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Editors office address:
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
E-mail: info@animalscience.com.ua
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03041, вул. Героїв Оборони, 15, м. Київ, Україна
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Investigation of technological parameters of manufacturing meat products from chicken fillet

Artem Antoniv*
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-6614-4248

Leonora Adamchuk
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
National Science Center "P.I. Prokopovich Institute of Beekeeping"
03680, 19 Zabolotnyi Str., Kyiv, Ukraine
https://orcid.org/0000-0003-2015-7956

Abstract. Compliance with the technological process and production parameters is the key to obtaining a high-quality product. Given the rapid development of the food industry and the needs of consumers for products that have not been subjected to repeated technological processing, where their nutritional value is preserved as much as possible, there is a need to investigate meat products that can meet such requirements. The purpose of the study was to determine and establish the technological parameters of the production of chicken jerky. The study involved experimental research, organoleptic evaluation of finished products, determination of the amount of waste after dressing meat, physicochemical parameters of raw materials, semi-finished products, and finished products: moisture content, pH, fat content by the Soxhlet method and protein content by the Kjeldahl method. Four methods of production of chicken jerky were investigated, namely: marinating with convective drying with a change in temperature conditions during the drying process; marinating with subsequent cooking using sous-vide technology to a temperature in the thickness of meat not less than 72°C and convective drying until ready; pre-salting of chicken meat with a ratio of raw materials to salt of 1/1, followed by marinating and convective drying

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*Corresponding author

with a change in temperature conditions during the drying process. The final moisture content of the finished jerky was determined to be between 20.8% and 37%, depending on the production method. The study calculated capital (2.33% ± 0.5%) and technical (12.53% ± 1.32%) waste from the preparation of raw materials for the production of jerky, and provided a method for calculating the gross weight of chicken fillet from the required net weight of meat raw materials. Waste after drying for each of the studied methods are shown, which ranged from 46.7%, to 65.03%, 68%, and 74.77%. The results of the study can be used by meat producers and restaurant establishments when planning and developing their own products, improving existing production technologies, and understanding trends in the production of meat delicacies on the Ukrainian market

Keywords: drying; marinating; jerky; snacks; poultry meat; moisture content; sous-vide

Introduction

Consumption of meat and meat products is popular among the population of Ukraine and the world. However, there is a need to develop new methods of processing products and use non-conventional raw materials to ensure a number of desired characteristics: high taste properties, the necessary chemical composition, a longer shelf life without using synthetic preservatives, and high competition among other meat producers.

In the last decade, the development of new meat products with improved nutritional properties has intensified. Consumers demand minimally processed meat products that do not contain preservatives and have a long shelf life. To meet these needs, natural additives are widely used instead of synthetic ones. In addition, research into environmentally friendly packaging materials that improve the shelf life of meat is gaining momentum (Gómez *et al.*, 2020).

Meat snack products are beginning to gain popularity, especially among students and people who lead an intensive, active lifestyle. According to L.P. Zahorui & Y. Mihel (2022), Ukrainian manufacturers occupy only 18% of the market, the rest are imported products. The researchers also note that such a group of products can be classified as healthy products, since it contains the maximum amount of protein and the minimum amount of fat. The analysis of meat snack consumption shows that 92% of respondents consume meat products daily. However, these products can be considered health-improving only if the content of salt, sugar, and preservatives is minimised.

There are a significant number of ways to extend the shelf life of food. One of them is drying. Especially valuable are dried foods that do not require additional recovery or reheating, that is, which can be consumed immediately. Usually, such products are subjected to heat treatment during the production process to undergo certain biochemical transformations, give taste and aroma, and undergo long-term ageing or fermentation. V.O. Skrypnyk & B.H. Ponomarenko (2023) suggests using a two-way heat supply during convective drying of meat, when the temperature of the heated surface does not exceed 130°C. This significantly reduces the development of unwanted flavour compounds and improves the organic properties of dried meat. In different regions of the world, different cutting methods and different recipes are used in the manufacture of products, including meat. This is conditioned by taste preferences, climate, and territory-specific raw materials.

As reported by M.I. Myroshnychenko & A.V. Bolshakova (2020), drying meat is a promising method of preservation that allows to preserve the original properties of meat to a large extent. During drying, meat retains not only its

taste qualities, but also its high biological and nutritional value, nutrients, vitamins, and amino acids. The researchers give their own definition of meat snacks: thin slices of dried meat seasoned with spices that are made from pork, beef, chicken, horse meat, turkey, ostrich, venison, and lamb. It was found that the method of slicing does not affect the drying time and colour of dried meat, but reduces the elasticity of the product in the direction of the fibres. In addition, thicker pieces of meat take longer to dry, and the structure and colour of the finished product are worse compared to thinner pieces. Researchers recommend eating meat snacks for people with an active lifestyle, athletes and tourists, as this type of food is low in fat and carbohydrates, and has high nutritional value.

