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IMPROVING THE QUALITY OF CUPCAKES BY OPTIMIZING THE RECIPE USING A MATHEMATICAL MODELING METHOD

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In order to model the process of developing new recipes for muffins from organic raw materials, a mathematical model of the problem has been built. The solution involved using a Microsoft Excel spreadsheet processor and a computer algebra system from the class of automated design systems Mathcad. The object of research is the cupcake "Grechanyk", and the control sample is the cupcake "Stolichny". The following components are proposed to be introduced into the cupcake: buckwheat flour, agave syrup, cane sugar, sesame oil, butter, dried raisins. All raw materials are organic. With the help of modeling the content of food nutrients – amino acids, fatty acids, carbohydrates, and the price of raw materials, a rational formulation of the product has been developed. In the developed cupcake, a comprehensive quality indicator is investigated by qualimetric evaluation. Group quality indicators included organoleptic, physical-chemical, and microbiological indicators. They also include the content of toxic elements, nutritional and energy value. The weighting coefficients of group quality indicators are: 0.15 for organoleptic, physical-chemical, microbiological indicators. The coefficient of weight of the energy value is 0.10; food – 0.20, toxicological elements – 0.25.

The results of the study showed that the integrated quality indicator is 0.82. These correspond to an excellent level of quality. The values of group quality indicators are as follows: organoleptic indicators – 0.14; physical and chemical indicators – 0.11. The content of toxicological elements is 0.22. Microbiological indicators – 0.14. The nutritional value is 0.13. Energy value – 0.09.

The results indicate the relevance of the use of the mathematical apparatus of design. The research results can be used by food industry enterprises to expand the range of products and to optimize the production process in the presence of the specified amount of raw materials

Keywords: muffins from organic raw materials, mathematical modeling, simplex methods, qualimetric evaluation

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1. Introduction

There is a certain issue when designing information systems to solve specific tasks related to food technologies as complex multivariate models. The result is influenced by both the physical-chemical parameters of formulation ingredients and their content in the composition of multicomponent food systems. There is also an impact on these systems of a number of processing parameters (mechanical, thermal, biochemical, etc.) throughout the entire technological cycle of production. That is why mathematical modeling makes it possible to quickly calculate multicomponent recipes. There are cases of application of mathematical modeling in many areas of food research. It is used in the study of the fermentation process, prediction of microbiological spoilage of products [1], the study of hydrolysis processes [2], drying [3], etc. Mathematical modeling has also been widely used in assessing the risks associated with food safety [4]. In particular, during the analysis of chemical risks, as well as the risks associated with the migration of toxic compounds from packaging [5].

In general, the development of new food formulations can be based on the results of tasting assessment and experimental studies. However, the advantage of mathematical modeling of recipes is that it makes it possible to simulate a product with specified parameters.

Given the high demands of consumers for the quality and safety of food products, an important step before the sale of new products is a comprehensive assessment of their quality. Comprehensive quality assessment makes it possible to assess the quality of the product by single, group indicators, and in general. The use of the principles and methods of qualimetry helps expand the possibilities of improving the quality of food [6].

Thus, mathematical modeling of muffin formulations and qualimetric assessment of their quality is a hot topic in the field of food science. The obtained data can be used not only for flour confectionery products but also in other branches of food production.

2. Literature review and problem statement

It is advisable to build a mathematical model for the development of the formulation composition on the basis of regression relationships between the input and output variables of the product. And by using the theory of experiment planning, one can reduce the number of experiments. Moreover, theoretical calculations can find the best ratios of the components of the study and experimentally check the obtained values [7]. A significant number of scientific works tackle mathematical modeling issues. Thus, in [8], with the method of simplex-centroid plans, formulations of functional margarines with a minimum content of trans-isomers have been developed. The processing and analysis of experimental research data was carried out using the Design-Expert 8 package (Stat-Easy Inc., Minneapolis, USA). As a result of mathematical modeling, systems of nonlinear equations describing the factor space of the content of the solid phase at the investigated temperatures for three-component mixtures of margarine fat bases were derived [9]. However, that study concerns the modeling of margarine formulations. Flour confectionery products (FCP) have more components in their composition, so more factors must be taken into account to create their recipes. In addition, studies of mathematical modeling of recipes of multi-vegetable semi-finished products are known [10].

In particular, it is proposed to carry out simulation of cheese formulation by solving the problem of conditional nonlinear optimization with a nonlinear objective function and linear constraints and boundary conditions [11]. In solving this problem, the Newton method was chosen. The solution is implemented using the Pascal 7.1 programming language. But that study describes a rather limited number of factors for modeling new formulations.

There are data on the application of the response surface methodology (RSM) in the modeling of formulations [12]. With the help of multivariate regression analysis, interpretation of the obtained polynomial equations and surface response graphs, it is possible to achieve optimization of bioprocesses in food systems [13]. This procedure is universal and can be applied to different types of food.

