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Mathematical modelling of quality assessment of cooked sausages with the addition of vegetable additives

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ABSTRACT

We studied the physicochemical composition and functional and technological properties of plant additives - wheat fibre with pumpkin pectin (WFwPP). The nutritional value of cooked sausages was increased when fibre was added to the recipe. We have replaced fatty pork meat with up to 5% WFwPP. Supplementation with fibre improves product digestibility "in vitro". We have used mathematical modelling, linear, flat, and spatial estimation models developed in a radial scheme, polygon, and polyhedron to optimize the content of essential amino acids. We have developed a new recipe for the composition of cooked sausage with wheat fibre and pumpkin pectin with the optimal proportion of main ingredients: beef grade I – 30%, fatty pork – 50%, WFwPP – 5%, water. Compared to the control sample, the finished product's organoleptic characteristics improved. The basis of the mathematical model for assessing the quality of the developed cooked sausage with wheat fibre and pumpkin pectin was chosen flat model of the polygon, taking into account the time of preservation of product quality, which was assessed as a result of regression analysis. The quality assessment results of the developed products using a computer program for calculating the area of quality profiles with subsequent graphical visualization are consistent with the organoleptic studies, which confirms the reliability of the results and the adequacy of the developed mathematical model.

Keywords: herbal supplement, pectin, chemical composition, biological value, quality indicators, shelf life

INTRODUCTION

One of the most promising ways to meet the human body's physiological needs and vital functions is the production of food products of high biological value, including sausages. Therefore, the relevance of finding new approaches to forming consumer characteristics in cooked sausage recipes through using new ingredients, namely fibre with pumpkin pectin, valuable for functional and technological characteristics, is obvious **[1]**.

It is determined that an effective and promising direction of individual protection of the population from the accumulation of radionuclides in the body is the use of dietary fibre and substances of natural origin that do not have side effects on the body and show a pronounced radioprotective effect **[2]**. Such substances, in particular, include pectin – organic compounds that have the property of forming gels in the presence of organic acids and sugars **[3]**, **[4]**; able to form insoluble complexes with metals in the digestive tract, which are not absorbed but excreted from the body. Food pectin is used as a filler for dairy, confectionery, and meat products, which has many valuable properties of therapeutic and protective action **[5]**, **[6]**. In Germany, boiled sausages are also produced with various herbal additives, allowing the final product to form with a delicate aroma of spicy plants, paprika, etc. **[7]**.

A promising direction in the meat industry is producing products that combine meat and herbal additives capable of biological and nutritional value regulations, taste conservation, and help to balance nutrition to avoid obesity, heart disease, and allergies **[8]**, **[9]**. Thus, the study of the properties of cooked sausages with the addition of wheat fibre enriched with pectin pumpkin, determining the effective structural composition of the product and its evaluation, is the relevance of the analysis.

This scientific work aims to substantiate the structural composition of newly cooked sausages using wheat fibre with pumpkin pectin by conducting organoleptic evaluation and mathematical modelling of quality assessment of developed products **[10]**. To achieve this goal, it is necessary to solve the following tasks: to systematize mathematical models for assessing the quality of the studied products depending on such features as clarity of presentation, depth and volume of information, possible branching of its flows; based on experimental evaluation of the nutritional and biological value of new recipes for cooked sausages to identify the rational content of additives with wheat fibre and pumpkin pectin (WFaPP).

Scientific hypothesis

An increase follows the development of mathematical models for assessing product quality in quantitative and qualitative characteristics of the studied process, which can be reflected with a high degree of clarity by building linear, planar, and spatial models. It is possible to show the patterns of change of each evaluation parameter over time.

MATERIAL AND METHODOLOGY

Samples

The following were used for experimental research:

• grade I boneless beef, in which muscle tissue with a mass fraction of connective and fatty tissue does not exceed 6%, producer Agro firm "Polyssia LTD", Kyiv region, Ukraine;

• boneless semi-fat pork, in which muscle tissue with a mass fraction of fatty tissue from 50% to 85%, producer Agro firm "Polyssia LTD", Kyiv region, Ukraine;

• wheat fibre "Poltermyshung Roth Superior" LLC "TD Lagis" with pumpkin pectin from LLC "Garbuz LTD", country of manufacture Ukraine – according to the product specification, table salt according to DSTU 3583:2015 **[11]**, containing 20.0% pumpkin pectin and 80.0% crushed wheat bran;

• multi-component minced meat, the composition of which includes de-veined semi-fat pork, grade I beef with a vegetable additive in the ratio of 3, 5, 7%;

• white sugar according to DSTU 4623:2006 **[12]**;

• sodium nitrite according to GOST 32781:2014 **[13]**.

Cooked Okrema sausage DSTU 4436:2005 **[14]** was used as a control sample.

Chemicals

Sodium hydroxide, NaOH (grade A, analytical grade, (Khimlaborreakt) Limited Liability Company, Ukraine).

Methyl red, $C_{15}H_{15}N_3O_2$ (grade A, analytical grade, (Khimlaborreakt) Limited Liability Company, Ukraine).