A survey on preferences regarding the type of meat used in snacks showed that chicken is the most popular (42.2% of respondents). 37.6% of respondents identified snacks as a healthy diet. Analysis of the results of the survey on choosing the type of meat delicacies shows that sausages are the most popular (45%), dried meat is in second place (14 %) and in third place – meat chips (7%) (Afanasieva, 2023). A. Lohinova *et al.* (2019) investigated the use of dried meat snacks in the diet of Ukrainian military personnel in the field. In combat zones, due to the constant lack of time, soldiers are forced to limit their meals or eat at a faster pace. To improve the quality of food, it was proposed to use dried meat snacks in military rations. According to the researchers, this will save food intake time and at the same time provide the body with the necessary proteins, fats, and carbohydrates for normal functioning. However, with the production of meat delicacies (snacks), there is a problem with standardisation and falsification of production. For example, meat snacks are often falsified in various ways, including assortment, quality, quantity, cost, and information methods.

Relevant today is the need to develop standardised methods of production with the establishment of technological parameters that will not depend on a number of factors, in particular, the volume of production, used raw materials and additional components, types of equipment, etc. This can be used in the future to improve the technologies of meat products and develop regulatory documents to ensure the quality and safety of products. The purpose of this study was to determine and establish the technological parameters of the production of chicken jerky.

Materials and Methods

The research was conducted at the laboratories of the Department of Meat, Fish, and Seafood Technology of the Faculty of Food Technology and Quality Management of the National University of Life and Environmental Sciences of Ukraine in October-December 2023.

Chicken fillet was chosen as the main raw material for the production of meat products. In the course of the study, the moisture content in the raw material and finished product was determined by drying to a constant mass at a temperature of 103°C ± 2°C (DSTU ISO 1442:2005, 2007); capital (not suitable for further processing) and technical waste (can be used for the production of other types of products) after weighting meat; pH in raw materials and semi-finished products (DSTU ISO 2917-2001, 2003); fat content by the Soxhlet method (DSTU ISO 1442:2005, 2007) and protein by the Kjeldahl method in raw materials (DSTU ISO 937:2005, 2007). In addition, during the manufacturing of meat products, the temperature in the thickness of meat was determined during marinating, after cooking using sous-vide technology (DSTU 3143:2013, 2014). The name of the meat delicacy was preliminarily determined – chicken jerky.

The amount of chicken fillet (gross) that must be taken to obtain the required amount of prepared meat raw materials (net) was determined by the equation:

$$x = \frac{n \times 100}{100 - (w_c + w_t)}, \quad (1)$$

where x – amount of chicken fillet (gross), kg; n – required amount of prepared meat raw materials (net), kg; w_c, – capital waste after meat curing, %; w_t – technical waste after meat curing,%.

Production of jerky was carried out according to the methods listed below.

Method 1. Prepared, peeled meat was cut across fibres 5-7 mm thick. The resulting meat slices were placed in a pre-prepared marinade and left for 12 hours at a temperature of 4°C ± 2°C. After marinating, the meat was distributed on special baking sheets and placed in a dehydrator preheated to 70°C. After an hour of drying, the temperature was reduced to 55°C and dried for another 8 hours. Thus, the total production time was 21 hours

Method 2. Prepared, peeled meat was cut across fibres 5-7 mm thick. The resulting meat slices were placed in a pre-prepared marinade and left for 4 hours at a temperature of 4°C ± 2°C. After marinating, the meat was distributed on special baking sheets and placed in a dehydrator preheated to 70°C. After an hour of drying, the temperature was reduced to 55°C and dried for another 6 hours. The total production time was 11 hours.

Method 3. The prepared, peeled meat was vacuumed and cooked using sous-vide technology at a temperature of 75°C for an hour. After cooking, the meat was cut across the fibres into slices 5-7 mm thick, then marinated and kept for another hour at a temperature of 4°C ± 2°C. After marinating, the meat was distributed on special baking sheets and placed in a dehydrator preheated to 55°C, dried for 6 hours. The total production time was 8 hours.

Method 4. Prepared, peeled meat was covered with salt (the ratio of salt to meat – 1: 1) and left for 12 hours. Next, the meat was washed under running water from the remaining salt and placed in ice water for 2 hours, changing the water twice in the process. After that, the meat was cut across the fibres into slices 5-7 mm thick, marinated and kept for another hour at a temperature of 4°C ± 2°C. After marinating, the meat was distributed on special baking sheets and placed in a dehydrator preheated to 70°C. After an hour of drying, the temperature was reduced to 55°C and dried for another 5 hours. The total production time was 21 hours.

Results

The amount of waste during dressing and preparation for meat processing was determined. Thus, the remains of cartilage tissue, veins, films, bruises and the fat part were separated from the chicken fillet. In addition, the chicken fillet was given an oval shape, so that when cutting into flat pieces there were no protruding parts of the fillet, pieces of different shapes, etc. To interpret the results, the % of capital waste (not subject to further processing) during preliminary preparation of chicken meat and the percentage of technical waste, i.e., trimmings that are not conditioned for the production of jerk, but can be used in the production of other products (e.g. in minced systems, etc.) were determined (Table 1).

