. 8. Amino acid content of gluten-free muffins from processed and unprocessed chickpeas of Miras variety

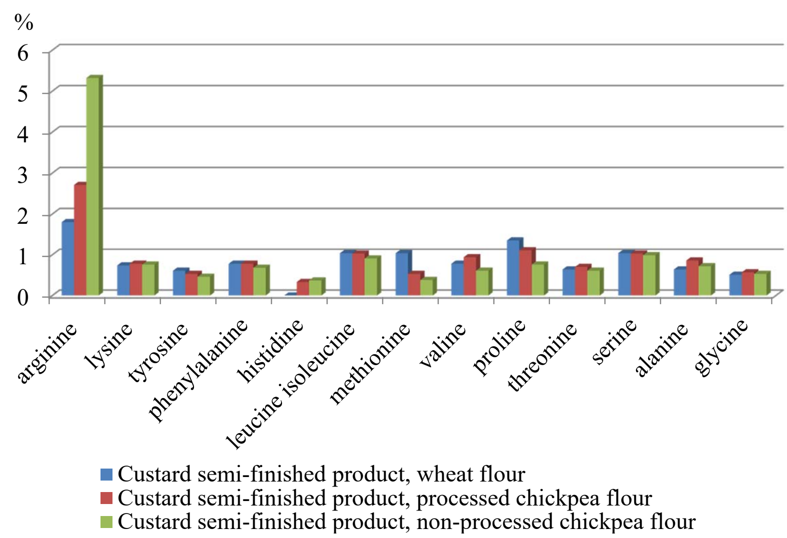

Fig. 9. Amino acid content of gluten-free custard semi-finished product from processed and unprocessed chickpeas

Table 8

Nutritional value of flour confectionery products

Name of indicators, %	wheat flour muffins	Muffins made from unprocessed chickpea flour	Muffins made from processed chickpea flour	Custard s/f wheat flour	Custard semi-finished product from flour of unprocessed chickpeas and corn flour 50:50	Custard semi-finished product from processed chickpea flour and corn flour 50:50
Mass fraction of carbohydrates, %	43.21±0.98	45.26±0.96	47.18±0.99	38.25±0.57	23.54±0.32	29.22±0.38
Mass fraction of protein, %	5.12±0.09	5.97±0.13	6.85±0.12	11.09±0.13	12.13±0.18	13.36±0.19
Mass fraction of fat, %	17.13±0.33 181.17	18.69±0.28	20.49±0.29	12.69±0.19	13.49±0.16	14.30±0.21
Content of antioxidants, mg/100 g	178±1.2	144±1.5	157±5.2	107±1.4	103±1.3	101±1.3
Mass fraction of ash, %	1.00±0.01	1.71±0.02	1.64±0.02	1.06±0.01	1.49±0.02	1.48±0.02
Energy value, kcal	347.49	373.13	400.53	311.57	264.09	299.02

Studies on the content of B vitamins in flour confectionery are illustrated in Table 9.

Based on the data obtained, it was established (Table 9) that the content of B vitamins does not change and remain within normal limits.

Table 9

The content of vitamins in flour confectionery products

Name of the main food substances, %	Cupcakes		Custard semi-finished product	
	Wheat flour muffins (Control)	A cake made of a mixture of chickpea, rice, and amaranth flour	Custard semi-finished product from wheat flour	Custard semi-finished product from a mixture of chickpea and corn flour
Vitamin E	2.41±0.04	1.17±0.02	1.98±0.02	1.33±0.01
B1 (thymine chloride)	0.094±0.019	0.643±0.129	–	0.041±0.008
B2 (riboflavin)	0.088±0.037	0.063±0.026	0.031±0.013	0.053±0.022
B6 (pyridoxine)	0.094±0.019	0.143±0.029	0.060±0.012	0.048±0.010
B3 (pantothenic acid)	0.123±0.025	0.345±0.069	0.275±0.055	–
B5 (nicotinic acid)	–	0.046±0.008	–	–
BC (folic acid)	–	0.020±0.004	–	–

The introduction of non-traditional types of flour into the recipe makes it possible to expand the range of flour confectionery products of increased nutritional and biological value and give the products functional properties.

