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DEVELOPMENT OF AN OPTIMAL RECIPE FOR LIVER-VEGETABLE PATE

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Abstract. Today, there is a steady trend toward fortifying food products with functional additives, particularly those derived from non-traditional plant sources. The use of amaranth seed processing products, such as amaranth flakes, represents a novel and promising direction that is only beginning to be implemented in the food industry. The aim of the study was to develop an optimal formulation for a liver-vegetable pâté that ensures high sensory and nutritional quality at an affordable cost. The research employed mathematical modeling and optimization techniques. Based on the developed mathematical models, dependencies were established between the quality and cost indicators of liver-amaranth pâtés and the mass ratios of their primary raw materials, followed by multi-criteria optimization. Sensory evaluation of the liver-vegetable pâté samples, based on theoretical data, was conducted using a 10-point scale. Testing samples with an amaranth flake content ranging from 17.0% to 43.0% revealed that the sample containing 23.2% flakes received the highest total score (42 points). Its aroma and consistency were rated 9 points, while taste, appearance, and juiciness scored 8–9. This indicates a well-balanced profile: a pleasant intense aroma, rich flavor, uniform texture, and high visual appeal. It was established that the peak sensory rating (5.0 points on a 5-point scale) was achieved with the following composition: 22.23 g of amaranth flakes, 50.00 g of liver, and 8.31 g of pork back-fat. Under these conditions, the protein content is 11.39%, with a raw material cost of 109.74 UAH/kg. The study demonstrated that the protein content in the pâté depends linearly only on the amaranth-to-liver mass ratio. A maximum protein content of 12.8% is achieved at a ratio of 45.0 g of amaranth flakes to 50.0 g of liver. Meanwhile, the sensory rating and raw material cost are also influenced by the mass fraction of pork back-fat: with fat content ranging from 5 to 30 g, the sensory scores varied from 3.4 to 1.5 points, while the cost ranged from 106.87 to 86.07 UAH/kg. The minimum raw material cost of 75.56 UAH/kg was achieved at a mass ratio of amaranth flakes, liver, and pork back-fat of 45:25:30 g, respectively. However, this formulation contains only 7.73% protein and has a low sensory rating of only 2.0 points.

Keywords: liver-vegetable pâté, chicken liver, amaranth flakes, processing, packaging, storage, mathematical modeling, formulation optimization.

Introduction. Formulation of the problem

The modification of meat products through the incorporation of health-promoting components and the reduction of harmful substances is both expedient and relevant. This approach allows not only for improved nutritional value but also for the enhancement of the functional properties of finished products.

In the context of modern food industry development, there is a growing interest in creating products that combine high nutritional density with improved sensory characteristics. One promising direction is the utilization of amaranth raw materials, which, due to their unique composition, can significantly enhance the quality and health benefits of traditional food products.

Amaranth is considered a high-value crop because its seeds are rich in proteins with a high content of essential amino acids (particularly lysine), polyunsaturated fatty acids, dietary fiber, minerals (calcium, iron, magnesium, zinc), vitamins (A, E, and B-group), and antioxidants, such as squalene.

Furthermore, amaranth contains bioactive compounds that contribute to cholesterol reduction, immune system reinforcement, and protection against oxidative stress.

Incorporating amaranth derivatives into liver pâtés is an effective method for enhancing their nutritional profile. While liver pâtés are traditionally a source of protein, lipids, and vitamins, their formulation often requires optimization to reduce the content of unhealthy saturated fats and increase beneficial properties. The use of amaranth flour, extracts, flakes, or other derivatives enables the achievement of a balanced composition, while also improving the texture, flavor profiles, and extending the shelf life of the pâtés.

Analysis of recent research and publications

Liver-vegetable pâtés exhibit a wide variety of types on both the domestic and international markets. Their composition and functional properties depend on the ingredients used, consumer dietary preferences, and the specific functional purpose of the product.

In Ukraine, traditional pâtés that combine liver with vegetables and cereals are the most common kind. Formulations often include carrots, onions, pumpkin, or paprika to enhance flavor, aroma, and visual appeal [1, 2]. To achieve the desired consistency and nutritional density, semolina, rice, oat, or corn grits are added. Options incorporating amaranth flakes are gaining increasing popularity due to their exceptional nutritional value. Furthermore, specialized categories include pediatric and dietetic pâtés, characterized by a milder flavor and reduced salt and fat content; these formulations frequently incorporate dairy ingredients, eggs, or butter.

Researchers Pasichnyi V.M. and Topchii O.A. from the National University of Food Technologies have identified effective fortifying agents for health-promoting pâtés, which serve as sources of dietary fiber, polyunsaturated fatty acids, vitamins, and minerals [2, 6, 7]. Additionally, specific formulations and technologies for liver-vegetable pâtés intended for athletes have been developed, with established indicators for quality, nutritional, and biological value [3].

Researcher Agunova L.V. conducted analytical and practical studies on the feasibility of combining animal and vegetable fats in liver pâté formulations designed for enhanced nutritional value. Evaluation of the fatty acid profile of vegetable oils available on the Ukrainian market demonstrated the efficiency of using soybean oil as a source of polyunsaturated fatty acids, particularly omega-3, which are essential for a balanced diet. Such components are appropriately added to meat emulsion products to improve their functional properties [4].

During the experiments, the impact of vegetable fat inclusion on the structural-mechanical and sensory characteristics of the pâté mass was examined. The research indicated that exceeding a vegetable oil inclusion level of 12.5% of the primary raw material mass results in intensive oil separation (syneresis), which adversely affects the flavor and textural attributes of the final product [4].