Table 1. *Waste after meat dressing (n = 10)*

No.	Indicator	Value, X ± Δ
1.	Meat weight before dressing, kg	3.63 ± 0.51
2.	Weight of prepared meat, kg	3.06 ± 0.49
3.	Capital waste, %	2.33 ± 0.50
4.	Technical waste, %	12.53 ± 1.32

Notes: X – arithmetic mean; δ – measurement error
Source: compiled by the authors

The results obtained allow calculating the required amount of meat and controlling the production process of meat products, calculating the economic component of production, and developing standardised technical documentation for the production of chicken jerky. Thus, 1,175 kg of chicken fillet is needed to obtain 1 kg of prepared meat raw materials for the production of jerky. Determination of physical and chemical parameters in raw materials is important for determining the degree of freshness and suitability of meat for further processing. The determination was performed in four repetitions (Table 2).

Table 2. *Basic physical and chemical parameters of raw materials (n = 4)*

Indicator	pH	Content, %		
		moisture	fat	protein
According to regulations*	not more than 6.70	not more than 78.0	not more than 11.0	not less than 17.0
X ± σ	6.20	73.76	1.36	19.17
Cv, %	1.27	0.59	5.54	0.34
Δ, %	0.08	0.44	0.08	0.07

Notes: *DSTU ISO 1442:2005 (2007); Order of the Ministry of Agrarian Policy and Food of Ukraine No. 625 (2023); DSTU 3143:2013 (2014); X – arithmetic mean; δ – measurement error; Cv – coefficient of variation
Source: compiled by the authors

Based on the results of the study of raw materials (Table 2), the obtained values of indicators comply with the current legislation of Ukraine. The average moisture content in the samples of raw materials (chicken fillet) was in the range from 73.34 to 74.04, and the average value was less by 4.24% compared to the maximum permitted concentration. The average pH value of chicken fillet was at the level of 6.2, which is 0.5% less compared to the maximum permitted concentration. The fat content of chicken fillet samples averaged 1.36%, which is 9.64% less compared to the maximum permitted concentration. The protein content of chicken fillet ranged from 19.1 to 19.3, and the average value was 2.17% higher compared to the absolute minimum concentration. The resulting average values will be used for comparison with the indicators of the finished product.

During the production of jerky according to the most common Method 1 (Han *et al.*, 2007; Lonnecker *et al.*, 2010; recipe dried chips (jerks), 2024), according to which cooked, sliced meat was first marinated for 12 hours at a temperature of 4°C ± 2°C. For this reason, the temperature in the thickness of the meat during marinating was set, which was + 2.5°C ± 0.5°C. Then the meat was placed in a dehydrator, where it was dried to a ready state under two temperature conditions (see Method 1). As a result, the indicators were obtained (Table 3), which allowed adjusting the production process to obtain the desired results.

Table 3. *Results of the study of technological parameters of manufacturing of meat products from chicken fillet (n = 4)*

No.	Indicator	Method, X ± Δ	
		1	2
1.	Weight of raw materials*, kg	0.7 ± 0.14	0.38 ± 0.16
2.	Weight of dried product, kg	0.18 ± 0.06	0.13 ± 0.06
3.	Waste after drying, %	74.77 ± 4.10	65.03 ± 0.67

Notes: * – chicken fillet after dressing; X – arithmetic mean; δ – measurement error
Source: compiled by the authors

As can be seen from Table 3, according to Method 1 (with a total drying time of 9 hours), a product with a low yield by weight compared to the product produced by Method 2 was obtained. Reducing the drying time by 2 hours and marinating meat for 8 hours allowed getting a product with better performance. In addition, the error in losses after drying according to Method 2 was only 0.67%, and according to Method 1, on average, 4.1 %. Considering the results of organoleptic evaluation, Method 2 has the best properties of the finished product. By organoleptic properties (Fig. 1) jerky obtained by Method 2 had higher evaluation indicators for such parameters as appearance, consistency, colour, smell, and taste. Thus, it was found that a long drying time is not suitable for obtaining a finished product with high quality indicators, and the production method, where the total drying time of meat from chicken fillet in a dehydrator is 7 hours, is suitable for the production of chicken jerky.

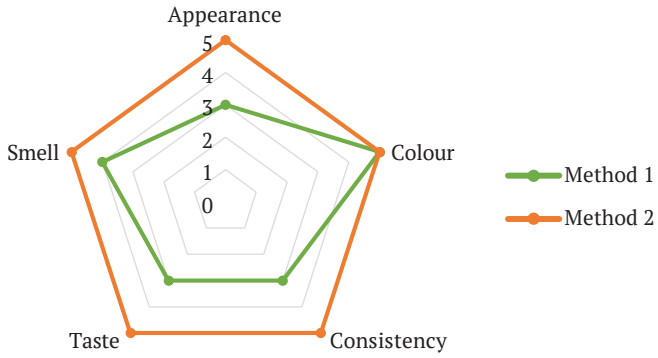

Figure 1. Profilogram of organoleptic evaluation of meat products from chicken fillet produced by methods 1, 2

Source: compiled by the authors

Another method of making meat delicacies that has been investigated is drying pre-cooked sous-vide meat (cooking meat in a vacuum polymer bag at a controlled temperature) (Table 4).