Sulfuric acid, H_2SO_4 (grade A, chemically pure, (Khimlaborreakt) Limited Liability Company, Ukraine).

Petroleum ether, $H_3C\text{-}O\text{-}CH_3$ (excise, analytical grade, (Khimlaborreakt) Limited Liability Company, Ukraine).

Animals and Biological Material

The meat of bulls obtained after slaughter under the age of 12 months and the meat of pigs under the age of 9 months were selected for research (Agro firm "Polyssia LTD", Kyiv region, Ukraine). Enzyme preparation of plant origin - "in vitro", (LLC "Alex", Kyiv, Ukraine)

Instruments

Drying cabinet (SNOL, producer (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Muffle furnace (SNOL, producer (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Fat analyzer (SOX 406, producer (Khimlaborreaktyv) Limited Liability Company, China).

Mineralizer (Velp Scientifica, producer (Khimlaborreaktyv) Limited Liability Company, Italy).

Distiller for steam distillation (Velp Scientifica UDK 129 producer (Khimlaborreaktyv) Limited Liability Company, Italy).

Automatic penetrometer (K95500, producer (Khimlaborreaktyv) Limited Liability Company, USA).

pH meter (HI8314 HANNA, producer (Spectro lab) Limited Liability Company, Ukraine).

Thermometer (digital laboratory thermometer TH310 Milwaukee, producer (Spectro lab) Limited Liability Company, Ukraine).

Laboratory scales (AXIS BDM 3, (Spectro lab) Limited Liability Company, Ukraine).

Laboratory Methods

The indicator characterizing the chemical composition of sausage products was determined according to standard methods:

- the mass fraction of moisture was determined by the drying method according to DSTU ISO 1442:2005 **[13]**;
- fat content was determined by the Soxhlet method according to DSTU 8380:2015 **[14]**;
- the proportion of protein was determined by the Kjeldahl method **[50]**;
- the degree of ashing using the Velp Scientifica DK6 device to determine the mass fraction of ash. The weight method was used according to DSTU ISO 936:2008 **[15]**.
- the study of active acidity was carried out by determining the pH according to DSTU ISO 2917:2001 **[16]**.
- mass fraction of protein - according to the Lowry method when using Folin's reagent, as a result of which a compound is formed that gives a blue colour to the protein solution **[17]**;
- fibre content - by the weight method of Kürschner and Hanek when boiling a portion of the product with an acid mixture in a reflux flask followed by filtering the solution and washing the precipitate with a hot acid mixture, water, and ether **[18]**;
- the content of pectin substances - by the titrimetric method, which is based on alkali titration of previously selected and prepared pectin substances before and after hydrolysis; • amino acid composition - by the method of ion exchange chromatography **[19]**;
- the moisture-binding capacity of product samples - by the Grau-Hamm press method in the modification of V. Volovynska and B. Kelman **[20]**;
- plasticity of minced meat - by the method of pressing according to the area of the meat stain on filter paper; content of micro toxin patulin - by liquid chromatography with spectrophotometric detection **[21]**;
- content of heavy metals - by atomic absorption method **[51]**;
- the content of radionuclides - by the gamma spectrometric method.
- the temperature of the samples was determined using a TH310 Milwaukee thermometer.
- samples were weighed using AXIS BDM 3 scales.

Description of the Experiment

Sample preparation: Samples were selected and prepared according to DSTU 7992:2015 **[22]**. On whole (uncut) sausage products, all samples' appearance, colour, and surface condition met the requirements of regulatory documents. The polyamide shell was dry, strong, and elastic, without mucus stains and mould deposits, without damage, which tightly adhered to the minced meat. The consistency when pressing with a finger on the surface of the sausages was dense. Sausage products cut into thin pieces were characterized by the following indicators: the appearance and pattern on the cut were typical for cooked sausages in samples with 1%, 3%, and 5% of the studied vegetable additive. In the process of preparing suspensions and emulsions, a weight of 2 g containing 0.5 g of water or vegetable oil, 1 g of the drug was composed; mixed to a homogeneous consistency, and transferred to glass centrifuges with a volume of 30 ml; placed in a thermostat with temperature t = 74 °C – 76 °C; kept for 15 minutes; the tubes were cooled with cold water to room temperature and centrifuged in an OPN centrifuge at 1500 rpm for 15 min. Microbiological studies of products were carried out on finished products immediately after preparation, as well as after 4, 8, 10, 12, and 15 days of storage in the refrigerator (+0 °C – +6 °C). The swelling coefficient was determined when the mesh was placed in water or oil for 15 minutes, after which it was removed, and the liquid was allowed to drain for 20 minutes and weighed.

Number of samples analyzed: Four types of sausages with different moisture content and shelf life were used to study samples.

Number of repeated analyses: The study was repeated 5 times, with the experimental data processed using mathematical statistics.

Number of experiment replication: Each study was carried out five times, and the number of samples was three, resulting in fifteen repeated analyses.

