UDC 637.523
DOI: 10.15587/1729-4061.2025.330486

IDENTIFYING OPPORTUNITIES TO IMPROVE QUALITY OF COOKED SAUSAGES BY OPTIMIZING THEIR RECIPES

Gulbagi Orymbetova
Corresponding author
PhD, Associate Professor*
E-mail: orim_77@mail.ru
Makhabat Kassymova
PhD, Professor
Department of Food Engineering**
Emit Orymbetov
PhD, Associate Professor*
Zhansaya Abish
Doctoral Student
Department of Technology and Food Safety**
*Department of Engineering Disciplines
South Kazakhstan Medical Academy
Al-Farabi sq., 1, Shymkent, Republic of Kazakhstan, 160001
**Mukhtar Auezov South Kazakhstan University
Tauke Khan ave., 5, Shymkent,
Republic of Kazakhstan, 160012

The object of the study is recipe for sausage products with addition of pea flour. The problem being solved is to create meat products with an optimal composition and quality with improved organoleptic nutritional characteristics while maintaining safety and technological effectiveness of product.

During study, a mathematical model for optimizing recipe was constructed using the linear programming method, and qualimetric assessment of the quality of final product was carried out. The optimal composition of sausage products consists of the following: beef – 820 g/kg; lamb fat – 80 g/kg; pea flour–53.35 g/kg; table salt – 1.5 g/kg; sodium nitrite – 0.002 g/kg; ground black pepper–0.1 g/kg; starch – 45 g/kg; sugar – 0.15 g/kg. The results of the study showed that complex quality indicator is 0.88. It corresponds to the best indicator of quality of finished products. The values of group quality indicators of cooked sausages are as follows: organoleptic indicators – 0.14; physicochemical indicators – 0.14, safety indicators – 0.36, nutritional value – 0.15, energy value – 0.09.

By using these approaches to selecting ingredients and their quantitative ratios, it was possible to achieve balance in amino acid and fat composition, reduce cost price and improve organoleptic characteristics of the product. These results are explained by use of a set of methods of mathematical modeling and organoleptic correction of the recipe based on tasting assessment. Using pea flour reduces raw material costs, it would be appropriate to use it as an alternative to meat. The data obtained can be used in practice in development of functional meat products, especially in context of the need to increase nutritional value, safety and competitiveness of products

Keywords: sausage products, mathematical modeling, simplex methods, qualimetric evaluation, recipe optimization

Received 16.04.2025
Received in revised form 20.06.2025
Accepted date 02.07.2025
Published date 26.08.2025

How to Cite: *Orymbetova, G., Kassymova, M., Orymbetov E., Abish, Z. (2025). Identifying opportunities to improve quality of cooked sausages by optimizing their recipes. Eastern-European Journal of Enterprise Technologies, 4 (11 (136)), 82–89. https://doi.org/10.15587/1729-4061.2025.330486*

1. Introduction

The creation of new food products with specified consumer properties is relevant. In conditions where the recipe of any food product depends on many factors, such as composition and properties of raw materials, technological parameters, nutritional value, organoleptic and physicochemical properties, also cost price – use of mathematical modeling allows for a systematic and rapid analysis of possible combinations of ingredients. Using linear programming, it is possible to quickly calculate optimal composition of product that meets specified criteria, which helps reduce volume of experiments, reduces development costs and accelerates process of introducing new products.

Currently, methods of mathematical modeling are widely used in the food industry, allowing for calculation of the balance of food products [1]. The use of forecasting using mathematical methods allows to increase production efficiency and reduce costs, optimize the recipe for manufactured products, facilitate the introduction of new technologies, improve product quality indicators, determine the shelf life of finished products, and increase customer satisfaction. Based on the results obtained, optimal ratios are selected that correspond to the main quality indicators of the finished product.

Many authors widely use mathematical model methods in food research. It is used in research into the prediction of the growth of microbiological contamination [2], drying processes [3], in the development of food products with increased nutritional value [4], food safety [5], pasteurization of food products [6], etc.

The use of a mathematical model will allow for the precise determination of the combination of ingredients and processing modes, which will accordingly reduce the number of experimental samples. In this context, it is important to note that the use of a mathematical model helps to ensure the prediction of precise characteristics with specified properties.