The disadvantage of mathematical modeling is the impossibility of taking into account all the criterion indicators of products and their mutually agreed impact on each other. The reason for this is the multicomponent nature of complex food dispersed systems and the complexity of mathematical forecasting of the behavior of these systems in the technological process. To obtain an objective model that characterizes the product according to different groups of properties, it is desirable to use a qualimetric model based on complex indicators of product quality. So, forecasting and planning of quality indicators of a new product is an important stage of research [14]. There are scientific studies on the development of a qualimetric model of quality of flour confectionery [15]. But these data relate only to organoleptic indicators. A comprehensive quality indicator should include both organoleptic and physical-chemical and microbiological indicators. Significant research in this area is described in [16, 17]. In study [16], the structure of qualimetric evaluation of the quality of waffle cakes is proposed. The structure has two levels. At the first level, the quality of waffle cakes is determined by organoleptic, physical-chemical, and microbiological parameters, the content of toxic elements, food, biological and energy value. At the second hierarchical level, quality indicators obtained directly by measuring the properties by the corresponding methods are taken into account. However, when assessing the quality of muffins, greater detail of single quality indicators should be used. Paper [17] proposes the structure of the tree properties of cookies. The structure consists of several levels. At zero, there is a comprehensive indicator of product quality (P0). At the first level, the set of properties is differentiated into groups: organoleptic characteristics (RA), physical-chemical indicators (RV), and chemical composition and energy value (PC). But safety indicators (toxic content and microbiological criteria) are also important. Therefore, the methods of qualimetric evaluation of flour confectionery products need to be improved. This is important when selling new products.

So, mathematical modeling is used to design new products. Scientific sources describe the methods of mathematical modeling of multicomponent vegetable mixtures, and cheeses. However, a limited number of articles consider mathematical modeling of flour confectionery. An important step in the creation of new products is qualimetric evaluation. A lot of research has been done in this direction, but it relates to other flour confectionery products. Qualimetric evaluation of the quality of muffins has its own characteristics, which is associated with the requirements of the standard. This suggests that it is advisable to conduct a study on the qualimetric assessment of the quality of cupcakes developed by using mathematical modeling.

3. The aim and objectives of the study

The purpose of this study is to determine the possibility of improving the quality of muffins by optimizing the recipe by mathematical modeling. This will make it possible to create an effective cupcake technology according to the criterion of competitiveness.

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

– to determine the recipe of the cupcake based on the formalization and solution of the optimization problem of linear programming;

– to carry out a qualimetric assessment of the developed products.

4. The study materials and methods

The object of our research is the recipe of a cupcake based on organic raw materials.

The subject of the study is ways to improve the quality of muffins.

The hypothesis of the study assumes that mathematical modeling of formulations will allow the development of high quality muffins.

Mathematical modeling of recipes was carried out by methods of mathematical programming by constructing a mathematical model, which is an accurate description of an economic problem using a mathematical apparatus.

The construction of the mathematical model included the following stages:

– in the form of some dependence on unknown quantities, the pursued goal is presented (profit from the sale of manufactured products, total costs for the production of muffins). The resulting expression is the objective function, function of the goal, functional or criterion of the effectiveness of this problem;

– the conditions are described that must be imposed on unknown quantities (variables) resulting from the availability of resources and their values, from the need to meet needs, from the conditions of muffin production technology. These conditions are constraints and represent inequalities.

To solve this problem, the tools of the Microsoft Excel spreadsheet processor were used – its capabilities make it possible to quickly find effective solutions to various economic problems, including optimization problems. The problem of compiling a recipe for muffins from organic raw materials, taking into account the limitations of its cost, was solved as a linear programming problem using the superstructure "Solution Finder" ("Data" – "Analysis"), as a calculation of the optimal value, taking into account variables and constraints. Also, to check the correctness of the solution and compare the results obtained, the Mathcad automated design system was used.

In order to conduct a qualimetric assessment of the quality of the finished cupcake, a hierarchical tree of the properties of the cupcake of the first and second levels was built (Fig. 1).

So, the assessment of product quality begins with the definition of properties that most fully characterize its quality. It is for this purpose that the "property tree" was built and the necessary and sufficient properties for assessing the quality of the group of properties were highlighted on it.

Fig. 2 shows the classification of quality indicators of the second level. At this stage, group indicators are classified into single ones. The more single quality indicators will be determined, the more accurately the qualimetric assessment will be carried out.

So, all group quality indicators are detailed into single ones. Organoleptic indicators and nutritional value are most detailed. Since organoleptic indicators are usually the most significant for the consumer, and nutritional value is important in terms of nutritional properties.