Design of the experiment: In the first stage, a study of the physicochemical parameters of the studied herbal supplement was carried out, namely, the amino acid composition of its proteins and mineral and vitamin composition. Based on the obtained indicators, the energy value, coefficients: protein, protein-water, fat-water, nutritional saturation, potential biological value, and the essential amino acid composition of the protein were calculated; as an indicator of excess content and index of essential amino acids. In the second stage, the development and substantiation of the technology of boiled sausages were carried out. The third research stage characterised finished cooked sausages according to organoleptic, physicochemical, biochemical, microbiological, and rheological indicators. The experimental results were conducted using the mathematical model of the polygon according to the characteristics presented in Figure 1.

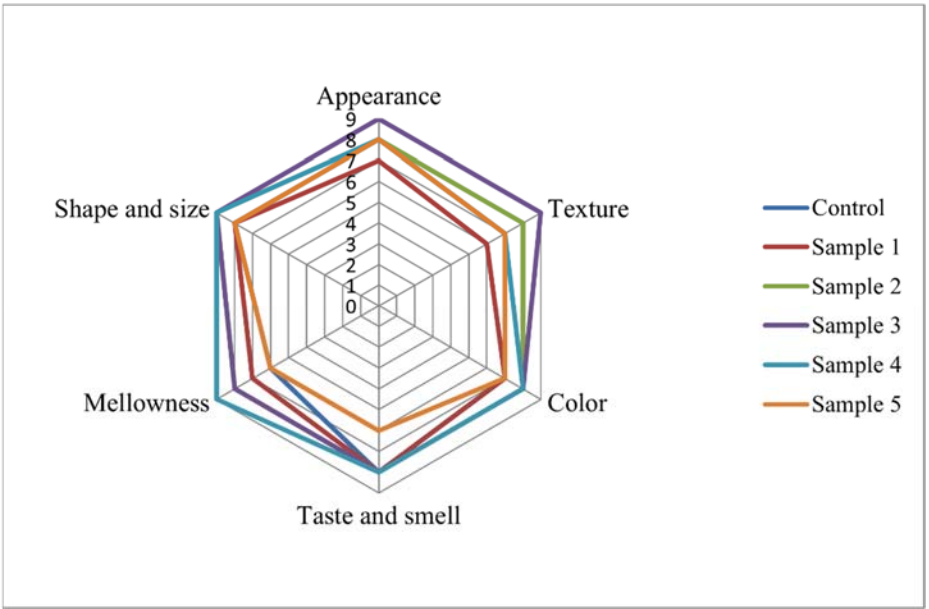


Figure 1 Organoleptic evaluation of recipes for cooked sausages with different amounts WFAPP: No. 1 – 1 %; No. 2 – 3 %; No. 3 – 5 %; No. 4 – 7 %; No. 5 – 9 %.

Statistical Analysis

The results were evaluated by standard methods using statistical software Statgraphics Centurion XVII (StatPoint, USA) – multifactor analysis of variance (MANOVA), LSD test. Statistical processing was performed in Microsoft Excel 2016 in combination with XLSTAT. Values were estimated using mean and standard deviations. The reliability of the research results was assessed according to the Student's test at a significance level of $p \leq 0.05$

RESULTS AND DISCUSSION

In developing and substantiating the mathematical model for assessing the quality of cooked sausages with the proposed ingredients, the following main properties of it were used clarity of presentation, depth and volume of information, and possible branching of its flows. Similar experiments are described in many scientific works, but they were conducted to evaluate the quality indicators of dairy products **[23]**, bakery products **[24]**, and canned meat **[25]** with a long shelf life. Linear, flat, and spatial estimation models were developed according to such evaluation criteria.

In the linear beam model, the parameter l_0 corresponds in value to the reference indicator of the quality of this product, which the maximum possible units can conditionally represent. The values $l_i = x_i = l_0 \cos\alpha_i$ correspond to the values of accurate production indicators according to the selected evaluation criterion or for the family of indicators X_i derived from the main reference. In several scientific papers, which are related to the modelling processes related to the production of sausage products, various models are presented, in which up to 10 main parameters were used **[26]** without taking into account reference indicators or only one reference indicator **[27]**, due to which the reliability of the results, which were obtained rather difficult to verify. The authors of the paper **[28]** carried out a modelling process where only 2 parameters were used. The reliability of such results may be quite imprecise.

In the presence of two prevailing or basic quality indicators, it is convenient to use a radial flat model in which reference indicators are presented on coordinate axes x, and y. When the number of prevailing or basic quality indicators is three, it is convenient to use a radial spatial model (Figure 2), in which the values of real indicators according to the selected evaluation criteria correspond to the families of indicators X_i, Y_i, and Z_i, which are derived from the main reference parameters x, y, z and are estimated at up to 10 units. Similarly, for this scheme, as a criterion for evaluating the radial spatial model, it is advisable to choose the following parameters.

$$\begin{cases} k_x = \dfrac{IL\,cos\,I\,\pm_i}{n} \\ k_y = \dfrac{IL\,cos\,I?_i}{n} \\ k_z = \dfrac{IL\,cos\,Il_i}{n} \end{cases} \quad (1)$$