Due to high consumer demand for the quality of manufactured products, competitiveness has increased many times over. Improvement of quality indicators (physicochemical, organoleptic, etc.) according to specified criteria and limitations can be effectively and efficiently achieved by optimizing recipe and computer modeling. Thus, mathematical modeling of the cooked sausage recipe and evaluation of quality indicators are topical issue in the field of food science.

2. Literature review and problem statement

The paper [4] presents the results of research recipes for muffins with use of Microsoft Excel and automated design Mathcad. However, this paper deals with the modeling of flour confectionery products. The use of these methods became the basis for further research into other products, namely meat products.

The study was aimed at optimizing thermochemical and biological transformations occurring during heat treatment of food products. The work is devoted to the development of mathematical model of Sous-Vide process of processing functional food products based on animal and plant raw materials. Issues related to complex effect of temperature conditions on quality and biochemical properties of product remain unexplored. The study is focused on solving heat transfer problem – modeling temperature fields based on differential equation of non-stationary thermal conductivity, taking into account Bio criterion. The model does not evaluate how thermal dynamics affects organoleptic indicators: taste, aroma, appearance of the product – parameters that determine consumer value [7].

In paper [8], an increase in profit from problem of red meat production using fuzzy linear programming with a single-objective function is shown. However, in this work only the economic factor of production is taken into account.

The study [9] presents mathematical modeling for a specific process of mixing minced meat in a vibration-mechanical machine, which allows for comprehensive consideration of the patterns of change in the main parameters of the vibration process. The study is mainly aimed at optimizing amplitude-force characteristics and energy costs. However, it does not consider complex multi-criteria optimization, including product quality, cost price, organoleptic and microbiological indicators.

In paper [10] propose a study of sausage mince extrusion using mathematical model as the most common in qualimetry, used to combine quality assessments into a complex indicator. Optimal ranges of values that affect the physicochemical, microbiological and organoleptic indicators of the finished product are determined. However, the study does not show influence of the mince composition (ratio of fat, meat, moisture-retaining components, protein additives, etc.) on the extrusion characteristics. No quantitative analysis or modeling of sanitary and hygienic indicators is presented. This is due to the fact that methodology was aimed at studying physical-mechanical and technological factors.

In work [11], results of calculations by experimental-statistical methods using optimized content of components in recipes “Puff buns” and “Grain bars” are presented. The main emphasis is on the efficient use of plant materials and expansion of range of functional food products. The recipe was optimized for limited number of factors, mainly quantitative composition of ingredients. However, the analysis of taste characteristics, appearance and aroma of final products was not studied. The economic efficiency was not assessed. A qualimetric model that would allow comprehensive quality of the product to be assessed in numerical terms was not included.

The paper [12] presents the specifics of quality management of minced meat semi-finished products using qualimetric forecasting model. A matrix of consumer preferences is proposed, which allows calculating the optimal content of particular component in a product. However, rather limited number of factors for modeling new recipes are described.

The paper [13] presents a comparative assessment of the quality and safety of canned meat from different manufacturers in modern types of combined and polymer packaging materials using the qualimetry method. Using the qualimetric model, a rating of the quality of canned food from different manufacturers was compiled taking into account organoleptic, physicochemical indicators, storage capacity indicators and nutritional value. The following issues remained unexplored in the work, such as analysis of migration of packaging components to products, consumer and ergonomic evaluation of packaging, resistance of packaging materials to logistical loads. The reason for lack of study of the problem is related to focus of the study on qualimetric comparative assessment.

Forecasting and planning important performance criteria for a new product is an important stage of research [14]. The presented study is aimed at applying qualimetric assessment for developing a recipe composition of combined snack products from plant raw materials. The work is focused on the basis of food, organoleptic and textural characteristics. However, despite practical value of the proposed model, study has following unexplored aspects: effect of dehydration parameters on product quality, cost-effectiveness of the recipe. The reasons for not considering these aspects are associated with target focus of the study on the development and testing of qualimetric model in a narrow technological context.

In the work [15] rational ranges of values influencing physicochemical, microbiological and organoleptic indicators of finished sausage products were established. However, when assessing quality of sausage products, more detailed studies should be used to guarantee high quality of products. In the work [16] principles of qualimetric assessment of the quality of semi-finished meat products from horse meat were proposed. Organoleptic indicators, biological and nutritional value, determined the quality of semi-finished meat products. However, following aspects need to be supplemented in the work: physical and chemical indicators of finished products, microbiological safety, implementation of multi-criteria mathematical optimization. The study focuses on qualimetry as forecasting tool.