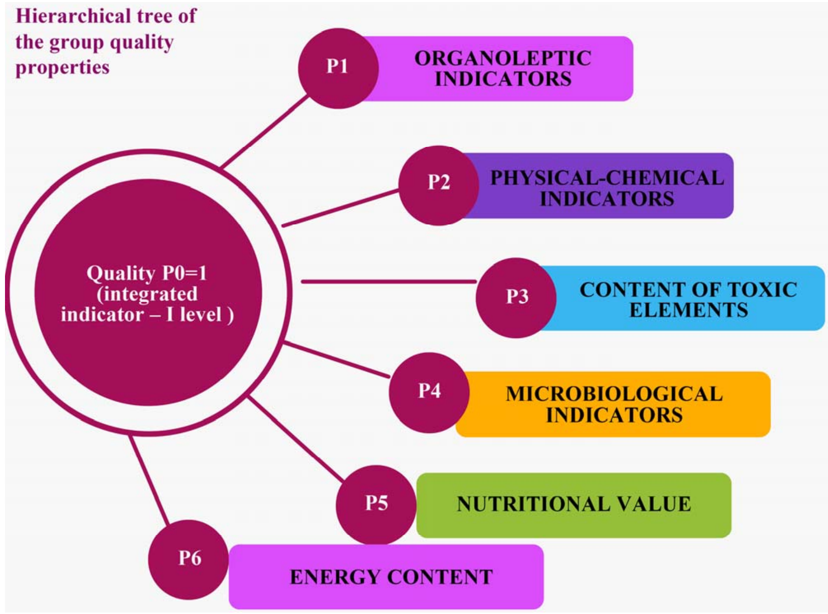

Fig. 1. Hierarchical property tree of muffins of the first level

Fig. 3 shows the scheme for conducting a comprehensive quality assessment by the qualimetric method.

To assess the quality of the cupcake, group indicators were selected:

– physical and chemical indicators (Group P_2);
– content of toxic elements (Group P_3);
– microbiological indicators (Group P_4);
– nutritional value (Group P_5);
– energy value (Group P_6).

The weighting factors of group quality indicators were determined by the expert method, and the assessment was carried out by 7 experts (for each indicator, a score was set from 0 to 1.5). In this case, 1.5 – the indicator is significant; 1.0 – the indicator is not very significant; 0.5 – the indicator is practically not significant; 0 – the indicator is not significant at all. The value of the significance coefficient was calculated by the formula:

$$K_i = \sum P_{ij} / y, \quad (1)$$

where K_i is the weighting factor;

P_{uj} – assessment of the i-th indicator by the y-th expert;

y – number of experts.

The results of the assessment of the weighting factors of group quality indicators are given in Table 1.

Table 1

Results of evaluation of weight coefficients of group quality indicators of organic FCP

Expert No.	Organoleptic parameters (P_1)	Physical and chemical indicators (P_2)	Content of toxic elements (P_3)	Microbiological indicators (P_4)	The nutritional value (P_5)	Energy value (P_6)
1	1.5	0.5	1.5	1.5	1.0	0.5
2	1.0	1.5	1.5	1.5	1.0	1.0
3	1.0	1.0	1.5	1.5	1.5	1.0
4	1.5	1.0	1.01	0.5	1.5	0.5
5	1.0	1.0	1.5	1.5	1.5	1.0
6	1.5	1.0	1.5	0.5	1.0	0.5
7	1.0	1.0	1.5	0.5	0.5	0.5
Sum of points	7.5	7	10	7.5	8	5
Weighting factor	0.71	0.67	0.95	0.71	0.76	0.48