Combining poultry meat and liver with plant-based raw materials (carrots, apples, pumpkin seeds) allows for a reduction in caloric density and cholesterol content while balancing unsaturated fatty acids. Simultaneously, the resulting product is enriched with natural bioactive substances, plant proteins, carbohydrates, vitamins, minerals, dietary fiber, and other compounds necessary for the optimal functioning of the human body [5].

The proposed meat pâté with plant-based additives incorporates mushroom raw materials, enabling a product with optimal sensory characteristics. The technical result consists of obtaining a meat pâté with high technological, structural, and mechanical performance [6].

The pâté formulation includes meat raw materials, skimmed milk powder, vegetable oil, whey, onions, food-grade salt, and pepper. The meat base consists of chicken meat and cooked chicken liver. Corn oil is utilized as the vegetable lipid source, supplemented by a specific phytocomplex [7]. Research into the inclusion of pumpkin, flaxseed, and cranberry press cakes in pâté recipes has demonstrated an increase in protein and dietary fiber content, alongside improved water-holding capacity and sensory attributes [8].

In international practice, the assortment of such products is even broader. In addition to classic formulas, there is active development of recipes based on legumes (lentils, chickpeas, beans), gluten-free cereals (quinoa, buckwheat, millet), vegetable blends, and various vegetable oils [9-14]. Plant-based analogs of liver pâtés – products free from animal-derived components suitable for vegetarians and vegans – occupy a significant market niche. These are formulated using plant proteins, mushrooms, vegetable purees, spices, and natural thickeners. In the EU, USA, and Canada, pâtés labeled as organic, low-sodium, low-fat, or gluten-free are widespread, aligning with modern healthy eating standards [15, 16].

Partial and total replacement of pork fat with rapeseed oil organogels has been conducted to improve the nutritional and sensory properties of liver pâté. Sensory analysis revealed that 100% replacement was indistinguishable from the control in terms of hardness, oiliness, cohesiveness, and off-flavor. Lipid loss results indicated good stability for pâtés containing up to 60% organogels. Microscopy showed a gradual increase in fat globule size as higher levels of pork fat were replaced, which may contribute to higher lipid loss. Overall, a 60% replacement of pork fat is recommended to maintain oil retention and textural properties without affecting sensory attributes or color, while achieving a nearly 40% reduction in saturated fats [17].

It has been established that replacing animal fat with flaxseed oil reduces the content of saturated and monounsaturated fatty acids by approximately 12% while increasing the contribution of polyunsaturated fatty acids by more than 70% compared to the control. This modification also enriched the pâté with phytosterols β-sitosterol, campesterol, and cycloartenol). The addition of 0.05% and 0.10% ethanolic flaxseed extract significantly inhibited lipid oxidation during storage [18].

Mushroom flour increased the moisture, dietary fiber, and protein content, thereby enhancing the nutritional value of the pâté. It also affected color parameters and resulted in a firmer paste at a 10% inclusion level. Sensorially, the aroma and flavor of formulations with 7.5% mushroom flour were considered acceptable. Its addition in a hydrated form (50/50 w/w ratio) is deemed the most suitable for improving nutritional value without significantly impacting sensory properties [19].

In pâté production, alongside meat raw materials, a wide range of plant-based ingredients is employed, including: onions, cereals (semolina, rice, oat, corn), flour, starch, soy products, vegetables (carrots, paprika, pumpkin), legumes (e.g., lentils), mushrooms, and spices [20-23].

Depending on the formulation, pâtés may also incorporate dairy components (cream, butter, etc.), egg products (mélange), blood plasma, vitamin supplements, colorants, and color stabilizers.

A particularly promising direction is the development of combined meat-vegetable products. An optimal example of such a combination is a pâté based on chicken liver and amaranth. Chicken liver is a valuable source of protein, vitamins A and B_{12}, and iron, all of which are essential for hematopoiesis and the immune system. However, due to its high cholesterol content, its consumption should be moderated.

Amaranth is rich in protein, dietary fiber, minerals (calcium, iron, magnesium), and antioxidants. It provides significant benefits for the cardiovascular system and digestion [24]. In pâté production, the quantity of flour may vary depending on the recipe and processing technology, but it is typically added within the range of 5-15% of the total raw material mass.

Wheat flour or other types of flour are generally used to achieve the desired consistency, reduce fat content, and stabilize the pâté's texture. Flour aids in improving the product's structure and reducing fluidity, allowing it to maintain its shape after thermal processing. When amaranth flour is utilized, it introduces additional nutrients, specifically high-quality protein and dietary fiber. For chicken liver pâtés, an inclusion level of 10-15% flour is often employed to provide density and smoothness. Nonetheless, formulations can be adjusted based on the target texture and nutritional profile.

Amaranth offers superior nutritional benefits compared to wheat flour, as it contains higher levels of protein, fiber, minerals, and healthy lipids. Notably, it is gluten-free, making it suitable for individuals with celiac disease or gluten intolerance [25]. In contrast, wheat flour is higher in carbohydrates and has a high glycemic index, which can lead to rapid spikes in blood glucose levels. The combination of animal-derived raw materials with plant-based components not only balances the nutrient composition but also creates a product with enhanced functional properties that meet modern consumer demands.

The purpose of this paper. The relevance of this study is driven by the need to develop innovative formulations and technologies that meet the growing consumer demand for health-promoting food products. Investigating the impact of amaranth-based raw materials on the characteristics of liver pâtés allows for determining its potential as a functional ingredient and opens new opportunities for expanding the range of high-quality food products.

The aim of the study was to develop an optimal formulation for a liver-amaranth pâté that ensures high sensory and nutritional qualities at an affordable cost.