Table 4. *Investigation of technological parameters of production of meat products from chicken fillet by Method 3 (n = 3)*

No.	Indicator	Value, X ± Δ	Cv, %
1.	Meat weight before cooking*, kg	0.32 ± 0.11	34.86
2.	Meat weight after cooking, kg	0.25 ± 0.09	35.12
3.	Temperature in the thickness of the meat after cooking, °C	72.87 ± 0.55	0.76
4.	Weight of dried product, kg	0.08 ± 0.03	33.69
5.	Total losses after drying, %	74.60 ± 0.88	0.88

Notes: * – chicken fillet after dressing; X – arithmetic mean; δ – measurement error, Cv – coefficient of variation

Source: compiled by the authors

According to the results obtained (Table. 4), cooked jerks have a low yield of the finished product. This is due to losses during cooking, and then – drying. However, based on the results of organoleptic evaluation (Fig. 2), the resulting finished product had high taste properties, pleasant aroma, crisp consistency, and satisfactory appearance.

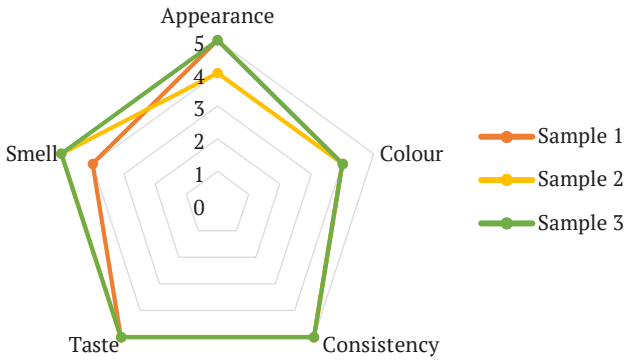

Figure 2. Profilogram of organoleptic evaluation of meat products from chicken fillet produced by Method 3

Source: compiled by the authors

The production of jerky using Method 3 heat treatment technology involves drying from cooked meat, which probably reduces the risks of rapid microbiological spoilage. According to the experimental technology of producing chicken jerky, when the meat was salted and aged for different times, the results were presented in Table 5 and in Fig. 3.

Table 5. *Investigation of technological parameters of production of meat products from chicken fillet by Method 4 (n = 3)*

No.	Indicator	Value, X ± Δ	Cv, %
1.	Weight of meat before salting*, kg	0.94 ± 0.02	1.84
2.	Weight of salt, kg	0.94 ± 0.09	1.84
3.	Meat weight after salting, kg	0.83 ± 0.01	0.7
4.	pH	4.60 ± 0.05	1.13
5.	Weight of dried product, kg	0.45 ± 0.01	2.29
6.	Total losses after drying, %	51.73 ± 0.23	0.45

Notes: * – chicken fillet after dressing; X – arithmetic mean; δ – measurement error, Cv – coefficient of variation

Source: compiled by the authors

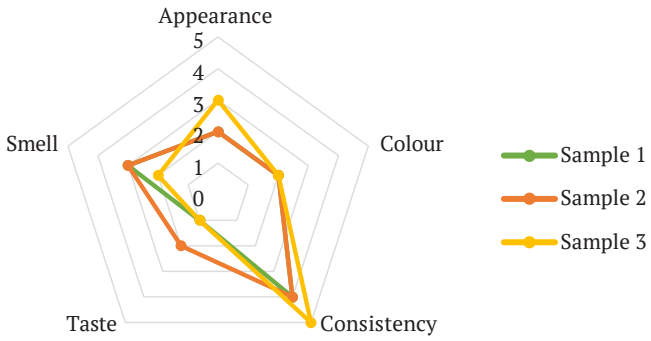

Figure 3. Profilogram of organoleptic evaluation of meat products from chicken fillet produced by Method 4

Source: compiled by the authors

As can be seen from Table 5, samples that were kept for 12 hours, (temperature in the thickness of the meat – 2.5°C ± 0.5°C), have the shortest drying time to the required moisture content of the finished product, compared to other methods under study. In addition, the total weight loss during the production of jerky is the smallest. Regarding organoleptic parameters, in particular taste properties (Fig. 3), the product is declared unfit for consumption due to an excessive amount of salt. The appearance is also unsatisfactory, because the product is covered with a white coating. The consistency is plastic and can be easily divided into smaller pieces. But given the preservative properties of salt, the potentially shorter drying time of meat, and the acquisition of a finished product of excellent consistency, it is necessary to continue exploring this method of producing jerky, using less salt and a shorter salting time.