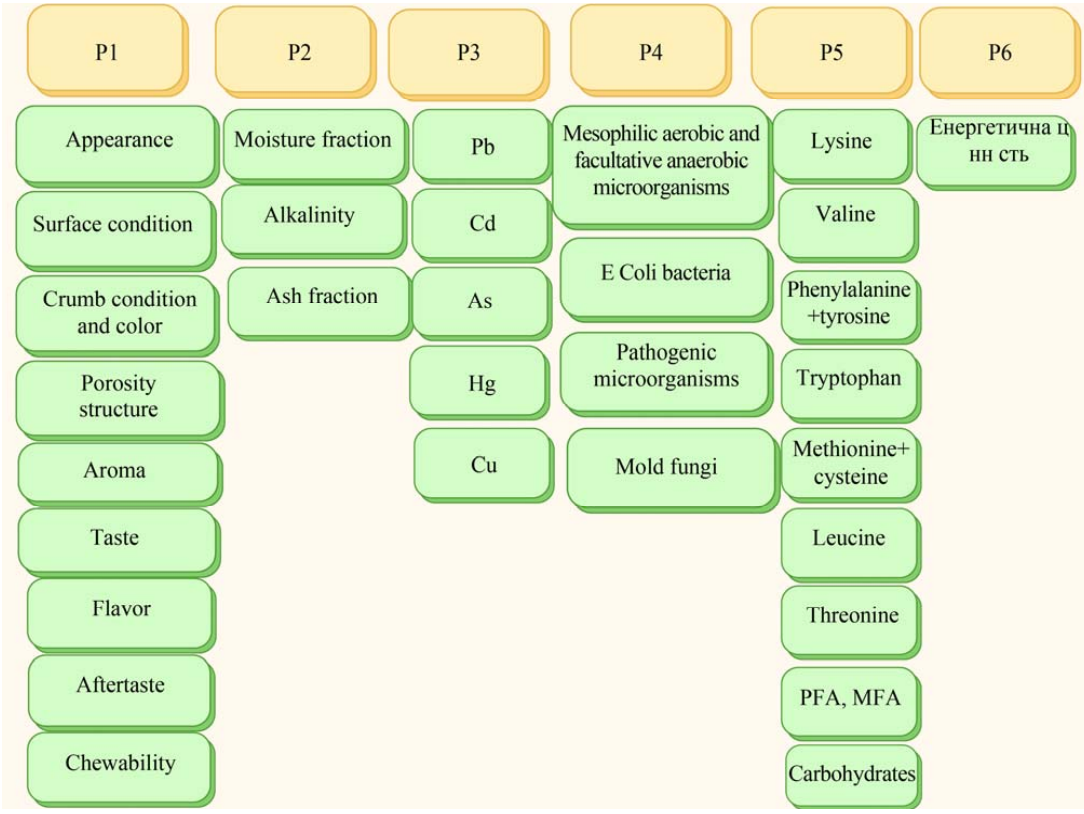

Fig. 2. Hierarchical muffins property tree of the second level

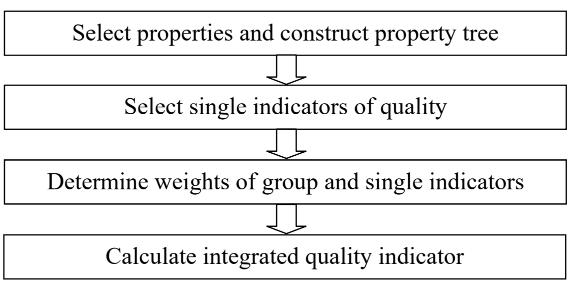

Fig. 3. Scheme of integrated quality assessment

The weighting coefficients of group quality indicators of organic FCP are indicated in Table 2.

Table 2

Weights coefficients of group quality indicators of organic FCP

No.	Name of group quality indicator	The value of the weighting factor (P_i)
1	Organoleptic parameters (Group P_1)	0.15
2	Physical-chemical indicators (Group P_2)	0.15
3	Content of toxic elements (GroupP_3)	0.25
4	Microbiological indicators (Group P_4)	0.15
5	Nutritional value (Group P_5)	0.20
6	Energy value (Group P_6)	0.10

So, we can conclude that experts consider the content of toxic indicators to be the most significant factor in the formation of a comprehensive indicator of the quality of muffins, and in second place is the nutritional value. It is noteworthy that 3 groups of indicators, namely organoleptic, physical-chemical, and microbiological indicators, have the same values of weighting coefficients – 0.15 each.

The actual values of the integrated quality indicator correspond to the following levels:

– from 0 to 0.25 – unsatisfactory quality;
– from 0.25 to 0.50 – satisfactory quality;
– from 0.50 to 0.75 – good quality;
– from 0.75 to 1 – excellent quality.

Among the organoleptic indicators, the following were evaluated: shape, surface condition, crust color, condition and color of the crumb, porosity structure, aroma, taste, flavor, aftertaste, crumb chewability [18].

Physical-chemical indicators were determined in accordance with the developed methods and standards:

– humidity – drying to a constant mass at a temperature of 105 °C according to DSTU 4910:2008. Confectionery products. Methods for determining the mass fraction of moisture and solids [19];

– mass fraction of ash, insoluble in solution with a mass fraction of hydrochloric acid of 10 % – wet ashing of the sample in nitric acid and burning it in an electric furnace according to DSTU 4672:2006. Confectionery products. Methods for determining ash and metal-magnetic impurities [20];

– fat content – according to DSTU 5060:2008. Confectionery products. Methods for determining the mass fraction of fat [21];

– amino acid composition of flour confectionery horns– by the method of ion exchange liquid-column chromatography on the automatic analyzer of amino acids T 339 produced by "Microtechnics" Czech Republic [22];

– amino acid score was determined by the ratio of the amount of the corresponding essential amino acid per 1 g of protein to its regulated content in the "ideal protein" on the FAO/WHO scale [23];

– fatty acid composition of FCP – by the method of gas chromatography on the gas chromatographer HP 6890 [24];

– the calculation of food and energy value in cookies was carried out using the calculation method [25].

