Современная наука и инновации.
2024. № 1 (45). С. 71-79.
Modern Science and Innovations.
2024;1(45):71-79.

ТЕХНОЛОГИЯ ПРОДОВОЛЬСТВЕННЫХ ПРОДУКТОВ /
TECHNOLOGY OF FOOD PRODUCTS

Научная статья / Original article

УДК 664
https://doi.org/10.37493/2307-910X.2024.1.7

Владимир Всеволодович Садовой
[Vladimir V. Sadovoy][1*],
Татьяна Викторовна Щедрина
[Tatiana V. Shchedrina][2],
Алла Смалиевна Хамицаева
[Alla S. Khamitsaeva][3],
Ирина Александровна Трубина
[Irina A. Trubina][4]

Нейросетевая разработка рецептурных составов пищевых продуктов, и оценка качественных характеристик готовых изделий

The Neural network development of food formulations and evaluation of the quality characteristics of finished products

[1]Белгородский университет кооперации, экономики и права, Ставропольский институт кооперации (филиал), г. Ставрополь, Россия / Belgorod University of Cooperation, Economics and Law, Stavropol Institute of Cooperation (branch), Stavropol, Russia
[2]Северо-Кавказский федеральный университет, Пятигорский институт (филиал), г. Пятигорск, Россия North-Caucasus Federal University, Pyatigorsk Institute (branch), Pyatigorsk, Russia
[3]Горский государственный аграрный университет, г. Владикавказ, Россия / Gorsky State Agrarian University, Vladikavkaz, Russia
[4]Ставропольский государственный аграрный университет, г. Ставрополь, Россия / Stavropol State Agrarian University, Stavropol, Russia

****Автор, ответственный за переписку: Владимир Всеволодович Садовой, vsadovoy@yandex.ru / Corresponding author: Vladimir V. Sadovoy, vsadovoy@yandex.ru***

Аннотация. *С помощью статистических методов визуализации экспериментальных данных обосновано использование искусственного интеллекта для разработки оптимальных по качественным характеристикам рецептур пищевых продуктов. На примере колбасных изделий разработана методика идентификации рецептурного состава пищевых продуктов для сравнения с показателями технической документации. Оценка адекватности химического и аминокислотного составов рецептур технической документации подтвердила эффективность разработанной методики.*

Ключевые слова: статистическая обработка результатов, искусственный интеллект, химический и аминокислотный составы, идентификация, качественные характеристики

Для цитирования: *Садовой В. В., Щедрина Т. В., Хамицаева А. С., Трубина И. А. Нейросетевая разработка рецептурных составов пищевых продуктов, и оценка качественных характеристик готовых изделий // Современная наука и инновации. 2024. № 1 (45). С. 71-79. https://doi.org/10.37493/2307-910X.2024.1.7*

Abstract. *Using statistical methods of visualization of experimental data, the use of artificial intelligence for the development of optimal food formulations in terms of qualitative characteristics is justified. Using the example of sausage products, a method for identifying the prescription composition of food products has been developed for comparison with the indicators of technical documentation. The assessment of the adequacy of the chemical and amino acid compositions of the formulations of the technical documentation confirmed the effectiveness of the developed methodology.*

Keywords: statistical processing of results, artificial intelligence, chemical and amino acid compositions, identification, qualitative characteristics

For citation: *Sadovoy VV, Shchedrina TV, Khamitsaeva AS, Trubina IA. The Neural network development of food formulations and evaluation of the quality characteristics of finished products. Modern Science and Innovations. 2024;1(45):71-79. https://doi.org/10.37493/2307-910X.2024.1.7*

Introduction. The production of food products with high quality characteristics is a priority task for the food industry. The use of various food additives in food formulations often helps not only to improve functional performance and adjust the chemical composition of finished products, but also to reduce their nutritional value and cost. In the pursuit of profit, sometimes there is non-standard use of various food ingredients, which has a negative impact on the quality of products. The use of additives in quantities that do not meet the requirements of regulatory and technical documentation can lead to gastrointestinal disorders, skin diseases, high blood pressure and other pathological changes in the human body [1, 2, 3, 4, 5, 6].