This paper examines the influence of various ingredients on the quality characteristics of the pâté using mathematical modeling and optimization methods. The study is aimed at enhancing nutritional value, improving sensory properties, and ensuring the rational use of raw materials during the formulation development process.

Tasks of the research**.** To achieve the stated aim, the following tasks were defined:

- to analyze the nutritional value, functional-technological, and sensory properties of the main ingredients used in liver-vegetable pâtés;
- to develop mathematical models describing the dependence of quality indicators and the cost of liver-vegetable pâtés on the mass ratios of their primary raw materials;
- to optimize the formulation ratios of the main raw materials for liver-vegetable pâtés in order to ensure a high sensory score, nutritional value, and acceptable cost of the finished products;

to conduct an analysis of the physicochemical, microbiological, and sensory parameters of the finalized liver-vegetable pâté.

Research materials and methods

Standard research methods were employed in this study, alongside mathematical modeling and formulation optimization techniques based on multifactorial experimental design.

At the initial stage of the research, an analytical review of liver-vegetable pâté production technology was conducted, followed by a comparative analysis of the sensory attributes (aroma, taste, consistency, appearance, and juiciness) of various pâté formulations.

The methodology for the sensory evaluation involved a comprehensive quality assessment of the liver-vegetable pâté using a 5-point scale with weighting coefficients. This technique enables the conversion of qualitative product characteristics into quantitative equivalents in accordance with DSTU ISO 6658:2005 standards.

The sensory evaluation based on a 10-point scale refers to profile-descriptive methods. Its scientific value lies in transforming qualitative characteristics (descriptors) into quantitative values.

In the subsequent stage, the influence of the primary raw material ratios on the sensory scores (points), protein content (%), and cost (UAH/kg) of the liver-vegetable pâtés was investigated. The mass fractions (in grams) of amaranth flakes, liver, and pork back-fat were considered the primary raw material variables.

To minimize the number of required experimental trials and enhance the reliability of the findings, multifactorial experimental design methods were applied. Given the complexity of the dependencies of sensory parameters and protein content on the raw material mass ratios, near-optimal Box-Behnken three-level quadratic designs were utilized. This approach allows for the generation of the following regression equations:

$$y_i = b_0 + b_1A + b_2\Pi + b_3C + b_{12}A\Pi + b_{13}AC + b_{23}\Pi C, + b_{11}A^2 + b_{22}\Pi^2 + b_{33}C^2, \quad (1)$$

y_i – i- organoleptic indicators (y_1 – sensory scores, points; y_2 – protein content, %; y_3 – cost (UAH/kg);

b_0 , $b_1, \ldots, b_{33}$ – regression coefficients determined by the method of least squares based on experimental results;

A, Π, C – content of primary raw materials, g (amaranth flakes, liver, and pork back-fat, respectively).

To minimize the impact of uncontrolled factors on the experimental results, the trials were randomized using random number tables. To determine the error variance (reproducibility of the experiment) $S_{\bar{y}}$, three parallel replicates were conducted at the center point of the experimental design.

Data processing and all necessary calculations were performed using the PLAN sequential regression analysis software, developed at the Odesa National University of Technology [26, 27].

The essence of the sequential regression analysis lies in calculating the regression coefficients using the least squares method implemented in matrix form. The significance of these coefficients is then verified; those found to be insignificant are removed – specifically, the coefficient with the minimum ratio of its value to the critical value of the confidence interval – after which the remaining coefficients are recalculated. This iterative procedure concludes when only significant regression coefficients remain in the equation. Subsequently, the Fisher's F-test was used to verify the adequacy of the resulting regression equation against the experimental data at a significance level of p = 0.05 (95% confidence level).

The regression coefficients were calculated using matrices in natural dimensions; consequently, the resulting equations were also obtained in natural units. These adequate regression equations, developed for the investigated quality indicators, served as mathematical models. They enabled the prediction of changes in the quality parameters of liver-amaranth pâtés based on the values of the input factors A, Π and C.

The construction of response surfaces based on the obtained regression equations was performed using MS Excel-2007. Formulation optimization was carried out using the adequate mathematical models with the MS Excel «Solver» add-in. The criteria considered in the conducted studies were used as optimality functions, namely the sensory score of the liver–amaranth pâté, the protein content, and the cost of the main raw materials of the pâté.

The optimization of the pâté formulation was conducted by aligning the chemical composition of the liver-vegetable products with recommended human nutritional requirements. During the development of the pâté compositions, significant attention was paid to the nutrient profile of the raw materials and their transformations during technological processing.

Results of the research and their discussion

The process flow diagram for the production of liver-vegetable pâté is shown in Fig. 1. According to the scheme, the pâté preparation proceeds as follows: after appropriate primary processing, the meat raw material (chicken liver) is minced with the addition of table salt and ground black pepper to initiate the formulation of the pâté mince. At this stage, the remaining recipe components are incorporated: pre-hydrated amaranth flakes (using a 1:2 hydration ratio), blanched pork back-fat, sautéed onions, chicken eggs (mélange), and broth.

Once the pâté mince is prepared, it is filled into containers (retort pouches) and subjected to thermal processing in accordance with traditional high-temperature technology. Following sterilization, the cooling process is performed, and the finished product is sent for storage at a temperature of 0-6 °C.

To investigate the liver-vegetable pâté, five formulation samples were developed. Their composition, expressed as a percentage of the total mass, is presented in Table 1. The primary objective is to study the effect of amaranth flake content and the reduction of meat ingredients on the product quality.

A gradual reduction in the proportion of animal-based ingredients combined with an increase in amaranth flakes allows for the creation of a more dietary product, potentially characterized by higher dietary fiber and plant-based protein content, as well as reduced fat content. This may positively influence the nutritional value and digestibility of the product.