All this suggests that it is advisable to conduct a study on the use of mathematical modeling and qualimetric assessment of the quality of cooked sausage products with the addition of pea flour at the stage of development and design of new products, ensuring high competitiveness and consumer satisfaction of the products.

3. The aim and objectives of the study

The aim of this study is to identify opportunities to improve quality of cooked sausages by optimizing their recipes using mathematical modeling. This is aimed at developing an effective technology for production of cooked sausages, taking into account competitive advantages.

To achieve this aim, the following objectives are accomplished:

– to determine optimal recipe for cooked sausage with added pea flour;

– to conduct a qualitative assessment of cooked sausage with added pea flour.

4. Materials and methods

The object of the study is recipe for cooked sausage. The subject of the research is methods for improving quality of cooked sausage by combining plant and animal raw materials in the recipe.

The research hypothesis suggests that creation of a new recipe for sausage products using mathematical modeling will allow development of food product with an optimal ratio of ingredients in the recipe.

Mathematical modeling of recipes was carried out using mathematical programming methods – the Mathcad automated design system.

The development of a mathematical model consists of the following sections:

– dependence on unknown quantities is presented (total costs for the production of cooked sausage);

– conditions are set that must be presented in the form of unknown quantities, which consist of available resources and their values to satisfy needs, conditions of technology of production of cooked sausage. These conditions are represented by restrictions and inequalities.

To carry out qualimetric assessment of the quality of sausage products, following is required [16]:

– establish a list of complex and individual indicators characterizing quality of products;

– build a hierarchical tree of properties;

– select scale that takes into account different dimensions of values of individual properties of products;

– select methods for determining and calculate weighting factors of complex and individual quality indicators at each level of the property tree;

– depending on the goals of constructing qualimetric model, develop method for calculating generalized, complex or integral indicator of product quality.

First, it is necessary to identify indicators by which it is possible to assess the quality of the products. The main groups of indicators are shown in Table 1. Among them, the organoleptic indicators were described in the most detail, since they are more significant for consumers.

Table 1

Main characteristics of cooked sausage

Organoleptic (A)	Taste
	Smell
	Appearance
	Consistency
	Color and cross-sectional view
Physicochemical (B)	Mass fraction of fat
	Protein mass fraction
	Mass fraction of sodium chloride (table salt)
	Mass fraction of starch
Safety indicators (microbiological and chemical hazards) (C)	Toxic elements:
	Lead
	Cadmium
	Arsenic
	Mercury
	Microbiological indicators:
	NMAFAM
	Coliform bacteria
Nutritional value (D)	Amino acid and fatty acid composition
Energy value (E)	–

A group of 8 experts was formed to assess the quality of sausage products. The experts carried out the assessment, filled out table according to the quality indicators of the samples, in accordance with 5-point scale (5-excellent, 4-good, 3-average, 2-unsatisfactory, 1-very bad). The value of relative quality indicator of product being assessed was calculated using the formula

$$K_i = \sum_{i=1}^{n} \frac{P_{ji}}{P_{.b}},$$

where K_i – weight coefficient; P_{ji} – assessment of the i-th product indicator; P_b – base product evaluation indicator.

Physicochemical, safety indicators (microbiological and chemical hazards) were determined according to regulatory documents. Energy value was determined by calculation.

5. Results of the study of quality indicators of sausage products using mathematical modeling of recipes

5. 1. Determination optimal recipe for cooked sausage with added pea flour

Modeling of the content of food nutrients in sausage products has been proposed for developing recipes (Table 2).

Based on the data in Table 2, the construction of a mathematical model for creating the optimal content of ingredients for sausage products is considered. If enter designation x_i, i=1, …, 8 – quantity of ingredient of the i-th type (grams) in the recipe for sausage products.

Content of all ingredients in the recipe for sausage products corresponds to the ratio:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 = 1{,}000,$$

$$x_i \geq 0, \quad i = 1...8.$$

The mathematical model of the problem takes the form, when it is possible to find the minimum value of the objective function

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

where $F(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8)$ is determined by the formula taking into account the limitations shown in Fig. 1.

To optimize the content of ingredients in a designed sausage product with pea flour consists of the following $X=(x_1, x_2, ..., x_8)$, maximizing the objective function. In this case, the coordinates of the above vector must satisfy systems of inequalities and equations. The solution to the presented problem obtained in the Mathcad system is shown in Fig. 1.