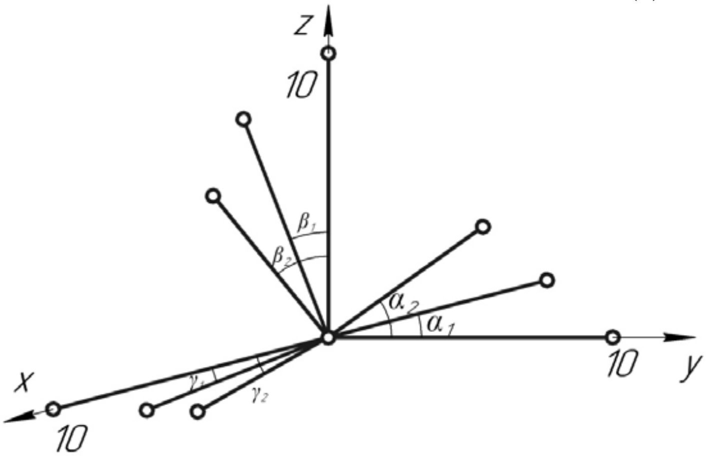


Figure 2 Radiation spatial model of product quality.

Features of the developed radial models of product quality are:
- effective assessment of extensive methods of quality assessment;
- it is advisable to evaluate up to 3 methods;
- requires large enough arrays of experimental research;
- ease of assessment.

When the rays of the shades, which reflect the prevailing or basic indicators of product quality, are set aside from a single centre, the boundary points form a shape in the form of a polygon. The number of angles in this figure shows the reference parameters used to assess the quality of certain products. Similar attempts to conduct a similar type of modelling are described in several manuscripts, but in our opinion, they had several shortcomings; in one case, only the parameters of the standard were taken into account **[29]**, and in the next series of experiments organoleptic evaluation was not carried out **[30]**, and in the third case, the physical and chemical composition was investigated. Only one reference parameter was taken into account **[31]**.

For simplifying the geometric construction of such figures, it is advisable to conduct them depending on the even (Figure 3 a) or odd (Figure 3 b) number of angles. In the case of estimating the basic reference parameters by a certain equal value, for example, up to 10 units, the constructed regular polygon corresponds to the ideal product; if to achieve the "ideal" it is enough to use a given number of reference parameters. Estimation of similar parameters using different values, for example, from 1 to 6 with a step of 2 units **[32]**, from 1 to 4 with a step of 2 units **[33]**, and from 1 to 3 with a step of 1 **[34]**, and also build irregular polygons cannot correspond to perfect products. One cannot agree with the statement that to achieve the "ideal" it is enough to use only a limited number of reference parameters in the range from 1 to 3 **[35]** or from 3 to 30 **[36]** or only to take into account the parameters of the input raw materials **[37]** such statements should be verified by conducting simulations using software with visualization of the results.

Deferring the numerical values of the accurate indicators of product quality for the corresponding rays, we obtain a figure inside the regular reference polygon. Comparing the areas of the presented figures allows us to estimate the approximation of the developed products visually to an ideal condition on the selected reference indicators. Therefore, for this scheme as an evaluation criterion, it is advisable to choose the following parameter.

$$k_S = \frac{S_{Dz}}{S_{DI}} \quad (2)$$

Where:

S_n – cross-sectional area according to the actual condition of the product; – the area of an ideal section on reference or absolute indicators of production quality.

The formula can find the area of an ideal section:

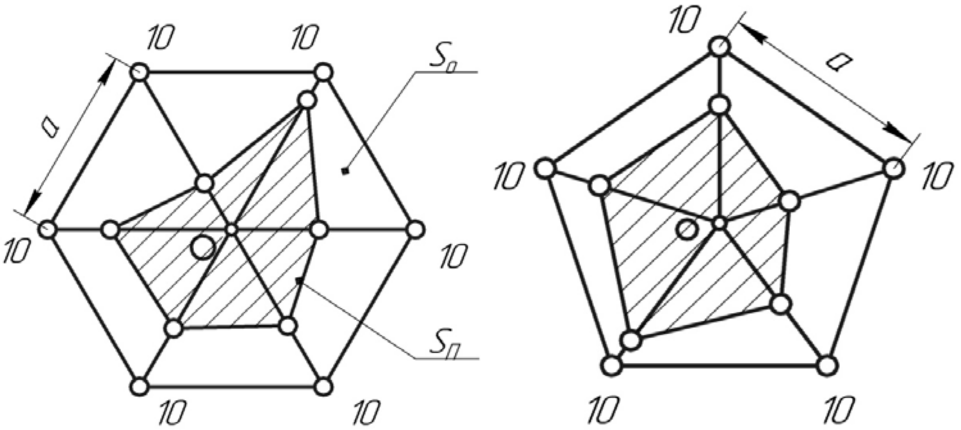
$$S_{Dl} = \frac{ma^2}{4tg\left(\frac{180}{m}\right)} \quad (3)$$

Where:

m – is the number of sides of the polygon; a is the value of the side face of the polygon (Figure 3).