Based on the developed variations of liver-vegetable pâté samples, a study of their sensory indicators was conducted. The analysis was performed according to five primary sensory characteristics: aroma, flavor, consistency, appearance, and juiciness.

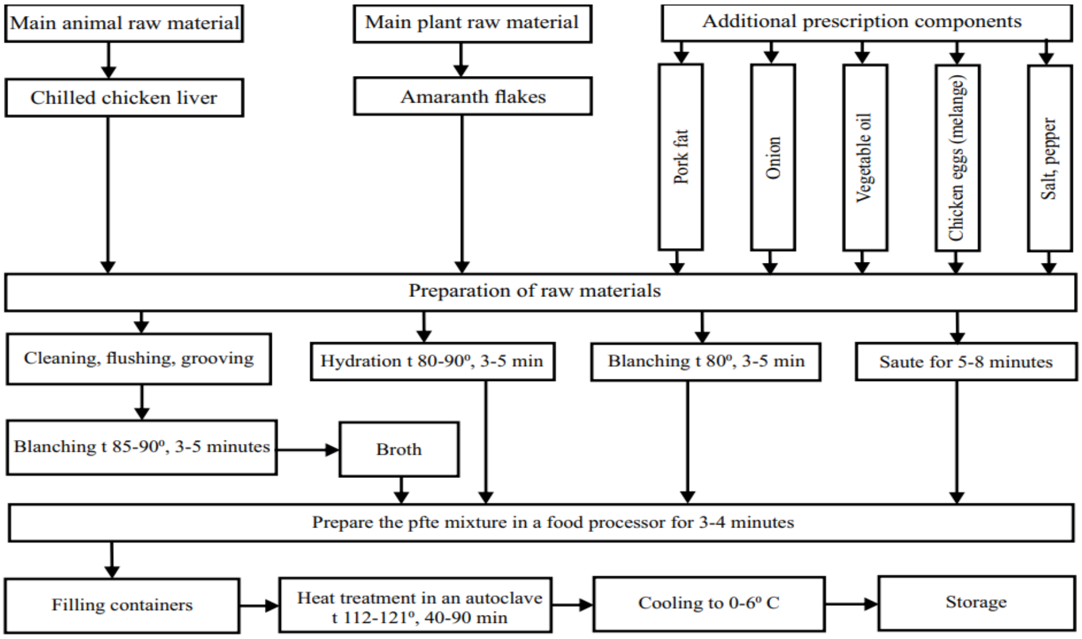
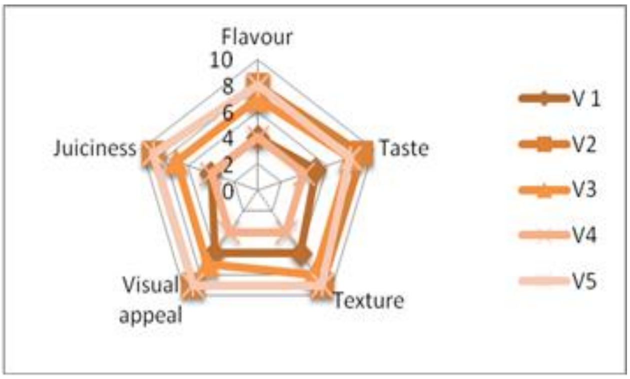


Fig. 1. The process flow diagram for the production of liver-vegetable pâté

Table 1 – Formulations of liver-vegetable pâté samples, wt. %

Ingredients	Composition 1 (V1)	Composition 2 (V2)	Composition 3 (V3)	Composition 4 (V4)	Composition 5 (V 5)
Chicken liver	35.30	50.00	35.30	25.00	30.30
Pork fat	26.00	11.92	16.00	20.00	6.00
Amaranth flakes	17.00	23.19	27.00	35.00	43.00
Onion	10.00	6.47	10.00	10.00	10.00
Melange	6.80	6.80	6.80	6.80	6.80
Table salt (*Sodium chloride*)	1.60	1.60	1.60	1.60	1.60
Ground black pepper	0.02	0.02	0.02	0.02	0.02
Broth	3.28	0.00	3.29	1.58	2.28

Five variations of liver-vegetable pâté formulations (V1–V5), differing in their amaranth flake content, were evaluated (Fig. 2).



Amaranth flake content in the formulations, wt. %: V1 –17.0; V2 – 23.19; V3 – 27.0; V4 – 35.0; V5 – 43.0

Fig. 2. Sensory profile of liver-vegetable pâté formulation samples

Sample V2, with an amaranth flake content of 23.19%, received the highest total score (42 points). Its aroma and consistency were rated at 9 points, while flavor, appearance, and juiciness received 8-9 points. This distribution of scores indicates a well-balanced profile: the sample features a pleasant, intense aroma, rich flavor, uniform texture, and high levels of visual appeal and juiciness. On the sensory profile, this sample forms an almost regular pentagon, indicating the uniformity of the ratings.

Sample V1 scored 41 points, only slightly lower than the previous one. It exhibited a balanced aroma (score of 8), as well as good consistency and juiciness (also 8-9 points). A slight decrease in the flavor and appearance scores did not significantly affect the overall positive impression, making it the second-best sample among those presented.

Third place in terms of the total score (40 points) was taken by sample V3. Its ratings are also high (8-9 points); however, it had a slightly lower aroma level (8 points), and juiciness was rated at 7. Despite this, its profile remains harmonious, and it possesses good overall quality.