It is important to note that mathematical modeling is not always used to finally determine the components of a formulation.

Tasting evaluation of the developed products is also an important stage. Therefore, the content of some ingredients was adjusted in accordance with the results of organoleptic studies. In particular, the amount of ground black pepper was increased and a small amount of sodium nitrite was added. According to the results of the organoleptic evaluation, it was found that sodium nitrite in small quantities significantly improves the color of the product.

So, recipe for sausage products will take the form presented in Table 3.

Table 2

Modeling of the cooked sausage recipe based on the content of food nutrients (g/100 g)

Raw materials	Valin	Methionine	Phenylalanine	Isoleucine	Leucine	Lysine	Tryptophan	Monounsaturated fatty acids	Polyunsaturated fatty acids	Price of 1 kg of raw material (in tenge/$)
Beef meat	0.743	0.675	0.841	0.781	1.709	1.901	0.370	1.5	0.28	2520/5.04
Lamb fat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	6.5	1865/3.73
Pea flour	2.3	0.96	1.83	2.014	3.95	4.01	1.1	0.37	1.03	525/1,05
Table salt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65/0.13
Sodium nitrite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1675/3.35
Ground black pepper	0.547	0.096	0.446	0.366	1.014	0.244	0.058	1.0	0.74	2410/4.82
Potato starch	0.356	0.107	0.316	0.299	0.425	0.413	0.115	0.2	0.15	1185/2.37
Sugar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	490/ 0.98

Exchange rate of 1 dollar = 500.10 tenge (25/03/2025).

$$f(x1,x2,x3,x4,x5,x6,x7,x8) := \frac{(5.04\cdot x1 + 3.73\cdot x2 + 1.05\cdot x3 + 0.13\cdot x4 + 3.35\cdot x5 + 4.82\cdot x6 + 2.37\cdot x7 + 0.98\cdot x8)}{1000}$$

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

Given

$$\frac{0.743\cdot x1 + 2.3\cdot x3 + 0.547\cdot x6 + 0.356\cdot x7}{100} > 4 \qquad \frac{0.675\cdot x1 + 0.96\cdot x3 + 0.096\cdot x6 + 0.107\cdot x7}{100} > 2.3$$

$$\frac{0.841\cdot x1 + 1.83\cdot x3 + 0.446\cdot x6 + 0.316\cdot x7}{100} > 4.1 \qquad \frac{0.781\cdot x1 + 2.014\cdot x3 + 0.366\cdot x6 + 0.299\cdot x7}{100} > 3$$

$$\frac{1.709\cdot x1 + 3.95\cdot x3 + 1.014\cdot x6 + 0.425\cdot x7}{100} > 6.1 \qquad \frac{1.901\cdot x1 + 4.01\cdot x3 + 0.244\cdot x6 + 0.413\cdot x7}{100} > 4.8$$

$$\frac{0.37\cdot x1 + 1.1\cdot x3 + 0.058\cdot x6 + 0.115\cdot x7}{100} > 0.66 \qquad \frac{1.5\cdot x1 + 41.1\cdot x2 + 0.37\cdot x3 + 1.0\cdot x6 + 0.2\cdot x7}{100} > 6$$

$$\frac{0.28\cdot x1 + 6.5\cdot x2 + 1.03\cdot x3 + 0.74\cdot x6 + 0.15\cdot x7}{100} > 1$$

$820 \le x1 \le 845 \quad 80 \le x2 \le 110 \quad 30 \le x3 \le 70 \quad 1 \le x4 \le 1.5 \quad x5 \ge 0$

$x6 \ge 0 \quad 45 \le x7 \le 50 \quad 0.1 \le x8 \le 0.15$

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

$$A := \mathrm{Minimize}(f, x1, x2, x3, x4, x5, x6, x7, x8)$$

$$A = \begin{pmatrix} 820 \\ 80 \\ 53.35 \\ 1.5 \\ 0 \\ 0 \\ 45 \\ 0.15 \end{pmatrix}$$

$$f(A) = 4.59$$

Fig. 1. Solving task in the Mathcad system

Table 3

Ingredients for the production of cooked sausage per 1 kg

Raw materials	Weight, g
Beef	820
Lamb fat	80
Pea flour	53.35
Table salt	1.5
Sodium nitrite	0.002
Ground black pepper	0.1
Starch	45
Sugar	0.15

Thus, it can be concluded that the proposed composition of cooked sausage with pea flour is optimized using mathematical modeling. However, to produce high-quality developed sausage products, it is necessary to conduct qualimetric assessment that meets consumer expectations and identifies potential problems at early stages of production.