Among the microbiological indicators, we identified the following:

– mesophilic aerobic and facultative-anaerobic microorganisms, CFU per 1 g – carried out by calculating colonies that grow on a solid nutrient medium after incubation at a temperature of 30 °C in accordance with DSTU ISO 4833:2006 191 [26];

– bacteria of the group of E. coli (coliforms) – the method of determination is based on the properties of bacteria of the group of intestinal coli (BGKP) to break down glucose and lactose [27];

– pathogenic microorganisms, including bacteria of the genus Salmonella – a method for detecting bacteria of the genus Salmonella in food products is based on the detection of characteristic colony growth on agarized differential diagnostic media, which have biochemical and serological properties typical of bacteria of the genus Salmonella in accordance with DSTU EN 12824:2004 193 [28].

To study the content of toxic elements in raw materials and FCP, generally accepted methods were used: copper, zinc, lead, and cadmium were determined by the atomic absorption method, arsenic – by the colorimetric method, mercury – by flameless atomic absorption [28].

5. Results of the study of qualimetric quality assessment of muffins developed using mathematical modeling of recipes

5. 1. Determining the cupcake recipe based on formalization and solution of the optimization problem of linear programming

To develop a cupcake recipe based on organic raw materials, modeling of the content of food ingredients in it is proposed (Table 3).

Based on the data in Table 3, the construction of a mathematical model of the problem to create a rational recipe for muffins was considered. If you enter the designation x_i, i=1,...,9 – the amount of the ingredient of the i-th type (grams) in the recipe of the confectionery, then the cost of 1 kg of the product will take the form (determined by the function):

Restrictions on the content of amino acids in the formulation of a confectionery product (per 100 g) are as follows:

$$F(x_1,x_2,x_3,x_4,x_5,x_6,x_7,x_8,x_9)= =\frac{78x_1+30x_2+685x_3+150x_4+400x_5+349x_6+80x_7+240x_8+80x_9}{1000}. \quad (2)$$

$$\frac{1.35x_1+0.01x_2+1.2x_4+0.02x_6+5.5x_8+1.2x_9}{100}\geq 5.5, \quad (3)$$

$$\frac{0.71x_1+0.9x_4+10x_8+0.9x_9}{100}\geq 4.4, \quad (4)$$

$$\frac{1.5x_1+1.1x_4+5x_8+1.1x_9}{100}\geq 5, \quad (5)$$

$$\frac{3x_1+0.1x_2+1.4x_4+0.05x_6+0.01x_7+6x_8+1.4x_9}{100}\geq 6, \quad (6)$$

$$\frac{0.5x_1+0.01x_2+1.2x_4+0.01x_7+3.5x_8+1.2x_9}{100}\geq 3.5, \quad (7)$$

$$\frac{2.5x_1+0.04x_2+2.8x_4+0.03x_6+0.01x_7+7x_8+2.8x_9}{100}\geq \geq 7, \quad (8)$$

$$\frac{1.5x_1+1.2x_4+4x_8+1.2x_9}{100}\geq 4, \quad (9)$$

$$\frac{0.9x_1+7.8x_4+19.5x_5+1.4x_6+0.07x_7+0.7x_9}{100}\geq 3.35, \quad (10)$$

$$\frac{0.7x_1+5.4x_4+12.8x_5+0.9x_6+0.8x_7+0.7x_9}{100}\geq 3.35. \quad (11)$$

Restrictions on the content of ingredients:

– buckwheat flour

$$200\leq x_1\leq 400; \quad (12)$$

– cane sugar

$$100\leq x_2\leq 200; \quad (13)$$

– butter

$$200\leq x_4\leq 300; \quad (14)$$

– sesame oil

$$20\leq x_5\leq 50. \quad (15)$$

The content of all ingredients in the confectionery recipe corresponds to the ratio:

$$x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8+x_1=1000, \quad (16)$$

$$x_i\geq 0,\ i=1...9. \quad (17)$$

Table 3

Modeling the cupcake formulation according to the content of food nutrients

Raw materials	Lysine	Isoleucine	Valine	Phenylalanine	Methionine	Leucine	Threonine	Polyunsaturated fatty acids	Monounsaturated fatty acids	Price of 1 kg of raw materials
Buckwheat flour	1.35	0.70	1.50	3.00	0.50	2.50	1.50	0.90	0.70	78.00
Cane sugar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.00
Agave syrup	0.01	0.00	0.00	0.10	0.01	0.04	0.00	0.00	0.00	685.0
Butter	1.20	0.90	1.10	1.40	1.20	2.80	1.20	7.80	5.40	150.0
Sesame oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.50	12.8	400.0
Dried physalis	0.02	0.00	0.00	0.05	0.00	0.03	0.00	1.40	0.90	349.0
Dried raisins	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.07	0.80	80.00
Mélange	5.50	10.00	5.00	6.00	3.50	7.00	4.00	0.00	0.00	240.0
Flax bran	1.20	0.90	1.10	1.40	1.20	2.80	1.20	0.70	0.70	80.00