Significantly lower results were demonstrated by samples V4 and V5, which received 20 and 25 points, respectively. Their sensory characteristics were rated at 4-6 points; specifically, flavor, consistency, appearance, and juiciness were at a minimal level. Although the aroma in sample V5 was slightly higher (6 points) compared to sample V4 (4 points), this does not compensate for the general imbalance and low quality of other characteristics. On the sensory profile, these samples have a very constricted shape, indicating poorly defined sensory advantages.

Thus, samples V2 and V1 are the best in terms of sensory indicators, possessing balanced sensory properties. At the next stage of the research, the influence of the ratios of the main raw materials on the sensory indicators (points), protein content (%), and cost (UAH/kg) of the liver-vegetable pâtés was studied. The mass fractions (in grams) of amaranth flakes, liver, and pork back-fat were considered as the primary raw materials. Based on the data in Table 1, the ranges for the mass fractions of these raw materials were selected as follows: amaranth flakes 0-45 g, liver 25-50 g, and pork back-fat 5-30 g.

The experimental conditions in the design matrix (mass fractions of amaranth flakes A, chicken liver П, and pork backfat C), along with the obtained results for the determined quality indicators of the liver-amaranth pâtés, are presented in Table 2.

Data processing and all necessary calculations were performed using the aforementioned sequential regression analysis software, PLAN [26].

The error variance (reproducibility) was determined based on the results of three parallel experiments conducted at the center of the experimental design. Since the regression coefficients were calculated using matrices in natural units, the resulting equations are also expressed in natural dimensions.

The consolidated data obtained from the regression equations expressed in natural variables are presented in Table 3. The same table provides the root mean square errors of the experiments $S_{\bar{y}}$ and the lack-of-fit errors $S_{н.ад}$, as well as the calculated F_p and critical $F_{кр}$ values of the Fisher criterion. Since the condition $F_p \le F_{кр}$ is satisfied for all three obtained equations, it can be concluded with 95% confidence that they adequately describe the influence of the mass ratios of amaranth flakes, liver, and pork back-fat on the sensory score, protein content, and cost of the pâté.

Table 2 – Experimental design matrix

N	Experimental conditions, g			Quality indicators		
	A	*П*	*C*	y_1, points	y_2, Protein content (%)	y_3, Cost, UAH/kg
1	0.0	25.0	5.0	2.8	5.0	115.00
2	45.0	25.0	5.0	2.2	7.7	94.00
3	0.0	50.0	5.0	3.1	10.1	121.82
4	45.0	50.0	5.0	4.0	12.8	103.00
5	0.0	25.0	30.0	2.7	5.1	80.91
6	45.0	25.0	30.0	3.1	7.8	80.50
7	0.0	50.0	30.0	2.8	9.9	96.25
8	45.0	50.0	30.0	2.3	12.7	90.40
9	0.0	37.5	17.5	2.7	7.5	101.36
10	45.0	37.5	17.5	2.3	10.3	91.75
11	22.5	25.0	17.5	4.6	6.4	88.46
12	22.5	50.0	17.5	4.6	11.5	100.00
13	22.5	37.5	5.0	3.8	8.9	105.77
14	22.5	37.5	30.0	3.6	8.8	87.50
15	22.5	37.5	17.5	4.6	8.9	95.16

The obtained regression equations serve as mathematical models that allow for the prediction of the quality indicators of liver-amaranth pâtés depending on the ratio of the mass fractions of amaranth flakes (A), liver (П), and pork back-fat (C).

Analysis of the regression equations shows that the influence of the mass ratios of the primary raw materials on the studied quality indicators varies, as evidenced by the structure of the obtained equations. Specifically, the influence of the mass fractions of all three types of raw materials on the sensory score (y_1) of the liver-amaranth pâté is the most complex. This is evident from the structure of the equation for y_1, which includes linear and quadratic effects for each raw material, as well as the pairwise interaction of the mass fractions of liver and pork back-fat on the sensory score of the finished pâté.

Table 3 – Regression equations in natural variables and statistical characteristics of the dependence of liver-vegetable pâté quality indicators on the ratio of mass fractions of amaranth flakes (A), liver (П), and pork back-fat (C)

Regression equations in natural variables	Standard deviation		Fisher criterion, F	
	Experimental, $S_{\bar{y}}$	Lack-of-fit, $S_{н.ад.}$	Calculated, F_p	Critical, $F_{кр}$
$y_1=5.386000+0.135407A-0.221600П+0.147467C-$ $-0.002240ПC-0.00303029A^2+0.003627П^2-0.002133C^2$, points	0.11	0.42	14.26	19.35
$y_2=0.0601A+0.2010П$, %	0.12	0.068	3.08	3.81
$y_3=101.145-0.248A+0.421П-0.832C$, UAH/kg	3.10	4.15	1.79	19.40

The second equation for y_2, which is the simplest one, shows that the protein content depends linearly only on the mass fractions of amaranth and liver. It is observed that increasing their proportion in the pâté formulation leads to an increase in protein content.

The third equation for y_3, used to evaluate the cost of the primary raw materials in the finished pâté, includes the mass fractions of all three main components: amaranth flakes, liver, and pork back-fat. The equation indicates that increasing the proportion of liver in the recipe increases the cost of the finished product, while decreasing the proportions of amaranth flakes and pork back-fat, conversely, allows for a reduction in the pâté's cost.