Features of the developed flat mathematical model of product quality in the form of a polygon are:

- clarity of assessment;
- the ability to evaluate any number of parameters;
- the ability to adjust the accuracy of the assessment;
- relatively simple assessment with a small number of areas of assessment.



a b

Figure 3 Polygon models of product quality assessment by even (a) and odd (b) number of reference parameters.

To estimate the retention time of certain quality indicators of the product, it is advisable to implement the spatial scheme of the mathematical model in the form of a polyhedron, which is presented in Figure 4.

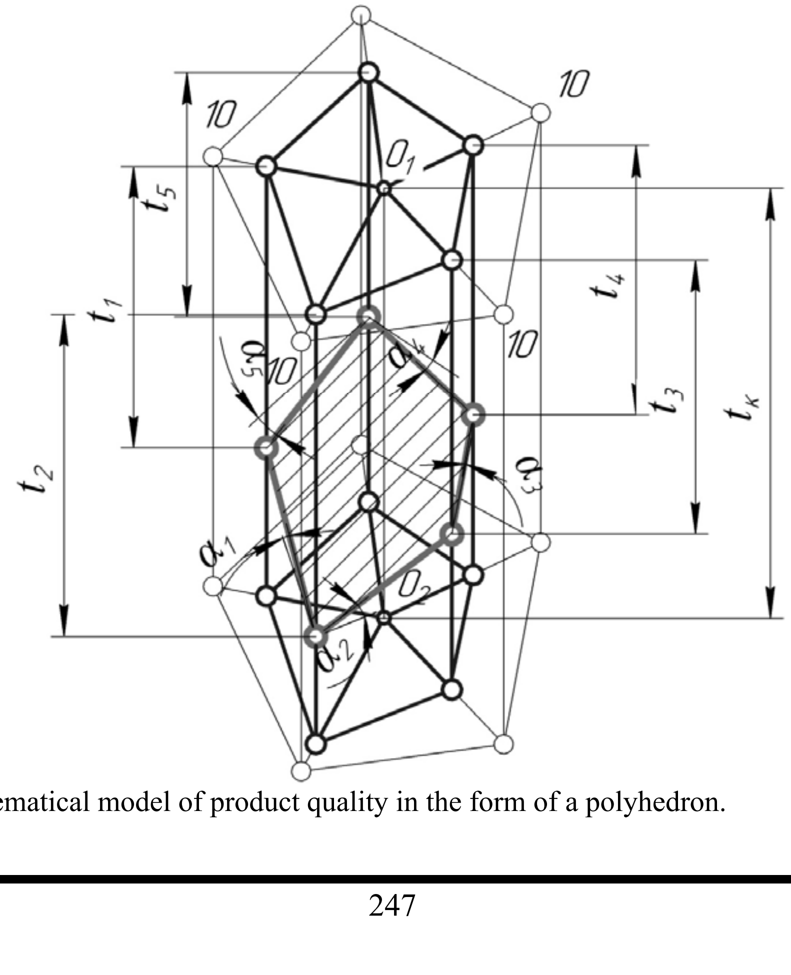


Figure 4 Spatial mathematical model of product quality in the form of a polyhedron.

According to this scheme, polygons make up the area of the base and the time of preservation of product quality – the height of the polyhedron. In the case of estimating the basic reference parameters by a certain equal value, for example, up to 10 units, the constructed correct polyhedron corresponds to the ideal product for a given number of reference parameters. The height of the polyhedron corresponds to the control period of storage of the product as a whole t_k .

Similar studies are described in the scientific works of L. Bal-Prylypko, which are devoted to the design of technological equipment **[38]**, **[39]**, the production of sausage products **[40]**, **[41]**, the development of technological schemes for the production of various products of the food industry **[42]**, but without taking into account time parameters that can affect the quality indicators of the final products. Deferring the numerical values of the real indicators of product quality for the corresponding rays, we obtain a figure inside the reference regular polyhedron. The height of each face of the constructed figure t_i corresponds to the product's shelf life according to certain quality parameters. This figure reflects the quality of the developed product in the spatial form: the approximation of the real polyhedron to the correct corresponds to its approximation to the "ideal".

Among the parameters that assess the quality of products, we can specify the following:

The average shelf life of quality parameters:

$$t_c = \frac{ILt_i}{m} \tag{4}$$

The average angle of deviation of the faces of a real polyhedron from the faces of the reference; - angles of deviation of the truncated base depending on the shelf life for certain quality parameters, where m is the number of sides of the polygon.

$$I \pm_c = \frac{ILI\pm_i}{m} \tag{5}$$

Comparing the volumes of the presented figures allows us to visually assess the approximation of the developed products to the ideal state according to the selected reference indicators. Therefore, for this scheme as an evaluation criterion, it is advisable to choose the following parameter.

$$k_v = \frac{V_{Dz}}{V_{Dl}} \tag{6}$$

Where:

$V_{Dl} = S_{Dl} a‹ \ldots t_k$ – the volume of the reference prism; t_k – control period of product storage;

$V_n = \frac{S_{Dz}}{\cos I\pm_c} a‹ \ldots t_{Nŕ}$ – the volume of the truncated prism according to the real quality parameters;

t_i – shelf life of products according to certain real quality parameters.