The mathematical model of the problem takes the form: find the minimum value of the objective function:

$$F(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9) \rightarrow \min,$$

where $F(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9)$ is determined by (2) taking into account the constraints (3) to (17), that is, determine the vector $X(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9)$ whose coordinates minimize the objective function (2) and satisfy the constraints (3) to (17).

The problem of optimizing the content of ingredients in the projected confectionery is to determine the vector $X=(x_1, x_2, ..., x_9)$, which maximizes the objective function, provided that the coordinates of this vector satisfy the systems of inequalities and equations. The solution to the problem, obtained in the Mathcad system, is shown in Fig. 4.

It is worth noting that mathematical modeling does not always serve for the final selection of formulation components. An important step is also the tasting assessment of the developed products. That is why the content of some ingredients has been adjusted based on the results of organoleptic studies. In particular, the amount of raisins was increased, and a small amount of agave syrup was added. According to the results of organoleptic evaluation, it was found that agave syrup, even in small quantities, significantly improves the taste of the product.

So, the cupcake recipe will take the form given in Table 4.

Table 4

Cupcake recipe developed on the basis of mathematical modeling

Raw materials	Consumption, g/kg
Buckwheat flour	400.00
Cane sugar	200.00
Agave syrup	0.10
Butter	200.00
Sesame oil	20.00
Dried raisins	10.00
Melange	180.00
Baking powder	0.10
Kitchen salt	0.10

Thus, it can be argued that with the help of mathematical modeling an optimized cupcake recipe has been developed in terms of its composition. However, to determine the quality of the developed cupcake, it is necessary to carry out a qualimetric assessment. This will make it possible to objectively evaluate the complex indicator of product quality.

$$F(x1, x2, x3, x4, x5, x6, x7, x8, x9) := \left[\frac{(78\cdot x1 + 30\cdot x2 + 685\cdot x3 + 150\cdot x4 + 400\cdot x5 + 349\cdot x6 + 80\cdot x7 + 240\cdot x8 + 80\cdot x9)}{1000}\right]$$

$x1 := 0 \quad x2 := 0 \quad x3 := 0 \quad x4 := 0 \quad x5 := 0 \quad x6 := 0 \quad x7 := 0 \quad x8 := 0 \quad x9 := 0$

Given

$$\frac{(1.35\cdot x1 + 0\cdot x2 + 0.01\cdot x3 + 1.2\cdot x4 + 0\cdot x5 + 0.02\cdot x6 + 5.5\cdot x8 + 1.2\cdot x9)}{100} > 5.5$$

$$\frac{(1.5\cdot x1 + 0\cdot x2 + 1.1\cdot x4 + 0\cdot x5 + 5\cdot x8 + 1.1\cdot x9)}{100} > 5$$

$$\frac{(0.7\cdot x1 + 0.9\cdot x4 + 10\cdot x8 + 0.9\cdot x9)}{100} > 4.4$$

$$\frac{(0.5\cdot x1 + 0.01\cdot x3 + 1.2\cdot x4 + 0.01\cdot x7 + 3.5\cdot x8 + 1.2\cdot x9)}{100} > 3.5$$

$$\frac{(3x1 + 0.1\cdot x3 + 1.4\cdot x4 + 0.05\cdot x6 + 0.01\cdot x7 + 6\cdot x8 + 1.4\cdot x9)}{100} > 6$$

$$\frac{(1.5\cdot x1 + 1.2\cdot x4 + 4\cdot x8 + 1.2\cdot x9)}{100} > 4$$

$$\frac{(2.5\cdot x1 + 0.04\cdot x3 + 2.8\cdot x4 + 0.03\cdot x6 + 0.01\cdot x7 + 7\cdot x8 + 2.8\cdot x9)}{100} > 7$$

$$\frac{(0.7\cdot x1 + 5.4\cdot x4 + 12.8\cdot x5 + 0.9\cdot x6 + 0.8\cdot x7 + 0.7\cdot x9)}{100} > 3.3$$

$$\frac{(0.9x1 + 7.8\cdot x4 + 19.5\cdot x5 + 1.4\cdot x6 + 0.07\cdot x7 + 0.7\cdot x9)}{100} > 3.35$$

$$x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8 + x9 = 1000$$

$x1 \ge 200 \quad x1 \le 400 \quad x3 \ge 0 \quad x6 \ge 0 \quad x7 \ge 0 \quad x8 \ge 0 \quad x9 \ge 0$