At the next stage, the produced jerky was examined for moisture content to determine the degree of readiness of the product and as a qualitative indicator for controlling the spoilage process (Fig. 4).

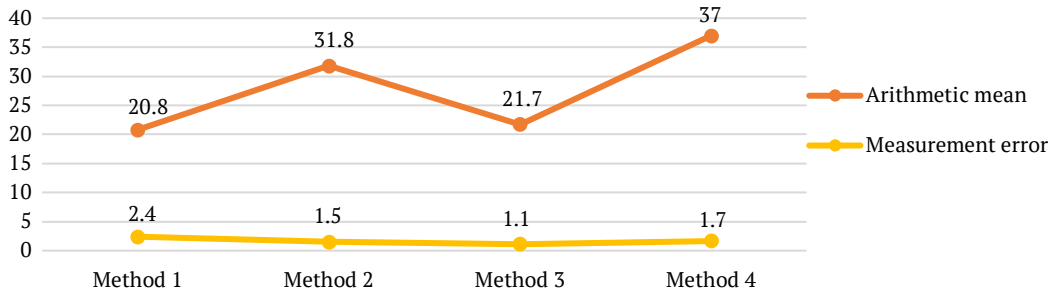

Figure 4. Moisture content in chicken jerky (n = 5)

Source: compiled by the authors

As can be seen from Figure 4, different moisture content is observed in all the obtained samples according to different methods. This is due to the temperature conditions of drying, methods of processing raw materials, and the production process. The moisture content also regulates the organoleptic properties of finished products, namely consistency and appearance. The lower the moisture content, the harder it is to divide the jerky into smaller pieces and chew. In addition, the loss of moisture is associated with total losses in the weight of the product, which implies an increase in the sealing of raw materials for the production of the finished product. The knowledge of the moisture content can be used to determine the degree of readiness of the jerky and can be a qualitative indicator to control the spoilage process.

Discussion

Meat and meat products are important elements of both daily nutrition and during specialised diets (González *et al.*, 2020). In addition, their consumption has been steadily increasing around the world since the 1960s and up to the present day. Ultimately, up to 58% of protein consumed and 30% of total calories come from meat and meat products, and they also provide important nutritional compounds in the diet, especially protein, fat, essential amino acids, minerals and vitamins. Determining the technological parameters of the production of products, and in this case, chicken jerky, will expand the range of meat products offered on the market and support the supply of important elements to the body for its functioning (Biesalski, 2005; Modi *et al.*, 2007).

Innovation activities of meat producers are usually associated with responding to changing consumer preferences and requirements. That is why there is a need to improve various technologies for the production of meat products to meet the needs of consumers and provide the human body with the necessary nutrients. However, if there is a small-scale production of traditional meat products, this leads to heterogeneity of their quality, which is also indicated in the paper by M. Halagarda & K.M. Wójciak (2022). The production methods used and the raw materials used make such products more expensive. Therefore, it is necessary to develop standardised methods and requirements for the products, so that, regardless of the volume of production, it would always be possible to produce a product that meets the established indicators and desired consumer expectations.

As noted by I. Doymaz *et al*. (2016), the drying process as a method of preserving and processing meat is one of the oldest and most common methods, as it is efficient and inexpensive. The researchers also describe the advantage of using this method of production in their study. Drying extends the shelf life of meat and meat products by reducing moisture activity. In addition, the drying process reduces microbial load, volume and weight, thereby reducing storage and transportation costs.

The effect of various drying methods, namely ultrasonic vacuum drying, vacuum drying and sublimation, on the drying kinetics and some quality parameters of dried minced meat was studied (Aksoy *et al*., 2019). The researchers also note that different drying methods and temperatures significantly affected the drying time, and higher drying temperatures increased the overall colour differences of the finished product. To speed up the drying time, ultrasonic treatment and vacuum drying were combined. According to this method, the vacuum process, breaking down the cell walls of food, accelerates the transfer of water, which accelerates drying. Comparing with the findings of this study, it can be recognised that combining different production methods can lead to significantly better results in terms of organoleptic characteristics, time spent on production, and higher product yield.

The combination of different methods of processing and preserving raw materials leads to better results of sensory evaluation. I. Gómez *et al*. (2020) also investigated combinations of different methods, but in such a way that the nutritional value of meat is not disturbed: drying in maturation chambers, high-pressure processing, and sous-vide cooking. The paper also considered chemical and biochemical methods, such as fermentation, smoking, and pickling to enhance the quality indicators of meat products. This study also combined pickling, sous-vide technology, and convective drying with different temperature settings. The results obtained indicate the need to adjust some parameters of the production process to obtain positive final results of the finished product.