Features of the developed spatial mathematical model of product quality in the form of a polyhedron are: – the ability to take into account the shelf life of products for individual quality parameters; – clarity of assessment with a large number of quality parameters; – high accuracy of assessment; – the complexity of analytical calculations. Given the latter shortcoming, the flat model of the polygon was chosen as the basis of the mathematical model for assessing the quality of the developed cooked sausage with wheat fibre and pumpkin pectin (WFwPP), taking into account the time of preservation of product quality, which was evaluated by regression analysis. The results of the assessment of organoleptic characteristics of cooked sausages with vegetable additive WFwPP on a 5-point scale are shown in Figure 5.

During the tasting evaluation of boiled sausages, depending on the studied factors, it was found that partial replacement of raw meat in minced cooked sausages with vegetable supplement wheat fibre with pumpkin pectin does not reduce their organoleptic characteristics. We have analyzed the results of other scientific works in which the process of production of cooked sausages **[43]**, sausages **[44]**, and semi-finished products **[45]** with the addition of plant materials.

Supplementation with WFwPP in sausages from 7% to 9% led to a deterioration of the structure in the sausage section. The tasting of sausages allowed us to determine the product's smell, aroma, and taste, as well as the absence of foreign odours and tastes in the variants of samples with meat substitution from 1% to 5% of WFwPP. The increase in the concentration of WFwPP led to the appearance of pumpkin flavour. According to the consistency index, when pressing portions of sausages, a dense consistency was felt in 3% and 5% WFwPP. Increasing the concentration of plant additives from 7% to 9% led to a more rigid consistency and unsatisfactory organoleptic characteristics. An analysis of scientific works was carried out, which were devoted to the introduction of various concentrations of plant additives into the composition of various meat and dairy products **[46]**, in particular, pectin from carrots and apples **[47]** and fibre from various bowls of cereal **[48]**.