5. 2. Qualimetric assessment of the quality of cooked sausage

The use of qualimetric model for assessing and predicting product quality allows:

– forecast consumer demand for finished products;

– set right priorities in product development;

– identify important indicators required in product development and quality control;

– identify promising directions for achieving desired quality;

– conduct qualimetric assessment of product quality using calculated indicators that determine product quality.

To study qualimetric assessment of finished products, selected reference indicators as basic values. The organoleptic indicators were studied in accordance with basic score values according to sausage quality assessment scale developed in State Standard [18]. To determine the organoleptic, physicochemical and safety indicators, the methods specified in the regulatory documentation were used. Requirements for the content of essential amino acids were equated to the protein reference indicators according to the FAO/WHO scale (2011). The content of unsaturated fatty acids was determined according to the "ideal lipid" model. The energy value was determined by calculation.

The results of the quality assessment of individual indicators of cooked sausage with addition of pea flour are presented in Table 4.

The results show that sausage products have fairly high organoleptic properties, also low content of toxic elements and microbiological impurities.

Table 4

Main characteristics of cooked sausage with added pea flour

Indicators		Base value	Weighting factors of a single indicator	Received data	Values of a single indicator taking into account the weight coefficient
Organoleptic (A)	Taste	5	0.15	5	0.15
	Smell	5	0.15	4.8	0.14
	Appearance	5	0.2	4.6	0.18
	Consistency	5	0.3	4.8	0.29
	Color and cross-sectional view	5	0.2	4.7	0.19
Physicochemical (B)	Mass fraction of fat, %	15	0.30	9.8	0.20
	Protein mass fraction, %	13	0.30	21	0.48
	Mass fraction of sodium chloride (table salt), %	2.3	0.15	1.9	0.12
	Mass fraction of starch, %	2.0	0.25	1.2	0.15
Safety indicators (microbiological and chemical hazards) (C)	Toxic elements, mg/kg				
	Lead	0.5	0.25	0.051	0.03
	Cadmium	0.05	0.25	0.00	0.00
	Arsenic	0.1	0.25	0.00	0.00
	Mercury	0.03	0.25	0.00	0.00
	Microbiological indicators				
	NMAFAM, CFU/g, no more than	1000	0.50	148	0.07
	Coliform bacteria in 0.1 g	Not allowed	0.50	0.00	0.00
Nutritional value (D)	Valin	4 g/100 g	0.1	2.355	0.06
	Methionine+cysteine	2.3 g/100 g	0.15	1.842	0.12
	Phenylalanine + tyrosine	4.1 g/100 g	0.1	3.260	0.08
	Isoleucine	3 g/ 100 g	0.1	2.316	0.08
	Leucine	6.1 g/100 g	0.10	4.135	0.07
	Lysine	4.8 g/100 g	0.15	4.211	0.13
	Tryptophan	0.66 g/100 g	0.1	0.428	0.06
	Monounsaturated fatty acids	60%	0.10	42	0.07
	Polyunsaturated fatty acids	10%	0.10	7.1	0.07
Energy value (E)		250 kcal/100 g of product	1.0	227.4	0.90

Table 5 shows the values of group quality indicators of cooked sausage products with addition of pea flour.

Table 5

Values of group quality indicators of developed cooked sausage products

Indicators	Result values	Base indicator (Literary data)
Organoleptic (A)	0.14	0.15
Physicochemical (B)	0.14	0.15
Safety indicators (microbiological and chemical hazards) (C)	0.36	0.40
Nutritional value (D)	0.15	0.20
Energy value (E)	0.09	0.10
Comprehensive quality indicator	0.88	1.00

Thus, according to the results of the qualimetric assessment, the complex quality indicator is 0.88. This indicator corresponds to the level of excellent quality. The table shows that the group indicators are close in their values to the reference ones. The best are the organoleptic indicators and nutritional value of cooked sausages with the addition of pea flour.

For a more visual representation of the results of qualimetric assessment of quality indicators, it is possible to show them in the form of a graph (Fig. 2).