Therefore, it is important to produce products that meet the requirements of technical documentation and constantly pay attention to improving technology, increasing nutritional value, and also be able to control the chemical composition, functional and technological indicators and nutritional value of manufactured products. To carry out these activities, it is necessary to have modern laboratory equipment and master the methods of mathematical planning and statistical processing of experimental data.

Technological processes in the food industry are complex and diverse and are usually difficult to describe using standard statistical methods.

Currently, there are a large number of computer applications that make it possible to carry out mathematical planning, process experimental data and determine the optimal conditions of technological processes and the recipe composition of food products. These most famous applications include Statistic, SPSS Statistics, Statistical Neural Networks, Math Lab, Net Logo and others. Recently, researchers in the field of biotechnology and food industry have been widely using artificial intelligence.

Materials and research methods. The purpose of the research was to develop a methodology for optimizing the recipe composition of food products based on the use of artificial intelligence and assessing the main indicators of the chemical composition of finished products.

To achieve this goal, the following tasks were envisaged:

- justify the feasibility of using artificial intelligence to optimize recipe compositions of food products;
- using the method of mathematical planning and processing of experimental data, develop a recipe for boiled sausage;
- perform an analysis of the chemical and amino acid composition of the developed recipe;
- to develop a method for determining the component composition of the finished product formulation based on the results of a study of chemical and amino acid compositions.

To create a data array on the chemical and amino acid compositions (with the exception of control and experimental samples) of the recipes, we used literary sources [7], and calculations were carried out in Excel [8, 9]. Experimental and control model samples of boiled sausages were produced in laboratory conditions. The chemical composition of finished products was determined using a FOSS analyzer FoodScan 2 Meat, a KNAUER modular amino acid analyzer was used to determine the amino acid composition of products.

Experiment planning and data processing were carried out in the STATISTICA application v.13. The Statistic application was used to create and process arrays Neural Networks v.4 e. Comparison of the composition of recipe options was carried out in the Time application Clast. Each experiment was carried out in 3-5-fold repetitions; in case of detection of errors and misses, the number of repetitions of the experiment was increased [10, 11, 12, 13].

Research results and their discussion. To justify the use of artificial intelligence and as an example, consider a diagram characterizing the influence of the chemical and amino acid compositions of food product formulations (in this case, boiled sausages) on the quality indicators of finished products (Fig. 1).