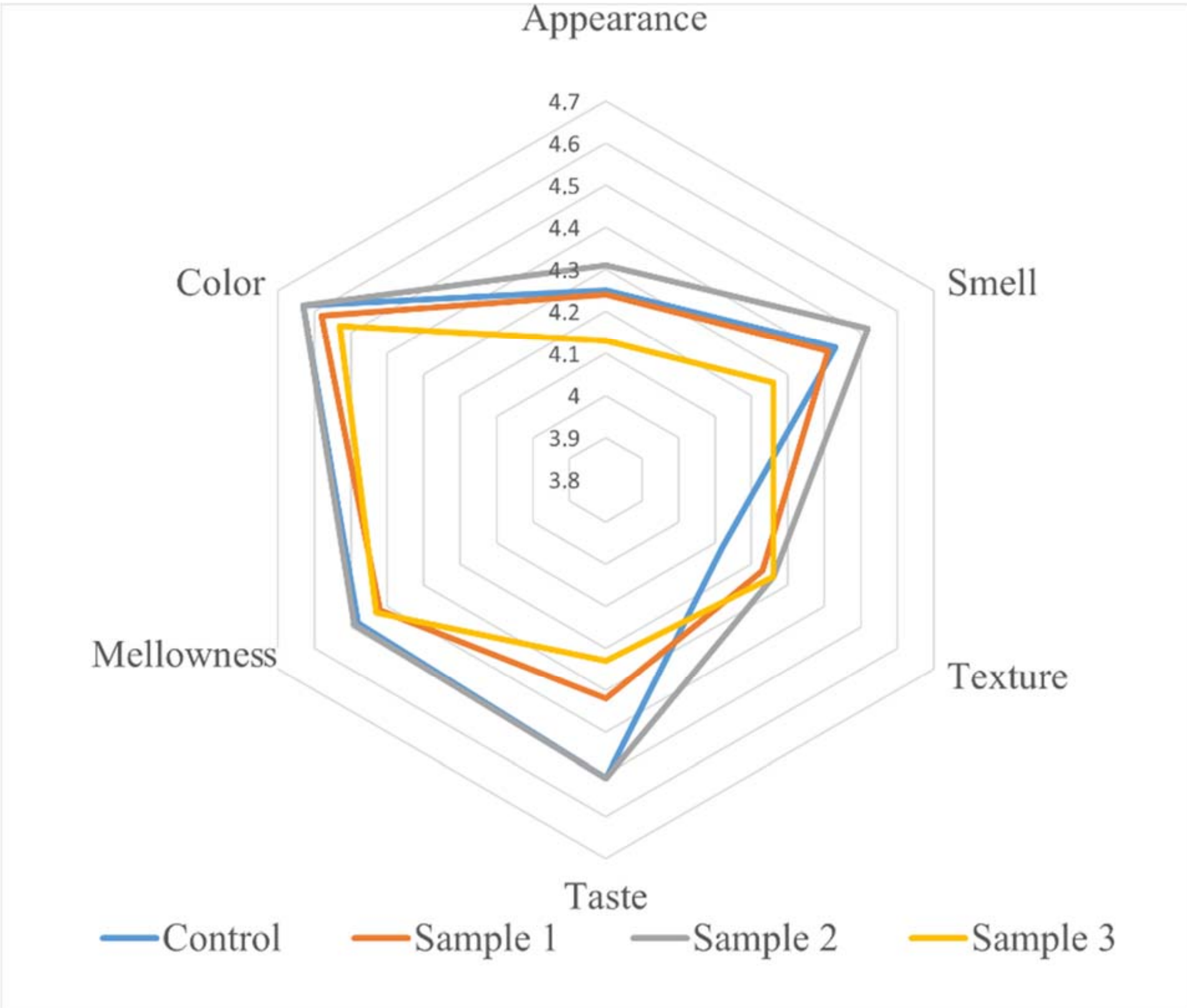


Figure 5 Profile of organoleptic parameters of cooked sausage samples with different content of WFwPP.

Considering the results of our experiments, we can say that an increase in the concentration of plant raw materials by more than 5% will lead to the appearance of a carrot or apple aftertaste, which in turn worsens the quality of finished products.%

Analysis of the aftertaste of sausages showed the best result regarding tenderness and juiciness in the sample with 5% WFwPP. In particular, the overall score of the experimental samples was in samples No. 1 – 4.44; No. 2 – 4.51; No. 3 – 4.41 points against 4.49 – In control. According to the results of the scores, the best sample is No. 2, with the content of WFwPP in 5%.

These studies also found that cooked sausages, besides the stuffing of various amounts of vegetable additives WFwPP on organoleptic indicators, had a pleasant taste, smell, colour, and texture. In second place was the quality indicator sample No. 3 with 7% WFwPP. The indicators of the control sample and No.1 with 3% of WFwPP were almost identical. The general analysis of the conducted research showed that the use of cooked sausages with vegetable additive in the amount of 5% by weight of minced sausage, namely wheat fibre with pumpkin pectin, does not reduce their quality in organoleptic parameters, and this product meets the requirements of regulatory and technical documentation. Comparative analysis of the evaluation of sausages according to the developed recipes 1, 2, and 3 with the control product and when used as a criterion for the ratio of the respective areas of the polygon is presented in Figure 6.

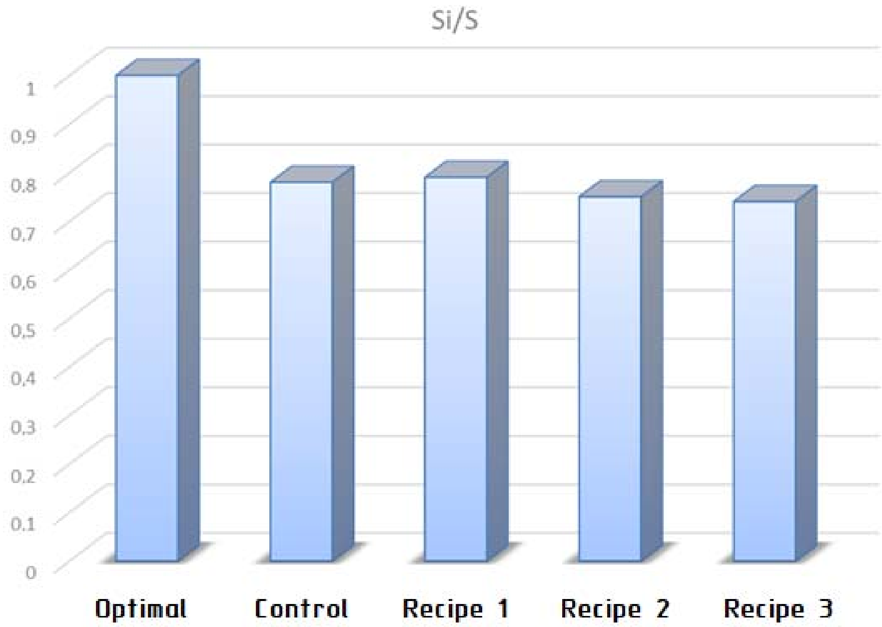


Figure 6 Comparative analysis of control and experimental samples of sausages.

The quality assessment results of developed cooked sausages using a computer program for calculating the area of quality profiles with subsequent graphical visualization are consistent with previous organoleptic studies by the classical method, confirming the research results' reliability.

The results of research on the appearance of the experimental and control samples are presented in Figure 7.