According to B.M. Naveena *et al*. (2008), consumers are demanding preservative-free, minimally processed meat products with a longer shelf life. Nowadays, it is also widely accepted to use natural additives instead of synthetic ones. In addition, research on packaging materials that improve the shelf life of meat is gaining momentum. Therefore, drying meat for a long time can be attributed to lean methods of processing raw materials, because with such a production technology, a significant part of nutrients is preserved and the finished product has a long consumption period, which is especially important for consumers.

Sous-vide processing, which was used in one of the jerky production methods, makes the meat juicier and more tender, and at the same time, this technique improves the digestibility of meat, according to studies conducted on digestion in vitro (Ingham *et al*., 2006; Kehlet *et al*., 2017). This technique maintains the same quality of meat and improves the organoleptic

characteristics of cooked meat. Sous-vide technology can be combined with other methods of processing and manufacturing products. Therefore, the next step was convective drying before the jerky were ready. Such a product is less vulnerable to microbiological spoilage, because drying took place already from a fully prepared product. Jerky, in turn, acquired specific organoleptic properties, which was highly appreciated.

S. Sorapukdee *et al*. (2016) investigated whether chicken meat can be used as a potential raw material for dried meat. The production was carried out using a hot air convection oven at a temperature of 85°C,until the temperature of the centre of the piece of meat reached 71.1°C. The temperature was then lowered to 60°C and left until further dehydration. The technology considered in this paper differs in temperature conditions, and in the fact that a whole piece with a thickness of 5-7 mm was dried, and these researchers used rectangular pieces with a thickness of 3-5 mm from crushed meat in a meat grinder for drying. Using another well-known technology, all subcutaneous fat and visible connective tissue were first removed from fresh chicken breast meat. Then drying (55°C, 30 min), smoking (65°C, 30 min), slow drying (65°C, 70 min), slow drying (75°C, 60 min), and dry cooking (75°C, 10 min) were performed. After cooling with chilled air (5°C, 30 min), the semi-dried chicken was individually vacuum packed with a plastic/nylon film and stored in the refrigerator at 4°C for subsequent studies (Choi, 2008; Song *et al.*, 2014). In this way, the authors of the article have obtained another variant of the jerky offered on the market.

Considering this study and the researchers mentioned above, it can be stated that the results obtained by the authors of this study are relevant, can be considered as fundamental in the creation of meat products according to the developed methods. Moreover, when developing new meat products, it is necessary to apply a comprehensive approach, including an evaluation of sensory characteristics and nutritional value, because consumers today are looking for minimally processed products with high nutritional value and extended shelf life.

Conclusions

Over the past decade, the number of new meat products with improved nutritional characteristics has increased. However, the choice of processing and canning technologies requires a comprehensive, global strategy that considers not only the impact on product quality, but also changes in sensory and nutritional characteristics, and consumer attractiveness.

According to experimental studies of the production of chicken jerky, it can be concluded that production according to Method 1 is impractical. A long pickling time and the longest drying time lead to high product losses – up to 79%. In addition, organoleptic parameters were also not satisfactory, since jerky were brittle, difficult to chew, and the smell and taste were not very noticeable. Production of jerky according to Method 2 provides high organoleptic indicators. Drying losses are significantly lower compared to Method 1 – 65.2%, which is quite acceptable for this type of product. Production of jerky by a combination of *sous-vide* technology, vacuum pickling, and convective drying is promising. The product obtained specific organoleptic properties, in particular a crisp, porous consistency, attractive appearance, and pleasant taste and smell. Additionally, variable drying parameters can be investigated to increase the yield of the finished product. The subsequent studies of the advantages of this method will be a comparison of shelf life and the level of microbiological spoilage, because drying took place already from pre-cooked meat, which should reduce these risks.

Results of the production of chicken jerky by Method 4 – salting – did not bring the expected results. Excessive amounts of salt and a white coating on the surface make the product unusable. Although the cooking time and yield of the finished product was better compared

to other methods. In further experiments, the salt-to-meat ratio will be changed and additional studies of the efficiency of jerky production will be conducted using pre-salting of raw materials. Summing up the conducted research, the authors have established the main technological parameters for which chicken jerky will be produced, namely marinating for at least 4 hours at a temperature of 4°C ± 2°C followed by convective drying for 1 hour at a temperature of 70°C, then 6 hours at a temperature of 55°C. Other ways to produce jerky require more research.

Promising research will be the development of recipes for the production of chicken jerky, in particular with the use of bee products that will serve as substitutes for preservatives and natural components to increase biological value. The combination of these components will expand the range of meat products developed from original raw materials, preserving and improving their nutritional and sensory characteristics for long periods of time.

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Conflict of Interest

None.