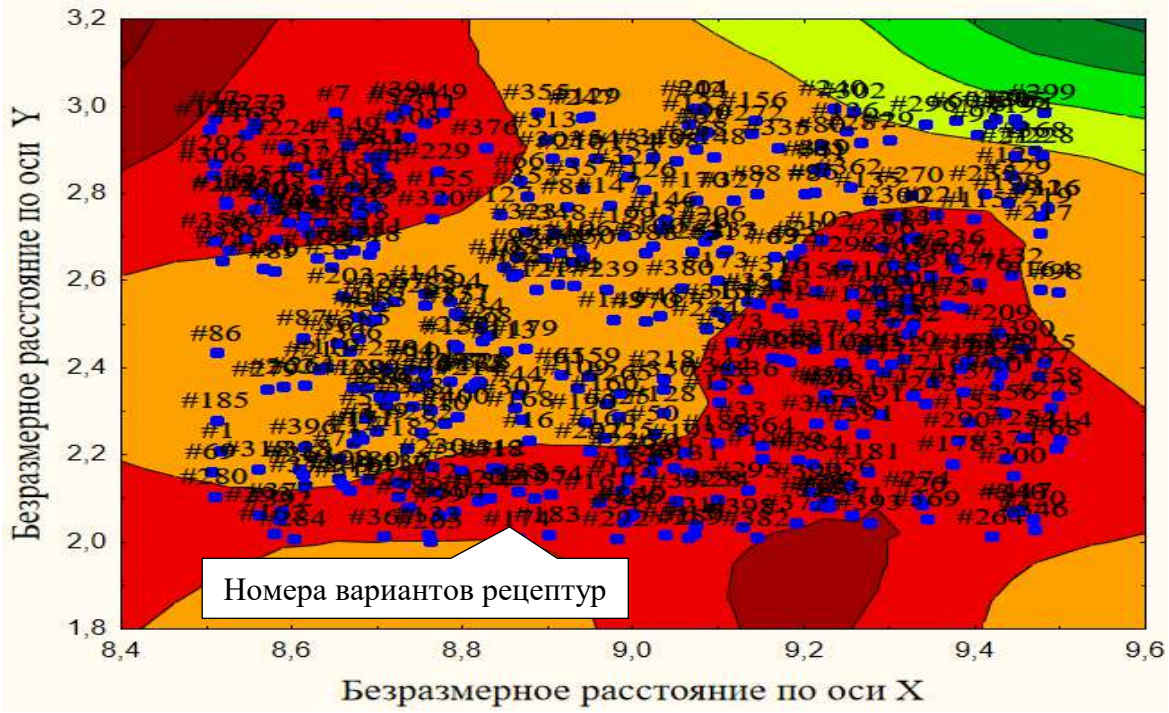

Figure 1 – Diagram of neural network approximation of the influence of the recipe composition of food products on the functional indicators of finished products

The presented diagram was compiled by processing matrix data of factors (formulation components) and output variables (technological and functional indicators) using neural network technologies for creating an array of indicators and multidimensional scaling. In order to visually analyze the process and determine the optimal recipe option, it is necessary to implement a planning matrix, that is, determine all the quality indicators of the recipes using the matrix. Then the neural network architecture should be developed and trained so that it accurately (with a given level of probability) describes the experimental data.

The next stage is to create an array of input variables (factors), usually the Pascal algorithmic language is used to implement this task. The resulting array of factors is processed using a trained neural network, that is, functional indicators are calculated for each variant of the array. Multidimensional scaling is then carried out: factors (formulation components) are scaled into a two-dimensional dimension; functional indicators – into one-dimensional ones. Scaling data is used to visualize the process of influence of the recipe composition on the quality characteristics of finished products. If you plot the array options (experiment numbers) on the graph, you can easily determine the optimal recipe composition.

Current Technical documentation for finished products usually regulates the chemical composition, organoleptic, microbiological characteristics and product yield in relation to the mass of raw materials. However, it should be noted that these indicators do not allow us to effectively assess the compliance of the formulation with regulatory requirements.

Each food additive is unique in its chemical and amino acid composition, therefore, depending on the types of raw materials and food additives used (meaning protein supplements), the chemical and amino acid composition of the finished product will be unique. Modern methods of analysis and the laboratory equipment used make it possible to quickly and accurately determine the chemical and amino acid compositions of raw materials and finished products; only a technique is needed to identify food compositions based on the results of laboratory tests.

The development of a methodology for assessing the recipe composition of food products will protect the consumer from the appearance of substandard products on the market.

As components of the recipes, we used trimmed raw meat (pork and beef) of all varieties, lard, cheek, chicken eggs, beef liver, pork brisket and skin, sodium caseinate, soy isolate, gelatin and other components. The research was carried out at four levels of the Greco-Latin square design. A fragment of the limits of variation of factors (formulation components) is presented in Table. 1. For each experiment of the plan, the chemical and amino acid compositions were calculated using Excel.

Table 1 – Fragment of indicators of the limits of factor variation

No. p/p	Formulation components	Values of factors in dimensionless dimension			
		0.00	0.33	0.67	1.00
		Indicators in natural values, kg			
1	Beef trimmed in. With.	0.0	33.0	67.0	100.0
-"-	- “ -	- “ -	- “ -	- “ -	- “ -
9	Lard or cheek	0.0	13.3	26.7	40.0
-"-	- “ -	- “ -	- “ -	- “ -	- “ -
25	Soy isolate	0.0	1.0	2.0	3.0

Based on the results of processing the planning matrix, a neural network in the form of a multilayer perceptron was developed, and then an array of input variables was created (including 17,026 recipe options) in order to evaluate the intermediate variety of composition options. The calculation of the functional indicators of each variant of the array (chemical and amino acid compositions) was carried out using a neural network. It should be noted that since the studies were carried out on meat products, when analyzing the amino acid composition, it is advisable to determine the amino acid hydroxyproline, which is a characteristic representative of connective tissue proteins. A fragment of data for calculating the chemical and amino acid compositions of array recipes by a neural network is given in Table. 2.