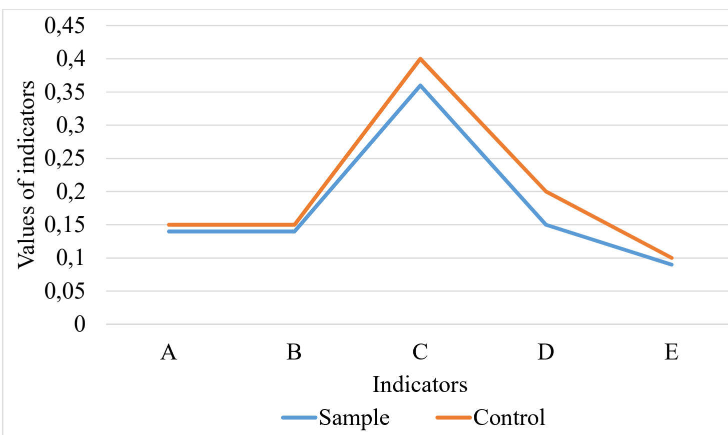

Fig. 2. Comparative graph of group quality indicators of developed cooked meat products with a control sample

The graph shows that the group quality indicators of the developed cooked meat products are higher than those of the control sample.

6. Discussion of the results of the study of the quality of cooked sausages

The results obtained during the study demonstrate effectiveness of using linear programming methods in developing an optimal recipe for sausage products with addition of pea flour. The use of mathematical model made it possible to accurately determine combination of ingredients and processing modes, which accordingly reduced number of experimental samples. The resulting model allows for prediction of precise characteristics with specified properties. The use of pea flour reduces raw material costs, and it is advisable to use it as an alternative to meat. The basis of mathematical modeling was data on the component composition given in Table 2, and solution to the recipe optimization problem is presented in Fig. 1. The product optimization was carried out taking into account nutritional value of ingredients, in particular content of essential amino acids. The optimization problem was solved in the MathCad software environment, which made it possible to determine the optimal ratios of ingredients that meet both economic and nutritional criteria. However, as noted in the study, mathematical modeling does not cover all the characteristics of perception of the finished product, so an organoleptic adjustment was made: an increase in sodium nitrite and ground black pepper. These changes significantly improved organoleptic characteristics of the finished product. The final recipe was presented in Table 3. This adjustment illustrates limits of applicability of the mathematical model and need for its comprehensive use with tasting data.

Unlike traditional empirical methods of formula selection using trial and error, this approach has following advantages: it allows problem to be formalized as system of constraints and an objective function, provides automatic selection of components taking into account economic and nutrient requirements, and makes it possible to adapt recipe to various raw material and price conditions.

Unlike [18], where proposed method is applied after experimental production of various formulations to assess influence of factors on the output characteristics of the product, in this study, method is applied at the product development stage, when it is important to select optimal composition taking into account multiple constraints and quality criteria.

Paper [19] applied a matrix method for designing multicomponent dairy products, but did not include organoleptic adjustments after modeling. There is also no qualimetric assessment after modeling, which allows taking into account set of factors (organoleptic, physicochemical, safety indicators, nutritional and energy value) and determining balanced assessment and justification of the quality of obtained modeling result.

Thus, study demonstrated effectiveness of using mathematical modeling to form preliminary optimization according to the specified recipe criteria. However, it also emphasizes that, taking into account tasting and qualimetric analysis, it is possible to ensure high quality and consumer appeal of finished products.

To conduct a qualimetric assessment of the finished product, individual quality indicators were determined, reflected in Table 4. They demonstrated that developed product has high organoleptic characteristics, also a low content of toxic elements and microbiological contaminants. Thus, it can be concluded that it is highly food safe.

The values of group quality indicators presented in Table 5 confirm overall high quality. The product is characterized especially favorably by organoleptic indicators and energy value. The product also meets established standards of safety indicators. For visual representation of the quality level, graph was constructed (Fig. 2), which shows that all group indicators are close to the reference values. High indicators of organoleptic characteristics stand out in particular, which emphasizes good perception of the product by consumers.

The generalized integral quality indicator calculated based on the qualimetry results was 0.88, which corresponds to the excellent quality level. This confirms effectiveness of the recipe used and composition optimization method applied. Thus, it can be stated that mathematical modeling supplemented by qualimetric assessment is reliable tool for developing food products.