$x2 \ge 100 \quad x2 \le 200$

$x4 \ge 200 \quad x4 < 300$

$x5 \ge 20 \quad x5 \le 50$

$Z := \text{Minimize}(F, x1, x2, x3, x4, x5, x6, x7, x8, x9)$

$$Z = \begin{pmatrix} 400 \\ 200 \\ 0 \\ 200 \\ 20 \\ 0 \\ 180 \\ 1.776 \times 10^{-15} \\ 0 \end{pmatrix}$$

$F(Z) = 89.6$

Fig. 4. Solution to the problem in the Mathcad system

5. 2. Qualimetric quality assessment

In order to carry out a qualimetric assessment of products, reference indicators were selected that served as basic values. For organoleptic group indicators, the base values are points in accordance with the scale for assessing the quality of cupcakes devised in [18]. Physical-chemical indicators and safety indicators were normalized in accordance with the approved standard. Requirements for the content of essential amino acids were equal to the reference indicators of protein on the FAO/WHO scale. Requirements for the content of unsaturated fatty acids were determined according to the "ideal lipid". The basic value of the energy value was the caloric content of the control sample.

The results of assessing the quality of single product indicators are given in Table 5.

Thus, single indicators of the developed cupcake are determined. The product has a rather high organoleptic characteristics, as well as a low content of toxic elements and microbiological contaminants.

Table 6 gives the values of group quality indicators.

Table 5

Results of evaluation of single indicators of cupcake quality

Group of indicators	Name of the indicator	Base value	The coefficient of weight of a single quality indicator	The resulting value	The value of a single quality indicator, taking into account the coefficient of weight
P_1	Appearance	5 points	0.1	5.00	0.10
	Surface condition	5 points	0.1	4.50	0.09
	Color of the crust	5 points	0.1	4.60	0.09
	The condition and color of the crumb	5 points	0.05	4.90	0.05
	Porosity structure	5 points	0.05	4.90	0.05
	Aroma	5 points	0.15	4.90	0.15
	Taste	5 points	0.15	4.90	0.15
	Flavor	5 points	0.1	4.80	0.10
	Aftertaste	5 points	0.1	4.60	0.09
	Crumb chewability	5 points	0.1	5.00	0.10
P_2	Mass fraction of moisture, %	10–31	0.25	21.00	0.20
	Alkalinity in terms of dry matter, in degrees, not more than	2.0	0.25	1.60	0.24
	Mass fraction of ash, undissolved in solution with a mass fraction of hydrochloric acid 10%, in % not more than	0.1	0.25	0.07	0.28
P_3	Lead	0.5	0.2	0.00	0.00
	Cadmium	0.1	0.2	0.00	0.00
	Arsenic	0.3	0.2	0.00	0.00
	Mercury	0.02	0.2	0.01	0.10
	Copper	10.00	0.2	1.60	0.02
P_4	Mesophilic aerobic and facultative anaerobic microorganisms	5000 CFU in 1 g	0.25	1800.00	0.09
	Bacteria of the E. coli group	0.1 mass of the product, which is not allowed	0.25	0.00	0.00
	Pathogenic microorganisms (bacteria of the genus Salmonella)	25 mass of product g/cm^3, which is not allowed	0.25	0.00	0.00
	Mold fungi	0 CFU in 1 g	0.25	0.00	0.00
P_5	Lysine content	5.5 g/100 g	0.2	1.25	0.02
	Isoleucine content	4.0 g/100 g	0.1	1.35	0.03
	Valine content	5.0 g/100 g	0.1	2.35	0.05
	The content of phenylalanine + +tyrosine	6.0 g/100 g	0.09	1.95	0.03
	Tryptophan content	1.0 g/100 g	0.11	2.00	0.20
	Content of methionine + cystine	3.5 g/100 g	0.15	1.11	0.03
	Leucine content	7.0 g/100 g	0.1	2.50	0.04
	Threonine content	4.0 g/100 g	0.15	1.45	0.04
	The content of monosaturated fatty acids	33.5 %	0.1	40.77	0.06
	Content of polyunsaturated fatty acids	33.5 %	0.45	27.60	0.08
	Carbohydrate content	72.8 g/100 g	0.3	47.80	0.04
P_6	Energy value	415.0 kcal/100 g of product	1	358.50	0.88

Table 6

Values of group quality indicators of the developed cupcake

Group indicator	The resulting value	Reference value
Organoleptic indicators (Group P_1)	0.14	0.15
Physical-chemical indicators (Group P_2)	0.11	0.15
Content of toxic elements (Group P_3)	0.22	0.25
Microbiological indicators (Group P_4)	0.14	0.15
Nutritional value (Group P_5)	0.13	0.20
Energy value (Group P_6)	0.09	0.10
Integrated quality indicator	0.82	1.00

Thus, the developed product has a high value of organoleptic indicators, energy value, and is also quite safe in terms of microbiological and toxicological indicators. For a clearer understanding of the level of quality according to group indicators, a profilogram is constructed (Fig. 5).