5. 3. Investigation of shelf life and safety of gluten-free flour confectionery products

Determining microbiological indicators is one of the important components of ensuring the safety of confectionery production. In work [14] it is proved that unprocessed chickpea flour in comparison with ultra-high-frequency processed chickpea flour is characterized by less resistance during storage, since during storage the indicator of fatty acids rises, and is quickly destroyed. Confectionery products are exposed to many adverse factors (temperature, moisture, oxygen from the surrounding air, microflora), which has a significant impact on the intensity of the course of a number of chemical and biochemical processes in them.

The dynamics of the development of various groups of microorganisms in confectionery products during storage is not the same, so the features of the vital activity of sanitary-indicative microorganisms are a factor in the shelf life of confectionery products. In the process of storing confectionery products, changes in organoleptic parameters, acid number of fat, microflora, enzyme activity. Since in the process of storage the quality of confectionery products decreases, it was considered advisable to study its microflora.

The analyzed samples were stored for 90 days in packaged form in a refrigerator at a temperature of +8 °C.

The obtained results of studies of the sanitary and microbiological state of confectioneries during storage for 3 months were compared with control samples that are prepared from unprocessed chickpea flour. The results of seeding with microorganisms in CFU/ml of confectionery products are given in Table 10.

Studies were conducted on the content of QMAFAnM (the number of mesophilic aerobic and facultatively anaerobic microorganisms) before storage and after 3 months. The obtained data on changes in microbiological quality indicators make it possible to conclude that if the requirements and storage conditions are met, the tested microbiological indicators of the quality of finished confectionery products meet the requirements of TR TC 021 [24]. It was found that the microbiological safety indicators of the samples met the hygienic requirements for prototypes with processed chickpea flour. As shown in Table 11, in terms of the QMAFAnM indicator, muffins with the addition of ultra-high-frequency processed flour contains the least number of microorganisms – 1×10^2 CFU/g. Custard semi-finished product with the addition of chickpea flour shows a large growth – 3.6×10^3 CFU/g, and the largest growth is seen on the control variant, the growth of microbes occupies an average position – 1.5×10^2 CFU/g. The maximum level of yeast content is $2.0*10^2$ CFU/g and molds $3.0*10^3$ CFU/g, characterizing the shelf life of confectionery products, were found in the control version of the custard semi-finished product at the end of the shelf life. However, these samples also meet the requirements of regulatory documentation, which guarantees a high level of quality and safety of confectionery products during their production cycle.

Thus, according to sanitary and microbiological control, gluten-free confectionery products from ultra-high-frequency processed chickpea flour indicate that the studied products meet the safety requirements of food products and confirm the established shelf life.

Table 10

Microbiological parameters in CFU/g when stored under different temperature conditions

Product Name	QMAFAnM, $\times 10^{-3}$ – GOST 10444.1594		Spore-forming bacteria, $\times 10^{-2}$		Yeast, CFU/g		Mold, CFU/g	
	1 month	3 months	1 months	3 months	1 month	3 months	1 month	3 months
Sample No. 1 – Unprocessed chickpea muffins	2×10^2	1.0×10^3	0.99×10^2	8×10^2	2×10^2	6×10^2	1.3×10^2	4×10^2
Sample No. 2 – Processed chickpea muffins	2×10^2	4.0×10^2	0.99×10^2	3×10^2	2×10^2	2.70×10^2	1.03×10^2	2.09×10^2
Sample No. 3 – Custard semi-finished product from unprocessed chickpea flour	0.18×10^2	1.0×10^4	0.79×10^2	$3.6\times\times10^2$	0.4×10^2	2.2×10^2	1.8×10^2	3×10^2
Sample No. 4 – Custard semi-finished product from processed chickpea flour	0.15×10^2	0.3×10^2	0.15×10^2	3×10^2	–	0.9×10^2	0.8×10^2	1.9×10^2

To determine the shelf life of the samples, the acid number of fat was determined at room temperature with a relative humidity of 59–60 % and when the samples were stored in a refrigerated chamber at a temperature of plus 8 °C. In the laboratory, the change in humidity, acidity, and acid number of fat during storage was studied in order to determine and establish shelf life terms. When stored at a temperature of plus 18–20 °C, a relative humidity of 58 % for 3 months (Fig. 10).