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Дослідження технологічних параметрів виробництва м'ясних продуктів з курячого філе

Артем Антонів

Аспірант
Національний університет біоресурсів та природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-6614-4248

Леонора Адамчук

Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів та природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
Національний науковий центр «Інститут бджільництва імені П. І. Прокоповича»
03680, вул. Заболотного, 19, м. Київ, Україна
https://orcid.org/0000-0003-2015-7956

Анотація. Дотримання технологічного процесу та параметрів виробництва є запорукою отримання високоякісного продукту. Через стрімкий розвиток харчової промисловості та врахування потреб споживачів у продукції, яка не піддавалася багаторазовому технологічному обробляню, де максимально можливо збережено її поживну цінність, – виникає потреба дослідження м'ясних виробів, які зможуть забезпечити такі вимоги. Метою роботи було визначити та встановити технологічні параметри виробництва джерок курячих. Виконання роботи здійснювали експериментальними дослідженнями, проводили органолептичне оцінювання готової продукції, визначали кількість відходів після жилування м'яса, фізико-хімічні показники сировини, напівфабрикату та готових виробів: вміст вологи, pH, вміст жиру за методом Сокслета та вміст білку за методом К'єльдаля. В процесі виконання роботи досліджено чотири способи виробництва курячих джерок, а саме маринування з конвективним сушінням зі зміною температурних режимів в процесі сушіння; маринування з подальшим варінням за технологією sous-vide до температури в товщі м'яса не менше 72°С та конвективним сушінням до готовності; попереднє засолювання курячого м'яса зі співвідношенням сировини до солі 1/1 з подальшим маринування та конвективним сушінням зі зміною температурних режимів в процесі сушіння. В готових джерках визначали кінцевий вміст вологи який становив від 20,8 % до 37 % в залежності від способу виробництва. Розраховано капітальні (2,33 % ± 0,5 %) та технічні (12,53 % ± 1,32 %) відходи від підготовлення сировини до виробництва джерок, а також наведено методику розрахунку маси брутто курячого філе, від необхідної маси нетто м'ясної сировини. Наведено втрати після сушіння за кожним з досліджуваним способом, що становило від 46,7 %, до 65,03 %, 68 % та 74,77 %. Результати дослідження можна використовувати виробникам м'ясних виробів, закладам ресторанного господарства під час планування та розробленнями власної продукції, удосконалення існуючих технологій виробництва, а також для розуміння тенденцій виробництва м'ясних делікатесів на ринку України

Ключові слова: сушіння; маринування; джерки; снеки; м'ясо птиці; вміст вологи; sous-vide

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Nutritional value of clariid catfish in the conditions of aquaculture in Ukraine

Ivan Bal*

Postraduate Student
National University of Life and Environmental Sciences of Ukraine
03040, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0007-1608-5263

Abstract. The nutritional value of raw materials is determined by a set of indicators that define the biological value of protein, lipids, mineral composition, and safety. Therefore, their investigation in the meat of one of Ukraine's aquaculture species – the clariid catfish – is relevant. The purpose of the study was to investigate the biological value of protein, lipids, mineral composition, and safety of catfish meat when grown in Ukraine and evaluate these indicators in accordance with the recommendations of FAO/WHO. The amino acid composition of the protein was determined by ion exchange liquid-column chromatography on an automatic analyser T 339 (Czech Republic); the fatty acid composition of lipids was determined on a gas chromatograph HRGC 5300 ("Carlo Erba", Italy). The mineral composition of meat was investigated by atomic emission spectrometry with inductively coupled plasma; the content of heavy metals was determined by atomic absorption spectrometry. The study of the amino acid composition of the protein established the presence of all essential amino acids in an amount significantly exceeded in the ideal protein in accordance with FAO/WHO recommendations, which indicates a high biological value. The fatty acid composition of lipids is typical for freshwater fish and catfish lipids from other aquacultures. The biological value of catfish lipids is determined by the ratio of fatty acids of the ω-6/ω-3 families as 1.8:1.0 at the recommended value of 10:5, which indicates the possibility of using lipids of this fish as a source of especially deficient ω-3 fatty acids in the human diet. The low level of polyunsaturated fatty acids and the absence of essential fatty acids eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids gives the basis for developing the design of biologically valuable catfish meat products by enriching it with lipids from marine aquatic organisms. The practical significance of the findings is to obtain original data on the nutritional value of meat

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*Corresponding author

from one of the aquaculture species in Ukraine, determine the degree of satisfaction of the daily human need for its consumption, and develop recommendations for rational use

Keywords: catfish meat; essential amino acids; fatty acids; safety indicators; heavy metals; radionuclides

Introduction

Ensuring a healthy human diet is a priority of the policy of any country in the world, including Ukraine (FAO, n.d.). The main objective of this policy is to create recommendations based on studies of the nutritional value and safety of raw materials and products. Fish is one of the main sources of biologically valuable protein, essential lipids, mineral elements, and vitamins. As a result, there is a tendency to increase its consumption in the world and by 2032 it is expected that the consumption of edible fish will reach 21.2 kg per capita, compared with 20.4 kg in the base period (average 2020-2022) (OECD/FAO, 2023). The contribution of aquaculture to global aquatic animal production reached a record 49.2% in 2020 and is planned to increase by another 15% by 2030, which could provide a larger share of humanity with food (FAO, n.d.). Freshwater aquaculture is also developing very rapidly in Ukraine. Along with the breeding of various carp species, the *Clarias gariepinus* catfish of the *Clariidae* family is a promising species for freshwater aquaculture in Ukraine. According to U.E. Sharylo *et al.* (2020), U. Knaus *et al.* (2021), M.V. Zadorozhnii (2023), this species is considered one of the most promising for aquaculture due to its unpretentiousness to growing conditions and relatively simple and easily controlled technology of mass reproduction. In Ukraine, the technology of growing this type of fish was also used during 2018-2023 (Zadorozhnii, 2023).