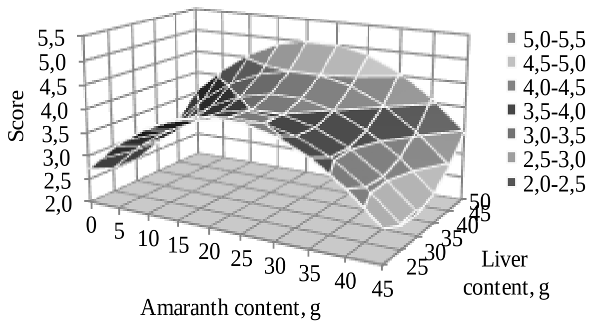
A more detailed and illustrative representation of the influence of the mass fractions of the main raw materials on the studied quality indicators of liver-amaranth pâtés is provided by the response surfaces constructed on the basis of the obtained adequate regression equations. Since the surfaces are three-dimensional figures requiring only two variable factors and the corresponding response, while the aforementioned equations for y_1 and y_3 include three factors, the third factor was fixed at the level optimal for each criterion, as indicated in Fig. 3 beneath each constructed surface.

Figure 3a illustrates the response surface showing the dependence of the pâté's sensory score on the mass fractions of amaranth flakes and liver. During the construction of this surface, the pork back-fat content was fixed at its optimal level. Analysis of the surface reveals a hyperbolic paraboloid shape (a saddle point). It is observed that amaranth flakes and liver mass fractions exert multidirectional effects on the product's sensory attributes; specifically, certain ratios can lead to a decline in the sensory profile. The maximum score of 5.0 points is attained at the following values: 22.23 g of amaranth flakes and 50.00 g of liver, with the pork back-fat content maintained at 8.31

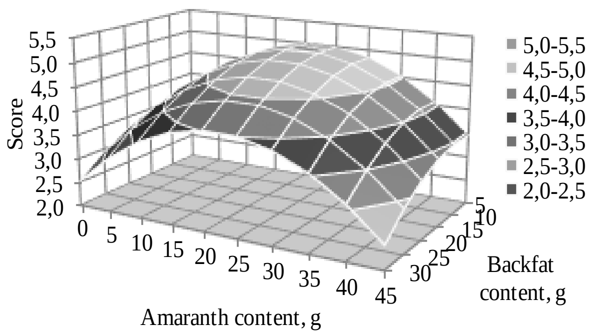
Figure 3b illustrates the variation in the sensory score as a function of the mass fractions of amaranth flakes and pork back-fat, with the liver mass fraction fixed at its maximum of 50.00 g. It is visually evident that the region of maximum sensory scores for the pâté lies within the range of 20-25 g of amaranth flakes and 5-10 g of pork back-fat.

The behavior of the sensory score relative to the mass fractions of pork back-fat and liver, shown in Fig. 3c, is similar to the trend observed in Fig. 3a. The position of the maximum score (5.0 points) is clearly visible at the coordinates corresponding to a pork back-fat mass fraction of 8.31 g and a liver mass of 50.00 g.

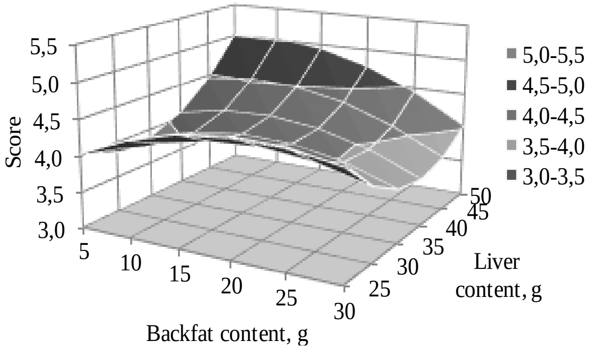
As noted above, the protein content depends linearly only on the mass fractions of amaranth and liver. Accordingly, the response surface shown in Fig. 3 has the form of a linear plane inclined at different angles to the two horizontal axes (abscissas), which represent the mass fractions of amaranth flakes and liver.



a) backfat content



b) liver content



c) amaranth content

Fig. 3. Sensory score of the pâté depending on the content of amaranth, liver and backfat

It should be noted that the tangents of the plane's inclination angles relative to the two axes, which are numerically equal to the regression coefficients in the equation for y_2, characterise the strength of the effect of the mass fractions of amaranth flakes and liver on the protein content of the pâté. Given that the coefficient for the liver mass fraction in equation y_2 is greater than the corresponding coefficient for the amaranth flake mass fraction (0.2010 > 0.0601), it can be concluded that the protein content in the pâté increases 3.34 times faster with an increase in the liver proportion within the formulation. Furthermore, the maximum protein content (12.80%) is achieved at a mass fraction of 45.00 g for amaranth and 50.00 g for liver, as clearly illustrated in Fig. 4.

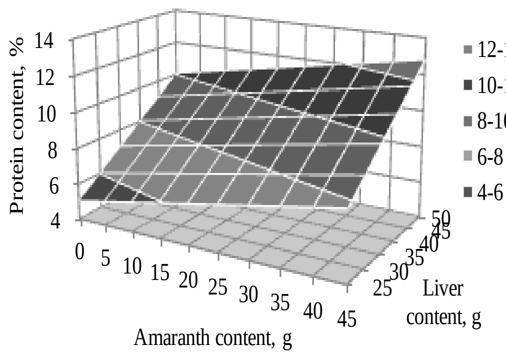


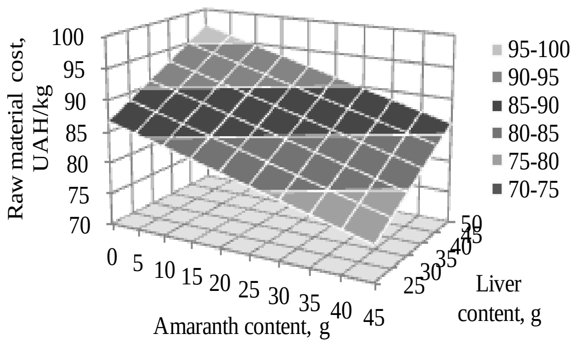
Fig. 4. Protein content in pâté depending on amaranth and liver levels

As seen from the equation for y_3, which characterizes the dependence of the primary raw material cost on the mass fractions of the main ingredients in the formulations, the response surfaces exhibit a linear form. Their angles of inclination relative to the corresponding axes indicate the rate of cost variation depending on the mass fractions of the respective primary raw materials in the formulations.
A brief analysis of the response surfaces shown in Fig. 4 clearly illustrates the trends in the cost variation of the primary raw materials included in the formulation. It should be noted, however, that these response surfaces were constructed for the specific mass ratios of raw materials that ensure the highest sensory score of the pâté (5 points).