To test the effectiveness of the Kohonen neural network, two prototypes of the highest-grade Stolichnaya boiled sausage were made:

1 – in accordance with the recipe of GOST 23670-2019 [14];

2 – with the replacement in the main recipe (according to GOST) of 2 kg of premium beef with hydrated soy isolate.

Table 2 – Fragment of the calculation of the chemical and amino acid compositions of an array of formulation compositions

Recipe Composition Options	Dry residue, %	Protein, %	Protein, % dry matter	Fat, % dry matter	Isoleucine, g/100g protein	Leucine, g/100g protein	Methionine+cystine , g/100g protein	Lysine, g/100g protein	Phenylalanine+tyrosine , g/100g protein	Valine, g/100g protein	Threonine, g/100g protein	Tryptophan, g/100g protein	Hydroxyproline , g/100g protein	Amount of NAC, g/100g protein
1	31.22	24.06	79.46	6.96	4.00	7.03	3.71	7.57	7.87	5.30	4.06	1.11	0.23	40.66
- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -
897	31.43	23.84	78.19	7.75	4.04	7.10	3.74	7.62	7.86	5.33	4.09	1.13	0.27	40.89
- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -
1297	39.25	30.08	79.03	8.61	4.04	7.14	3.65	7.42	8.05	5.35	4.08	1.14	0.24	40.89
- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -	- “ -
Sampl e	22. 60	17.9	78.40	5.10	4.30	7.5	3.80	7.60	8.20	5.70	4.30	1.20	0.20	41.4
Stand ard -	22.52	17.25	74.88	4.95	3.90	6.85	3.50	7.02	7.88	5.16	3.90	1.10	0.19	39.31
Stand ard	23.71	18.16	78.82	5.21	4.10	7.21	3.68	7.39	8.29	5.43	4.10	1.16	0.20	41.36
Stand ard +	24.90	19.07	82.76	5.47	4.31	7.57	3.86	7.76	8.70	5.70	4.31	1.22	0.21	43.43

The 1st sample in the database was designated by the term Standard, the 2nd sample with soy isolate - Sample. At the same time, the recipe and calculated indicators (chemical and amino acid compositions) of the highest grade boiled Stolichnaya sausage were entered into the array of variables, taking into account the deviation of the composition of each component of ±5% (Standard + and Standart –), as well as indicators obtained as a result of studying the chemical and amino acid compositions a standard sample of top-grade boiled Stolichnaya sausage (Standard) and a product with soy isolate (Sample).

A preliminary assessment of the chemical and amino acid composition data set was performed using unsupervised learning of Kononen maps in the application Time Clast (Fig. 2, 3). The fullness of cluster cells (Fig. 2) characterizes the quantitative content of variants in each cluster. Each cluster contains similar variants in the composition of the recipes. As a result of cell analysis, it was established that samples Sample, Standart -, Standard, Standart + are in the same cluster - No. 7, which indicates the similarity of the chemical and amino acid compositions and, therefore, the formulations of these variants. If you change the program task and reduce the number of cluster zones, you can determine the location of the sample by replacing 2 kg of premium beef with hydrated soybean isolate in the main recipe (Fig. 4).

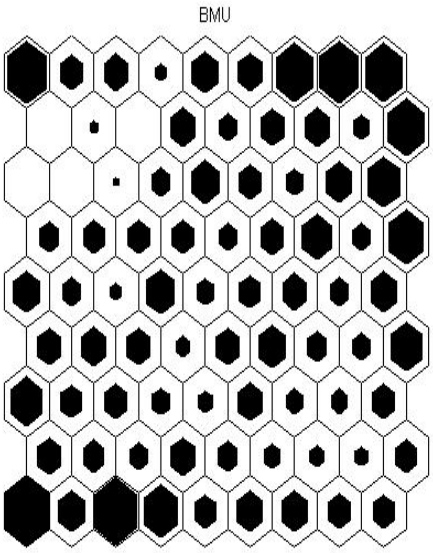

Figure 2 – Cluster cells Kohonen neural network

```
Cluster N. 6

1340
1341
1342

N. of elements for the cluster:3

Cluster N. 7

Sample
Standart-
Standart
Standart+
```

Figure 3 – Clustering listing fragment

The cluster under study, consists of 61 recipe options, includes all compositions of interest (Sample, Standart -, Standart, Standart +), which are located in close proximity to each other.