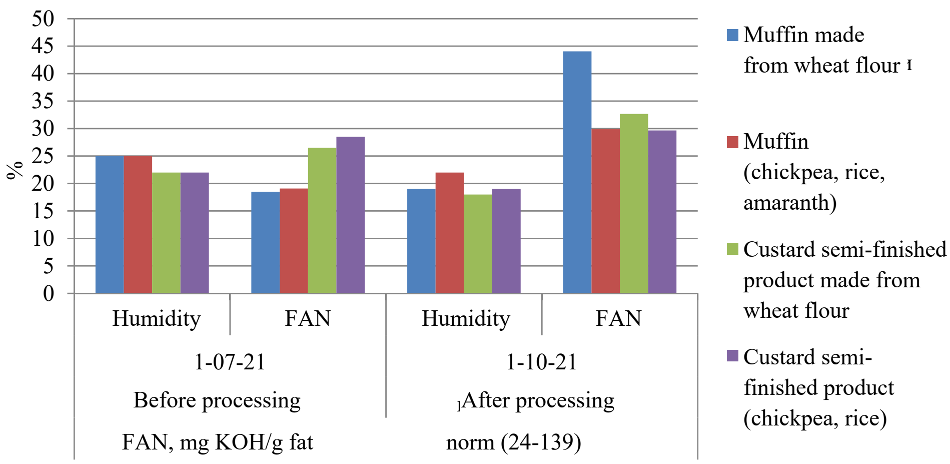

Fig. 10. Quality indicators of gluten-free flour confectionery products stored at a temperature of +18–20 °C

The acid number of fat in the control sample increased from 18.5 to 44.06 mg KOH per 1 g of fat. In the control custard semi-finished product from 26.5 to 32.66 mg KOH per 1 g of fat. As a result of the studies, it was revealed that when storing confectionery products from unprocessed chickpeas, the acid number of fat indicators increase over time and, accordingly, the humidity index decreases.

In the prototypes of the cake and custard semi-finished product, the acid number of fat increases slightly within 3 months. Of course, it is necessary to take into account the appropriate packaging for the storage of confectionery.

6. Discussion of results of the study of optimization of the recipe composition and quality indicators of the new product

Analysis of response surfaces describing the specific volume of the finished product – custard semi-finished product (Fig. 1), and equation (5), makes it possible to establish the optimal formulation. If one uses chickpea flour in the amount of 65 g, then the optimal mass of corn flour will be 89 g, and the optimal mass of chicken eggs will be 146 g. With such quantities of prescription components of gluten-free flour confectionery, the maximum specific volume of finished products – custard semi-finished products – will be 11.86 cm^3/g. However, it should be noted that the value of the input variable x_2 fell outside the range of variation (x_2=2.81) and, therefore, there is no guarantee that the volume of finished products will actually reach the specified maximum value. In this case, it is necessary to take into account the limitations of the form r<1.414 imposed by the experimental plan in the factor space normalized to the range [–1; +1] (k–1)-factor space [37]. Such constraints are typical in the study of mathematical models "composition – properties", regardless of the technological object in respect of which such models are built and make it possible to determine the best values of the output variable achieved at the boundary, called suboptimal.

If one uses chickpea flour in the amount of 70 g, then the optimal mass of corn flour will be 77 g, and the optimal mass of chicken eggs will be 149 g. With such quantities of prescription components of gluten-free flour confectionery, the maximum specific volume of finished products – custard semi-finished products – will be 10.34 cm^3/g.