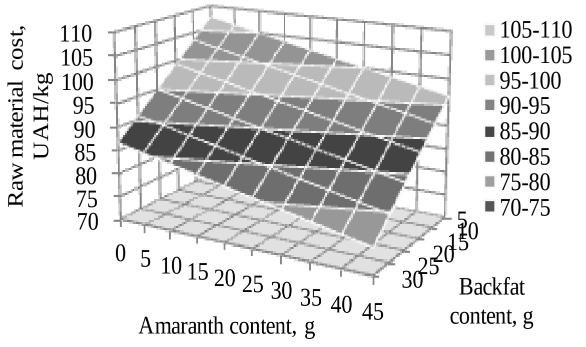
As seen from Fig. 5a, to reduce the cost of the pâté, it is necessary to increase the mass fraction of amaranth flakes and decrease the mass fraction of liver. At the same time, the most significant reduction in the pâté's cost (by nearly 1.7 times) can be achieved by reducing the mass fraction of liver.

As shown in Fig. 5b, increasing the mass fractions of amaranth flakes and pork back-fat allows for a reduction in the cost of the pâté; notably, a more significant cost reduction (by 3.34 times) is observed with an increase in the mass fraction of pork back-fat. The response surface in Fig. 5c confirms the previous conclusions regarding the reduction of pâté cost by increasing the pork back-fat content and decreasing the liver content. The cost decreases more rapidly (by 1.96 times) due to the higher proportion of pork back-fat in the formulation. It should also be noted that the minimum cost of the primary raw materials, amounting to 75.56 UAH/kg, can be achieved at the following mass ratios: 45.0 g of amaranth flakes, 25.0 g of liver, and 30.0 g of pork back-fat.

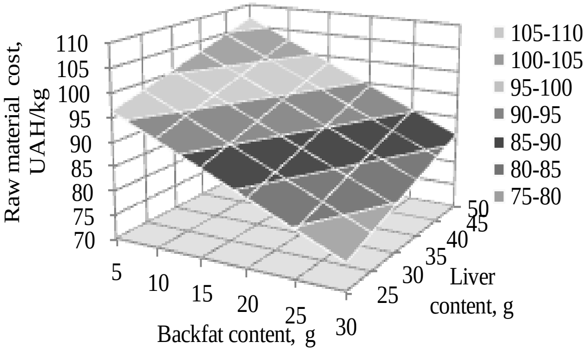
The analysis conducted has shown that the optimal mass ratios of the primary raw materials (22.35 g of amaranth flakes, 50.00 g of liver, and 8.31 g of pork back-fat) result in a pâté with the highest sensory quality (5.0 points). However, at these ratios, the protein content calculated by equation y_2 is 11.41%, which is 1.38% lower than the maximum value (12.77%).



a) backfat content



b) liver content



c) amaranth content

Fig. 5. Cost of primary raw materials for the pâté depending on the content of amaranth, liver and backfat

Calculating the cost of the primary raw materials based on the equation for y_3 yields 109.74 UAH/kg for the pâté with excellent sensory quality. In contrast, for the pâté with maximum protein content, the cost ranges from 86.08 UAH/kg (at a fat content of 30 g) to 106.56 UAH/kg (at a fat content of 5 g).

As previously noted, the minimum cost of primary raw materials can be as low as 75.56 UAH/kg. However, such a formulation results in a protein content of only 7.73% and a low sensory score of just 2.0 points. The optimal mass ratios of the primary raw materials, based on the respective optimality criteria considered, are summarized in Table 4.

Table 4 – Optimal mass ratios of the primary raw materials according to the considered optimization criteria

Optimization criteria	Primary raw material contents, g			Pâté quality indicators *		
	Amaranth flakes, *A*	Chicken liver, *П*	Pork back-fat, *C*	sensory indicators (points)	protein content (%)	cost (UAH/kg)
Sensory score, $y_1 \rightarrow max$	22,35	50,00	8,31	5,0	11,39	109,74
Protein content, $y_2 \rightarrow max$	45,00	50,00	5-30	3,4–1,5	12,80	106,87–86,07
Cost of primary raw materials, $y_3 \rightarrow min$	45,00	25,00	30,00	2,0	7,73	75,56

**Note: The optimal values for the considered optimization criteria are highlighted in bold*

Thus, the optimization of the mass ratios of the primary raw materials in liver-amaranth pâtés based on various criteria demonstrated that sensory indicators, protein content, and the cost of the primary raw materials significantly depend on the mass fractions of amaranth flakes, chicken liver, and pork back-fat. By adjusting these ratios according to the developed mathematical models, it is possible to design various formulations of liver-amaranth pâtés and regulate their essential quality indicators – sensory, nutritional, economic, and others.

The research results were tested and approved at the enterprise "Smak Zhyttia" (Taste of Life), Zaporizhzhia.