Figure 4 shows that Sample is located in close proximity to Standard and Standard +. If we analyze the composition of the Sample recipe using matrix data (Fig. 4), it is easy to establish that this sausage product contains 2% hydrated soy isolate.

The program is designed in such a way that if you hover the cursor over the hexagon of interest to the researcher, the characteristics of the option will appear on the X-axis. In this example, the standard sample corresponds to the standard.

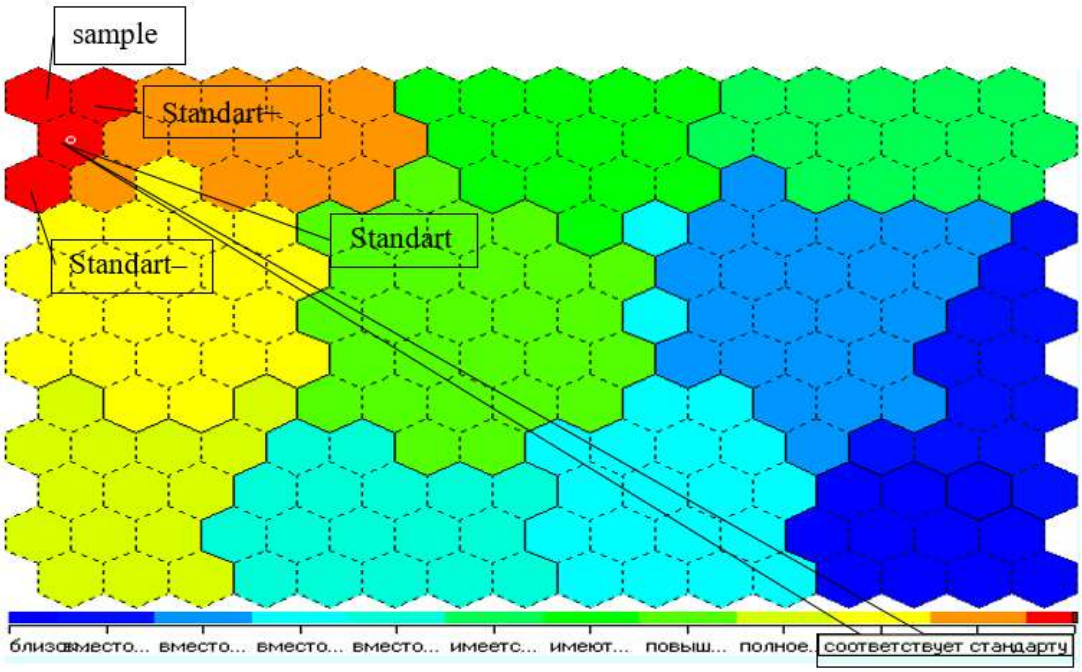

Figure 4 – Analysis of the recipe composition of the sausage product

Thus, the use of modern techniques and laboratory equipment for the analysis of the chemical and amino acid composition of food products in combination with modern Data methods Mining, including planning and neural network processing of research results, will allow one to accurately identify the recipe composition of finished products.

Conclusion.

1. The use of artificial intelligence to determine the quality characteristics of food products is theoretically justified.

2. An array of compositions has been developed using the main types of raw materials for sausage production, and the chemical and amino acid compositions have been calculated for each option.

3. Model prototypes of premium boiled sausage were produced in accordance with GOST and replacing 2 kg of premium beef with soy isolate in the main recipe.