The developed cooked sausage products have competitive advantages due to the expansion of the range of finished products and the improvement of their quality, also the reduction of cost price, the intensification of production, which are carried out through the following activities:

– combining raw materials of plant and animal origin, improving the nutritional value of products: amino acid, fatty acid, vitamin and micro- and macroelement composition;

– use of low-grade meat raw materials;

– reduction of development time and labor costs for designing recipes and technologies for sausage products enriched by pea flour.

Thus, results of this study are confirmed and consistent with existing data, which emphasizes the reliability and relevance of the proposed method. The proposed method of mathematical modeling and qualimetric assessment allows not only to accurately predict the properties of meat products, but also to optimize its composition to achieve better quality characteristics compared to existing methods.

The obtained results can be used to expand model to nonlinear methods that take into account more complex dependencies between components; expand study to other types of meat products, which will ensure universality of the model; conduct large-scale consumer testing to confirm commercialization of the developed recipe.

The following limitations should be considered in this study. The proposed models are based on certain production conditions, such as temperature, processing time and cooking methods. Changing these conditions may lead to distortion of the results and, accordingly, to a decrease in the quality of the product. The results may vary depending on the quality of the raw material (meat, various substitutes). These indicators may affect the reproducibility of the data obtained under changed conditions. Also replace one of the ingredients, it can affect the organoleptic indicators, and as a result, qualimetric assessment. A certain set of input data was used for the studies, which were obtained as a result of experiments. The results are adequate within the specified values. If change the proportions of components of recipe or replace them with other ingredients, it can lead to different results. The assessment of organoleptic properties can vary depending on the preferences and tastes of different consumer groups. The model cannot take into account changes in the quality indicators of the product during its storage (temperature, humidity).

The disadvantage of this work is possibility of organoleptic deviation when scaling recipe to an industrial level, also limited scientific research on modeling recipe of sausage products only.

Thus, despite significance and usefulness of the proposed method of mathematical modeling and qualimetric assessment, it is necessary to take into account above limitations for further use in practical activities.

7. Conclusions

1. A optimal recipe for sausage products was developed using modeling the content of nutrients amino acids, fatty acids, and the price of raw materials. Thus, the content of raw materials in the proposed sausage products is proposed as follows: beef – 820 g/kg; lamb fat – 80 g/kg; pea flour–53.35 g/kg; table salt – 1.5 g/kg; sodium nitrite – 0.002 g/kg; ground black pepper–0.1 g/kg; starch – 45 g/kg; sugar – 0.15 g/kg.

2. The developed sausage products were examined for a comprehensive quality indicator using qualimetric assessment. The results of the study showed that the complex quality indicator is 0.88. They correspond to the best quality indicator of finished products. The values of the group quality indicators are as follows: organoleptic indicators – 0.14; physicochemical indicators – 0.14, safety indicators (microbiological and chemical hazards) – 0.36, nutritional value – 0.15, energy value – 0.09.

Conflicts of interest

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

Data availability

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

Financing

The authors would like to note that there are no financial supports for this study.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Balsa-Canto, E., Alonso, A. A., Arias-Méndez, A., García, M. R., López-Núñez, A., Mosquera-Fernández, M. et al. (2016). Modeling and Optimization Techniques with Applications in Food Processes, Bio-processes and Bio-systems. Numerical Simulation in Physics and Engineering. Cham: Springer, 187–216. https://doi.org/10.1007/978-3-319-32146-2_4
2. Tarlak, F. (2023). The Use of Predictive Microbiology for the Prediction of the Shelf Life of Food Products. Foods, 12 (24), 4461. https://doi.org/10.3390/foods12244461
3. Castro, A. M., Mayorga, E. Y., Moreno, F. L. (2018). Mathematical modelling of convective drying of fruits: A review. Journal of Food Engineering, 223, 152–167. https://doi.org/10.1016/j.jfoodeng.2017.12.012
4. Tkachenko, A., Olkhovska, O., Chernenko, O., Chilikina, T., Basova, Y. (2022). Improving the quality of cupcakes by optimizing the recipe using a mathematical modeling method. Eastern-European Journal of Enterprise Technologies, 6 (11 (120)), 99–108. https://doi.org/10.15587/1729-4061.2022.268973