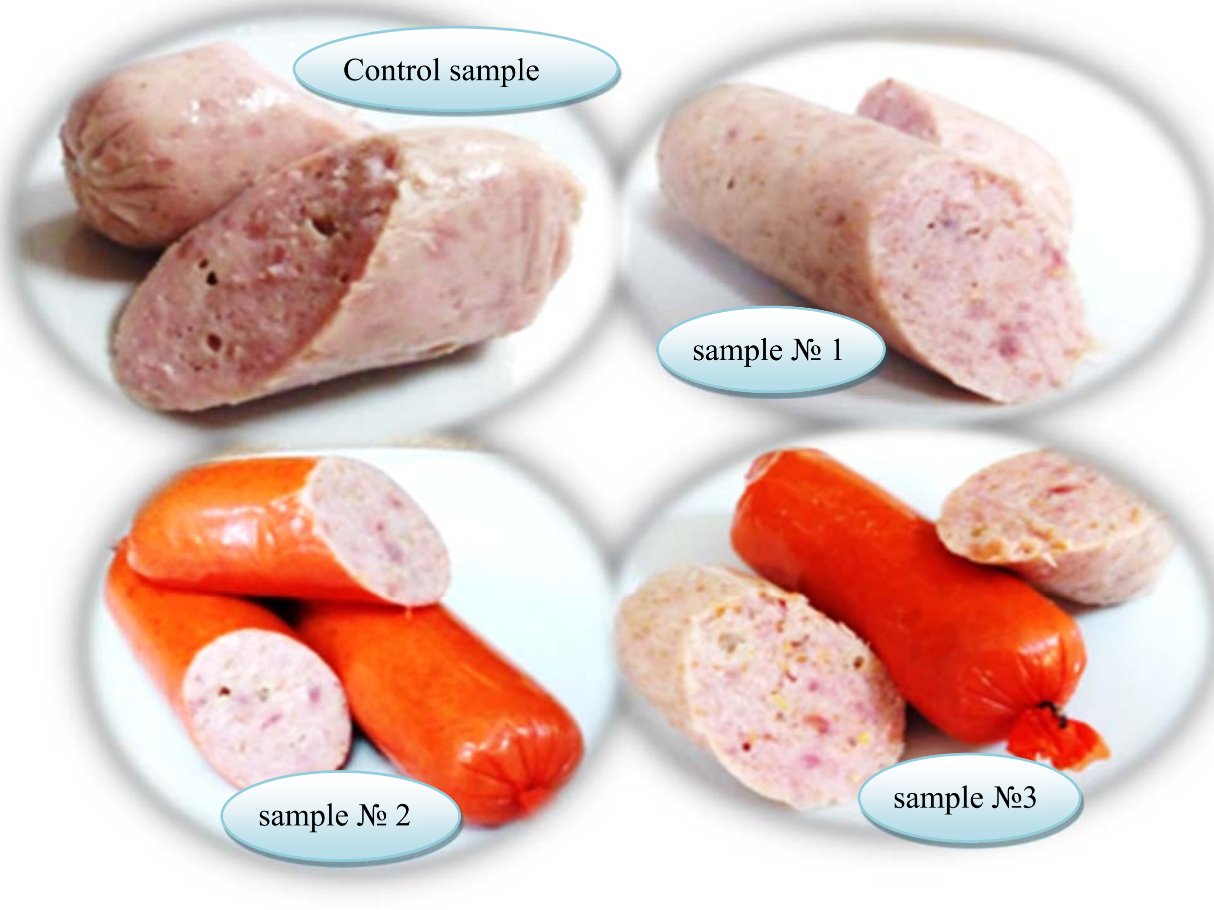


Figure 7 Appearance of samples of newly cooked sausages and control sample.

%

Analyzing Figure 7, which shows the appearance of the organoleptic indicators of the newly finished cooked sausage, it can be concluded that sample No. 1 had a loose, loose consistency; sample No. 2 has a dense consistency, proper plasticity and juiciness, and sample No. 3 has a denser consistency and unsatisfactory organoleptic indicators. Thus, using wheat fibre with pumpkin pectin in the amount of 5% ensures the consistency of the finished new sausage, which meets the requirements of the relevant regulatory documentation.

The final product must meet the basic food safety requirements applicable in the country of destination **[49]**.

Prospects for further research are related to the modelling of nutritional value indicators of similar sausage products and quality control of finished sausage products, which includes the selection of control points according to the system of risk analysis, dangerous factors, and control of critical points of HACCP, as well as optimization of production processes and determination of rational equipment parameters for production of sausage products from land and waterfowl meat.

CONCLUSION

Taking into account the main properties of the mathematical model for evaluating the quality of cooked sausages with the proposed ingredients: clarity of presentation, depth, the volume of information and possible ramifications of its flows, an appropriate systematization was carried out, and linear, flat and spatial evaluation models were developed in the form of a ray diagram, a polygon and a polyhedron.

The use of this type of model made it possible to evaluate the extensive methods of quality indicators effectively and to evaluate the corresponding number of parameters with high accuracy, to regulate the accuracy of the assessment with a small number of reference parameters, and take into account the duration of the shelf life of finished products according to individual quality parameters.

The results of the evaluation of the quality of the developed products according to the polygon model revealed that the replacement of raw meat increased by up to 9% WFwPP in the recipe of cooked sausages reducing the intensity of taste and aroma, giving a specific taste, negatively affects the juiciness. According to such indicators as consistency, color, smell, taste, and appearance were the best experimental samples using 5% WFwPP; according to the overall score, the best results are obtained when making these additives in the amount of 3% to 5%.

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