4. The chemical and amino acid compositions of model prototypes of sausage products were studied.

5. Using artificial intelligence and cluster analysis, prototypes of sausage products were identified.

ЛИТЕРАТУРА

1. ФАО, МФСР, ЮНИСЕФ, ВПП и ВОЗ. Положение дел в области продовольственной безопасности и питания в мире – 2020. Преобразование продовольственных систем для обеспечения финансовой доступности здорового питания. Рим, ФАО. 2020.
2. United Nations. Policy Brief: The Impact of COVID-19 on Food Security and Nutrition. June 2020 (2020). [Электронный ресурс]. URL: https://www.un.org/sites/un2.un.org/files/sg_policy_brief_on_covid_impact_on_food_security.pdf. (дата обращения: 20.01.2024).
3. ВОЗ. 2020 год. Ожирение и лишний вес. Бюллетень 2020 (2020). [Электронный ресурс]. URL: https://www.who.int/news-room/fact-sheets/detail/obesity-andoverweight) (дата обращения: 20.01.2024).
4. Пищевые добавки: их роль и влияние на здоровье человека (2017). [Электронный ресурс]. URL: https://scienceforum.ru/2017/article/2017031171. (дата обращения: 20.01.2024).
5. Диетология. 4-е изд. / под. ред. А. Барановского. СПб: Питер. 2012, 1024 с.
6. Пищевые добавки – полезные и вредные, классификация и влияние на организм. [Электронный ресурс]. URL: https://www.59fbuz.ru/press-center/news/pishchevye-dobavki-poleznye-i-vrednye-klassifikatsiya-i-vliyanie-na-organizm/ (дата обращения: 20.01.2024).
7. Скурихин И. М., Тутельян В. А. Химический состав российских пищевых продуктов. М.: ДеЛи принт, 2002. 237 с.

8. Садовой В. В., Щедрина Т. В., Хамицаева А. С. Анализ механизма усвоения глюкозы клетками организма человека в присутствии биологически активной добавки лецитина // Современная наука и инновации. 2023. № 3 (43). С. 117-125.
9. Садовой В. В., Медведев А. Е. Изучение использования казеино-альбуминового комплекса в составе многокомпонентной добавки // Вестник Северо-Кавказского государственного технического университета. 2003. № 1. С. 93-96.
10. Espinosa Sandoval L. A., Polania Rivera A. M., Castaneda Florez L. Chapter 13 – Application of artificial neural networks (ANN) for predicting the effect of processing on the digestibility of foods. Food Struct Eng Design Impr Nut Health Well-Being. 2023;333-361. https://doi.org/10.1016/B978-0-323-85513-6.00011-6
11. Алибеков И. Ю. Теория вероятностей и математическая статистика в среде MATLAB. Учебное пособие. М.: Лань, 2019. 184 с.
12. Мойзес Б. Б., Плотникова И. В., Редько Л. А. Статистические методы контроля качества и обработка экспериментальных данных. М.: Юрайт, 2019. 118 с.
13. Горобец Б. С. Теория вероятностей, математическая статистика и элементы случайных процессов. Упрощенный курс. М.: Едиториал УРСС, 2020. 232 с.
14. Standartinform (2019) Изделия колбасные вареные, ТИ ГОСТ 23670-2019, 11 января 2019, Moscow.

REFERENCES

1. FAO, IFAD, UNICEF, WFP and WHO. 2020. The State of Food Security and Nutrition in the World – 2020. Transforming food systems for affordable healthy diets. Rome, FAO. (In Russ.).
2. United Nations. Policy Brief: The Impact of COVID-19 on Food Security and Nutrition. June 2020 (2020). Available from: https://www.un.org/sites/un2.un.org/files/sg_policy_brief_on_covid_impact_on_food_security.pdf [Accessed 20 January 2024].
3. WHO. 2020. Obesity and overweight. Bulletin 2020 (2020). Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-andoverweight) [Accessed 20 January 2024]. (In Russ.).
4. Food additives: their role and impact on human health (2017). Available from: https://scienceforum.ru/2017/article/2017031171 [Accessed 20 January 2024]. (In Russ.).
5. Dietetics. 4th ed. / under. ed. A. Baranovsky. SPb: Peter. 2012, 1024 p.Dietologiya. 4-e izd. / pod. red. A. Baranovskogo. SPb: Piter. 2012, 1024 p. (In Russ.).
6. Food additives - beneficial and harmful, classification and effect on the body. Available from: https://www.59fbuz.ru/press-center/news/pishchevye-dobavki-poleznye-i-vrednye-klassifikatsiya-i-vliyanie-na-organizm/ [Accessed 20 January 2024]. (In Russ.).
7. Skurikhin IM, Tutel'yan VA. Chemical composition of Russian food products. M.: DELi print. 2002. 237 p. (In Russ.).
8. Sadovoy VV, Shchedrina TV, Khamitsaeva AS. Analysis of the mechanism of glucose uptake by human body cells in the presence of a biologically active lecithin supplement. Modern Science and Innovations. 2023;3(43):117-125. (In Russ.).
9. Sadovoy VV, Medvedev AE. Study of the use of casein-albumin complex as part of a multicomponent additive. Bulletin of the North Caucasus State Technical University. 2003;1:93-96. (In Russ.).
10. Espinosa Sandoval LA, Polania Rivera AM, Castaneda Florez L. Chapter 13 – Application of artificial neural networks (ANN) for predicting the effect of processing on the digestibility of foods. Food Struct Eng Design Impr Nut Health Well-Being. 2023;333-61. https://doi.org/10.1016/B978-0-323-85513-6.00011-6
11. Alibekov IYu. Probability theory and mathematical statistics in the MATLAB environment. Tutorial. M.: Lan', 2019. 184 p. (In Russ.).
12. Moizes BB, Plotnikova IV, Red'ko LA. Statistical methods of quality control and processing of experimental data. M.: Yurayt; 2019. 118 p. (In Russ.).
13. Gorobets BS. Probability theory, mathematical statistics and elements of random processes. Simplified course. M.: Editorial URSS, 2020. 232 p. (In Russ.).
14. Standartinform (2019) Boiled sausage products, TI GOST 23670-2019, 11 January 2019, Moscow (In Russ.).