5. Stratev, D., Valdramidis, V. P. (2023). Quantitative tools in microbial and chemical risk assessment. EFSA Journal, 21. https://doi.org/10.2903/j.efsa.2023.e211016
6. Indumathy, M., Sobana, S., Panda, B., Panda, R. C. (2022). Modelling and control of plate heat exchanger with continuous high-temperature short time milk pasteurization process – A review. Chemical Engineering Journal Advances, 11, 100305. https://doi.org/10.1016/j.ceja.2022.100305
7. Popov, E. S., Pozhidaeva, E. A., Pevtsova, E. S., Sokolova, A. V., Kolmakova, A. S. (2019). Application of methods of mathematical modeling in the optimization design of technological processes of food production. Proceedings of the Voronezh State University of Engineering Technologies, 81 (2), 47–55. https://doi.org/10.20914/2310-1202-2019-2-47-55
8. Abdullah, L., Abidin, N. H. (2014). A Fuzzy Linear Programming in Optimizing Meat Production. International Journal of Engineering and Technology, 6 (1), 436–444. Available at: https://www.researchgate.net/publication/287236707_A_Fuzzy_Linear_Programming_in_Optimizing_Meat_Production
9. Riabovol, M. (2022). Mathematical modelling of the process of vibration mixing of minced sausage. Animal Science and Food Technology, 13 (2). https://doi.org/10.31548/animal.13(2).2022.53-62
10. Kuzmin, O., Pasichnyi, V., Levkun, K., Riznyk, A. (2017). Determination of the factor space of the process of extrusion of sausage products. Ukrainian Journal of Food Science, 5 (1). https://doi.org/10.24263/2310-1008-2017-5-1-8
11. Rustemova, A., Kydyraliev, N., Kirillova, T., Sadygova, M., Batyrbayeva, N. (2020). Modeling of recipes of special purpose bakery products. BIO Web of Conferences, 27, 00017. https://doi.org/10.1051/bioconf/20202700017
12. Dunchenko, N. I., Svinina, A. A. (2018). Convenience Minced Meat Quality Management on the Basis of the Qualimetric Forecasting. Food Industry, 3 (3), 59–64. https://doi.org/10.29141/2500-1922-2018-3-3-9
13. Guryeva, K., Soldatova, S. (2023). Comprehensive Assessment Of The Quality Of Canned Meat In Combined Packaging Materials. Bulletin of Science and Practice, 9 (4), 173–182. https://doi.org/10.33619/2414-2948/89/23
14. Strizhevskaya, V. N., Simakova, I. V., Pavlenkova, M. V., Nemkova, S. A. (2019). Development of qualimetric model of combined snack foods. Novye tehnologii (Majkop), 1 (47), 178–188. Available at: https://cyberleninka.ru/article/n/razrabotka-kvalimetricheskoy-modeli-kombinirovannyh-snekovyh-izdeliy/viewer
15. Rebezov, M. B., Zhumanova, G. T. (2020). Application of mathematical modeling and the principles of qualimetric forecasting in the production of semi-finished horse meat products with the use of a protein fortifier. IOP Conference Series: Earth and Environmental Science, 613 (1), 012121. https://doi.org/10.1088/1755-1315/613/1/012121
16. Rabenko, E. B. (2014). Osobennosty kvalymetrycheskoi otsenky urovnia kachestva pyshchevoi produktsyy. Resursoeffektyvnye systemy v upravlenyy y kontrole: vzghliad v budushchee. Tomsk: Yzd-vo TPU, 210–212. Available at: https://core.ac.uk/download/pdf/53088231.pdf
17. GOST 9959-2015. Miasl i miasnye produkty. Obshchie usloviia provedeniia organolepticheskoi otcenki (2016). Standartinform. Available at: https://internet-law.ru/gosts/gost/61830/
18. Mushtruk, M., Palamarchuk, I., Palamarchuk, V., Gudzenko, M., Slobodyanyuk, N., Zhuravel, D. et al. (2023). Mathematical modelling of quality assessment of cooked sausages with the addition of vegetable additives. Potravinarstvo Slovak Journal of Food Sciences, 17, 242–255. https://doi.org/10.5219/1845
19. Lisin, P. A., Kister, I. V., Moliboga, E. A., Skokov, A. P., Voronova, T. D., Branitsky, V. V. (2013). Optimizatciia retceptury mnogokomponentnogo produkta metodom lineinogo programmirovaniia. Agrarnyi vestnik Urala, 8, 29–32. Available at: https://cyberleninka.ru/article/n/optimizatsiya-retseptury-mnogokomponentnogo-produkta-metodom-lineynogo-programmirovaniya/viewer