If one uses chickpea flour in an amount of 75 g, then the optimal mass of corn flour will be 65 g, and the optimal weight of chicken eggs will be 74 g. With such quantities of prescription components of gluten-free flour confectionery, the maximum specific volume of the finished product – a custard semi-finished product – will be 11 cm^3/g. However, in this case, the value of the input variable x_2 also fell outside the range of variation (x_2=–1.97, r=1.98) and, therefore, there is no guarantee that the volume of finished products will actually reach the specified maximum value. Therefore, only suboptimal values can be determined. An example of the implementation of the corresponding optimization procedure can be found in work [38].

It should be noted that corn flour has a different level of amylase activity, which significantly affects the rheology of the dough from this flour. Studies [39] have found that with an increase in the concentration of amylose in corn flour, the temperature at which the starch began to paste increased, and, as a result, the peak viscosity of the mixture decreased markedly. Processing of corn grain into flour does not lead to significant changes in the mass fraction of protein, fat and carbohydrates.

Experiments in this study showed that after kneading, the dough for the custard semi-finished product from pure chickpea flour did not brew, did not form well during baking, and spread. The finished products at the same time had an unstable shape. This was the reason for the need to increase the proportion of corn flour in compositions with processed chickpea flour. For this, dough was brewed with the addition of 20–50 % corn flour.

It is important to emphasize that the qualitative indicators of chickpea flour depend on the content of protein substances that reduce the level of glucose in the blood and increases the feeling of satiety. The composition of gluten-free flour and the recipe determine the texture of the product and organoleptic characteristics. Other factors such as grain grinding methods, flour particle size, and flour processing may also have an impact [14].

According to the results of studies of physicochemical parameters of the custard semi-finished product, it was found that samples with chickpea and corn flour had the highest humidity at their dosage of 50 %. The lowest alkalinity is custard semi-finished products with chickpea flour and corn flour at a dosage of 60 and 40 %, respectively. Samples with 80 % chickpea flour were characterized by the greatest elasticity and density (Table 6).

Analysis of response surfaces describing the specific volume of the finished product – a gluten-free cake (Fig. 2), and equation (7), does not make it possible to establish the optimal formulation since the extremum point is saddle. If one uses chickpea flour in an amount of 75 g, then the masses of rice flour and amaranth flour corresponding to this saddle point are, respectively, 27 g and 4 g. With such quantities of prescription components of gluten-free flour confectionery, the maximum specific volume of finished products – gluten-free cake – will be 20.1 cm^3/g.

Despite the fact that the value of the input variable x_2 slightly fell outside the range of variation (x_2=1.47, r=1.48), it can be assumed that the volume of finished products will approximately correspond to this value.

If one uses chickpea flour in an amount of 80 g, then the masses of rice flour and amaranth flour corresponding to the saddle point are, respectively, 23 g and 4 g. With such quantities of prescription components, the maximum specific volume of finished products – gluten-free cake – will be 20.4 cm^3/g.

If one uses chickpea flour in an amount of 85 g, then the masses of rice flour and amaranth flour corresponding to the saddle point are, respectively, 19 g and 4 g. With such quantities of prescription components, the maximum specific volume of finished products – gluten-free cake – will be 20.5 cm^3/g.

In all these cases, the maximum yield value is not reached, although it can be seen that the amount of rice flour should be reduced with a constant amount of amaranth flour. A suboptimal solution can be obtained using ridge analysis [40], which converts the description of the response surface into a parametric form, followed by the construction of nomograms, which are sets of suboptimal values of input variables $x_2=\phi_1(x_3)$ or $x_3=\phi_2(x_2)$ [41, 42]. This will make it possible the formulation sets to be defined (C; R; A), providing the maximum value of the specific volume of the finished product – a gluten-free cake achieved at the boundaries of the experimental planning area (r=1.414), or at least its acceptable values. The latter may be due, for example, to the technical conditions of the technological process.

Rice flour contains a large amount of amylose, which gives muffins a porous crumb texture, and amaranth flour gives elastic-elastic characteristics due to a large amount of starch, protein, and fiber (Table 5).