ИНФОРМАЦИЯ ОБ АВТОРАХ

Владимир Всеволодович Садовой – доктор технических наук, профессор кафедры товароведения и технологии общественного питания, Ставропольский институт кооперации (филиал), Белгородский университет кооперации, экономики и права, +79188639013, https://orcid.org/0000-0002-0182-9318, vsadovoy@yandex.ru

Татьяна Викторовна Щедрина – кандидат технических наук, доцент кафедры технологии продуктов питания и товароведения, Пятигорский институт (филиал), Северо-Кавказский федеральный университет, +789283730813, https://orcid.org/0000-0001-5201-7961, tany1812@yandex.ru

Алла Смалиевна Хамицаева – доктор технических наук, профессор кафедры технологии продуктов питания, Горский государственный аграрный университет, +79034833663, https://orcid.org/0000-0002-3894-9620, allahamicaeva@mail.ru

Ирина Александровна Трубина – кандидат технических наук, доцент кафедры производства и переработки сельскохозяйственной продукции, Ставропольский государственный аграрный университет, 355017, Ставропольский край, +79624419174, https://orcid.org/0009-0003-8644-1404, stgau.75@mail.ru

INFORMATION ABOUT THE AUTHORS

Vladimir V. Sadovoy – Dr. Sci. (Techn.), Professor of the Department of Commodity Science and Public Catering Technology, Belgorod University of Cooperation, Economics and Law, Stavropol Institute of Cooperation (branch), +79188639013, https://orcid.org/0000-0002-0182-9318, vsadovoy@yandex.ru

Tatiana V. Shchedrina – Cand. Sci. (Techn.), Associate Professor of the Department of Food Technology and Commodity Science, North-Caucasus Federal University, Pyatigorsk Institute (branch), +79283730813, https://orcid.org/0000-0001-5201-7961, tany1812@yandex.ru

Alla S. Khamitsaeva – Dr. Sci. (Techn.), Professor of the Department of Food Technology, Gorsky State Agrarian University, +79034833663, https://orcid.org/0000-0002-3894-9620, allahamicaeva@mail.ru

Irina A. Trubina – Cand. Sci. (Techn.), Associate Professor, Department of Production and Processing of Agricultural Products, Stavropol State Agrarian University, +79624419174, https://orcid.org/0009-0003-8644-1404, stgau.75@mail.ru

Вклад авторов: все авторы внесли равный вклад в подготовку публикации.
Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Contribution of the authors: the authors contributed equally to this article.
Conflict of interest: the authors declare no conflicts of interests.

Статья поступила в редакцию: 28.01.2024;
одобрена после рецензирования: 28.02.2024;
принята к публикации: 06.03.2024.

The article was submitted: 28.01.2024;
approved after reviewing: 28.02.2024;
accepted for publication: 06.03.2024.