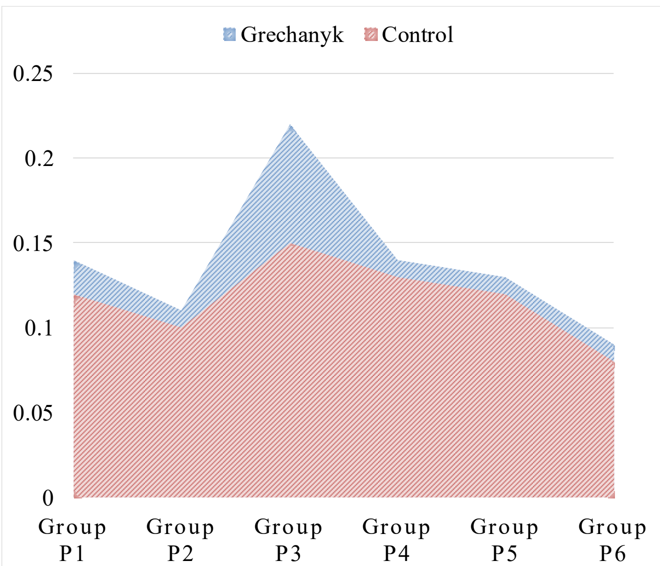

Fig. 5. Profilogram of group quality indicators of the developed cupcake

So, according to the results of a qualimetric assessment, the comprehensive quality indicator is 0.82. This indicator corresponds to the level of excellent quality. As evidenced by data in Fig. 5, group indicators are close in their values to the reference. The best are organoleptic indicators.

6. Discussion of results of the study of qualimetric quality assessment of muffins developed using mathematical modeling of the recipe

On the basis of research data, a model of the problem was built in the form of a linear programming problem. It was solved using a Microsoft Excel spreadsheet processor and a computer algebra system from the class of automated design systems Mathcad (Fig. 3). An important factor is the research and comparison of the results of solving this problem. The solutions in MS Excel and Mathcad coincide, and therefore we can talk about the reliability of the results. The obtained solutions differed from the studies where the methods of objective [29] and linear programming [30] were used. This proves that for modeling recipes, it is important not only to build the problem but also to correctly select ingredients and to study their chemical composition in advance.

The results of a qualimetric assessment of the quality of muffins (Table 5) confirm the hypothesis that the method of mathematical modeling makes it possible to design high-quality flour confectionery products. It was established that the integrated quality indicator is 0.82. This indicator corresponds to the level of excellent quality. And group indicators in their values are close to the reference. All this indicates the high quality of the developed products. However, there are certain limitations for applying the obtained data in practice. In particular, different ingredients should be used to model products and their cost should be taken into account.

The disadvantage of the study is the limited scientific data only by modeling muffin formulations. Flour confectionery products have a much wider range. The obtained results can serve not only to develop a new range but also to optimize the work of bakeries. Further research is planned to be directed to mathematical modeling of recipes of other flour products: cookies, muffins, waffles, etc. Studies are planned in this area since the data obtained have proven the effectiveness of mathematical modeling in the development of new recipes for flour products.

7. Conclusions

1. The recipe of the cupcake as a solution to the problem of linear programming is determined. The solution of the problem was carried out using a Microsoft Excel spreadsheet processor and a computer algebra system from the class of automated design systems Mathcad. The following components are proposed to be introduced into the cupcake: buckwheat flour, agave syrup, cane sugar, sesame oil, butter, dried raisins. With the help of modeling the content of food nutrients – amino acids, fatty acids, carbohydrates, and the price of raw materials, a rational formulation of the product has been developed. Thus, the content of raw materials in the proposed muffin was as follows: buckwheat flour, 400 g/kg; cane sugar, 200 g/kg; butter, 200 g/kg. It is also proposed to introduce sesame oil to the recipe – 20 g/kg, agave syrup, and mélange.

2. In the developed cupcake, a comprehensive quality indicator was investigated using a qualimetric assessment. The results of the study showed that the integrated quality indicator is 0.82. These correspond to an excellent level of quality. The values of group quality indicators are as follows: organoleptic indicators – 0.14; physical and chemical indicators – 0.11. The content of toxicological elements is 0.22. Microbological indications – 0.14. Nutritional value – 0.13. Energy value – 0.09. Based on these data, a profilogram of group quality indicators was constructed.

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Conflicts of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

All data are available in the main text of the manuscript.

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