Due to the inclusion of chickpea flour in the composition of gluten-free flour confectionery products, the nutritional and biological value of the finished product increases. This is confirmed by the comparative chemical analysis of the developed product with the control sample. Due to the chemical composition (Table 8) of chickpea flour, namely the content in it of a large amount of protein (1.3 times), fat (1.2 times) and vitamin composition (Table 9), the results exceed the indicators over the control option. This indicates the prospects for the development and introduction to the consumer market of new gluten-free flour confectionery products with increased nutritional and biological value.

The results of studies on changes in microbiological quality indicators (Table 10) and determination of the optimal shelf life of the developed products are confirmed by studies on the acid number in fat (FAN) – Fig. 10. It was established that the prototypes had a longer shelf life compared to the control sample. This is due to the fact that ultra-high-frequency processed chickpea flour is used in the recipes of flour confectionery products. When stored at a temperature of plus 18–20 °C, the relative humidity of the air of 65 % for 3 months, FAN in samples of cupcake and custard semi-finished product from ultra-high-frequency processed chickpea flour increased from 19.0–28.9 to 29.9–32.6 mg KOH per 1 g of fat.

The limitations of the study are related to the chosen area of experiment planning. In fact, the results obtained are adequate within the boundaries of the selected ranges of variation, forming in the normalized k-dimensional space (k=3) a $r=\sqrt{3}=1.732$ radius ball or a circle of radius $r=\sqrt{2}=1.414$ when moving to the (k–1)-dimensional factor space by fixing the mass of chickpea flour at three constant levels. In order to find the best options for optimizing the formulation according to criterion $Y_1\rightarrow$max, it is necessary to go beyond these boundaries, which requires additional experimental studies. To find the best options for optimizing the prescription composition according to criterion $Y_2\rightarrow$max, it is necessary to conduct a ridge analysis with the identification of yield values at the boundaries of the planning area described by condition r=1.414 for the (k–1)-dimensional factor space. This may determine the direction of further development of the study, the results of which may provide better decisions regarding the choice of recipe for gluten-free flour confectionery.

7. Conclusions

1. It has been established that by selecting the optimal ratio of chickpea flour, corn flour, and chicken eggs, the specific volume of finished products – custard semi-finished products – provided at the level of 10.34 cm^3/g. Such a maximum is achieved with the following values of the input variables of the process: the mass of chickpea flour is 70 g, the mass of corn flour is 77 g, the mass of chicken eggs is 149 g.

The specific volume of the finished product – a gluten-free cake – can be guaranteed at the level of (20.1–20.5) cm^3/g but this value does not correspond to the maximum yield. This is due to the fact that on the response surface of the output variable in the studied range of input variables there is a saddle point. The specified values of the output variable are achieved with the following approximate values of the input variables: chickpea flour in the amount of (75–85) g, rice flour in the amount (27–19) g, respectively, the mass of amaranth flour is about 4 g. This means that there is a reserve to increase the yield, ensuring the fulfillment of the criterion $Y_2 \rightarrow$max.

The use of the resulting recipe is possible in the proposed technological schemes for the production of cupcake and custard semi-finished products.

2. Based on the analysis of the nutritional and biological value of the products, it was found that when processed chickpea flour was introduced into the cupcake formulation, the amount of the limiting amino acid lysine increased by 1.08 times compared to unprocessed chickpea flour. In the custard semi-finished product, the amount of the limiting amino acid arginine increased by 1.97 times compared to unprocessed chickpea flour. The biological value of enriched cake and custard semi-finished product on average exceeds the control sample by 1.5 times.

3. The influence of chickpea flour on microbiological indicators and shelf life of flour confectionery products has been established. A new type of enriched flour confectionery can be stored without changing the quality indicators for up to 3 months, which exceeds the same indicator of the control sample. The results of the determination of safety indicators indicate the sanitary and hygienic safety of the developed gluten-free products.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

Data will be provided upon reasonable request.

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