Conclusion

1. Sensory evaluation of liver-amaranth pâté samples with amaranth flake content ranging from 17.0% to 43.0% showed that the sample with 23.2% amaranth flakes received the highest total score (42 points). Its aroma and consistency were rated at 9 points, while taste, appearance, and juiciness received 8-9 points. This score distribution indicates a well-balanced profile: the sample possesses a pleasant intense aroma, rich flavor, uniform texture, and high scores for visual appeal and juiciness. Analysis of the nutritional value, functional-technological, and sensory properties of the primary ingredients in liver-vegetable pâtés demonstrated that a gradual reduction in animal-derived ingredients and an increase in amaranth flakes allows for the creation of a more dietary product with potentially higher dietary fiber and plant protein content, alongside reduced fat levels. This positively affects the product's nutritional value and digestibility.

2. Based on the analysis of the developed mathematical models regarding the influence of primary raw material ratios on the studied quality indicators of liver-amaranth pâté, the following was established: Regardless of the liver content, increasing the amaranth flake content from 0 to 22.35 g leads to an increase in the sensory score, while any further increase in amaranth flakes results in a score decrease. The highest sensory score of 5.0 points is achieved with the following mass fractions: amaranth flakes 22.23 g, liver 50.00 g, and pork back-fat 8.31 g. However, at these ratios, the pâté will have a higher primary raw material cost (109.74 UAH/kg) and a slightly lower protein content (11.39%, which is 1.41% less than the maximum).

3. It was shown that the protein content of the pâté depends linearly only on the mass ratio of amaranth flakes and liver. Moreover, the protein content increases 3.34 times faster with an increase in liver content within the primary raw material composition. The maximum protein content of 12.80% is achieved with mass fractions of 45.00 g for amaranth flakes and 50.00 g for liver, while the sensory score and cost of primary raw materials will depend on the pork back-fat proportion. With a pork back-fat mass fraction between 5–30 g, the sensory score and raw material cost will range from 3.4-1.5 points and 106.87-86.07 UAH/kg, respectively.

4. Regarding the cost of primary raw materials, the minimum value of 75.56 UAH/kg is achieved at a ratio of amaranth flakes, liver, and pork back-fat of 45.00:25.00:30.00 g. However, in this case, the primary raw materials will provide only 7.73% protein and a low sensory score of only 2.0 points. It was also demonstrated that to reduce the pâté's cost, it is necessary to increase the mass fraction of amaranth flakes and decrease the mass fraction of liver. The most significant cost reduction (nearly 1.7 times) can be achieved by decreasing the liver mass fraction. Increasing the mass fractions of amaranth flakes and pork back-fat also reduces the cost, with a more substantial reduction (3.34 times) observed when increasing the pork back-fat proportion.

5. The optimization of the mass ratios of primary raw materials for liver-vegetable pâtés based on various quality criteria showed that sensory indicators, protein content, and raw material cost significantly depend on the mass fractions of amaranth flakes, chicken liver, and pork back-fat. By adjusting these ratios according to the developed mathematical models, various formulations of liver-vegetable pâtés can be designed, allowing for the regulation of essential quality indicators – sensory, nutritional, economic, and others.

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РОЗРОБЛЕННЯ ОПТИМАЛЬНОЇ РЕЦЕПТУРИ ПЕЧІНКОВО-РОСЛИННОГО ПАШТЕТУ

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Анотація. На сьогодні спостерігається стійка тенденція до збагачення харчових продуктів різноманітними добавками, зокрема на основі нетрадиційної рослинної сировини. Використання продуктів переробки насіння амаранту на амарантові пластівці у цій сфері є новим і перспективним напрямом, що лише починає впроваджуватися у харчову промисловість. Метою дослідження була розробка оптимальної рецептури печінково-рослинного паштету, яка забезпечить його високі смакові та поживні якості за прийнятної вартості. У роботі використано методи математичного моделювання та оптимізації. На основі розроблених математичних моделей встановлено залежності показників якості та вартості печінково-амарантових паштетів від масових співвідношень їх основної сировини та проведено їх оптимізацію за різними критеріями якості. Дослідження органолептичних показників зразків печінково-рослинних паштетів за теоретичними даними оцінювались за десятибальною системою і з вмістом амарантових пластівців у діапазоні 17,0 – 43,0% показали, що найвищу сумарну оцінку (42 бали) отримав зразок з вмістом амарантових пластівців 23,2%. Його аромат і консистенція оцінені на 9 балів, смак, зовнішній вигляд і соковитість – на 8–9. Такий розподіл балів свідчить про добре збалансований профіль: зразок має приємний інтенсивний аромат, насичений смак, однорідну текстуру та високі показники візуальної привабливості й соковитості. Встановлено, що найвища органолептична оцінка виготовленого зразка паштету (за п'яти бальною системою) була оцінена у 5,0 балів досягається за масових часток: амарантових пластівців 22,23 г, печінки 50,00 г та сала 8,31 г. Але при цьому вміст білка складає 11,39%, а вартість основної сировини становить 109,74 грн/кг. Показано, що вміст білка паштету лінійно залежить лише від масового співвідношення амарантових пластівців та печінки. Максимальний вміст білка 12,8 % досягається за масових часток амарантових пластівців 45,0 г та печінки у 50,0 г, а органолептична оцінка та вартість основної сировини залежить ще й від масової частки сала: при частці сала в межах 5–30 г основна сировина має органолептичну оцінку 3,4–1,5 бали та вартість 106,87–86,07 грн/кг. Найменше значення вартості основної сировини у 75,56 грн./кг досягається за співвідношення масових часток амарантових пластівців, печінки та сала як 45:25:30 г. Але при цьому основна сировина має лише 7,73% білка та низьку органолептичну оцінку – всього 2,0 бали.

Ключові слова: печінково-рослинні паштети, куряча печінка, амарантові пластівці, переробка, фасування, зберігання, математичне моделювання, оптимізація рецептури.

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