Research on the nutritional value of *C. gariepinus* meat in vivo and in aquaculture were conducted in Nigeria by C.O. Okonkwo *et al.* (2020), in aquaculture of Ukraine – by I.M. Bal *et al.* (2023a; 2023b). The analysis of the above sources indicates the dependence of the chemical composition of *C. gariepinus* meat depends on the growing conditions and weight of fish and is consistent with generally established patterns. Fish weighing from 989 g is characterised by a high protein and fat content in the aquaculture of Ukraine and is 67.74 ± 3.45 and 26.20 ± 1.32%, respectively, in terms of dry matter. In natural conditions and in aquaculture of Nigeria, with a fish weight of 200 g or more, the protein and fat content is almost half that (30.27 ± 1.79; 42.90 ± 3.37 and 12.0 ± 1.4; 12.9 ± 2.8 in %, respectively (Okonkwo *et al.,* 2020). Meat of *C. gariepinus* in the aquaculture of Ukraine has the highest caloric value (506.7 ± 7.1 kcal) compared to all the conditions of existence of this fish species in Nigeria. Fish with a low weight (200 g) is characterised by high fibre content (39.8 ± 1.8; 50.6 ± 4.2 vs. 0.22 – 1.01 ± 0.6%, respectively.

It is known that one of the most significant indicators of the nutritional value of fish meat is the amino acid composition of protein. Unfortunately, these data are not available in the literature, which makes it necessary to investigate these indicators. Evaluation of the lipid profile of the clariid catfish in aquaculture conditions is presented in the paper by Å. Krogdahl *et al*. (2022). The correspondence of the lipid profile of fatty acids of clariid catfish to the composition and ratio of fatty acids in freshwater fish lipids is shown, that is, the sum of biologically valuable fatty acids EPA and DHA is 5.3, the total amount of PUFAs ω-3 is 6.47 and ω-6 is 22.45% (Bal-Prylypko *et al*., 2018).

Clariid catfish is in demand in Ukraine due to its high taste properties and the possibility

of producing a large variety of culinary dishes. Considering the recommendations of FAO/WHO and the European Organisation in the field of health nutrition, it is important to know the biological value of proteins, lipids, mineral composition, and safety indicators of catfish meat in aquaculture of Ukraine and assess their compliance with these recommendations. Therefore, the study of the amino acid, lipid profile, and mineral composition of meat of this type of fish in the aquaculture conditions in Ukraine is relevant.

The purpose of the study was to investigate the biological value of protein, lipids, mineral composition, and safety of catfish meat when growing in Ukraine and evaluate these indicators in accordance with the recommendations of FAO/WHO to meet the daily human need for essential nutritional factors.

Materials and Methods

The research was conducted at the laboratories of the Department of Meat, Fish and Seafood Technology of the Faculty of Food Technology and Quality Management of the National University of Life and Environmental Sciences of Ukraine in June-December 2023.

The object of research was the nutritional value of the meat of clariid catfish *C. gariepinus* grown in the aquaculture farm LLC "Aqua System Organic" (Kyiv Region, Vasylkiv city). Meat samples were taken from fish weighing 956, 986 and 1,021 g, crushed in a blender, and the amino acid composition of protein, fatty acid profile of lipids, mineral composition and content of heavy metals and radionuclide ^{90}Sr was analysed. The content and composition of fatty acids were determined by liquid chromatography at the O.V. Palladin Institute of Biochemistry of the National Academy of Sciences of Ukraine using an HRGC 5300 device ("Carlo Erba", Italy). The lipid extract was prepared according to the method described in (Folch *et al*., 1957), dissolved in benzene, placed in a flask closed with a glass plug, and stored at a temperature of negative 18°C. An aliquot of 0.5 cm^3 of the lipid extract was placed in a glass ampoule, 1.5-2.0 cm^3, 1.0N of HCl solution in methyl alcohol was added, the ampoule was hermetically sealed and boiled for 50 min in a water bath. At the end of heat treatment, the ampoule was opened, the same amount of water was added, the organic component was extracted with distilled hexane and dried with anhydrous sodium sulphate. The dried extracts were evaporated on a rotary evaporator, the resulting fatty acid methyl esters were dissolved in benzene, applied to glass plates coated with KSK silica gel, and the solvent was evaporated. A layer of purified esters was removed from the glass plate and washed with hexane on a Schott No. 4 filter. The resulting pure ester mixture was dissolved in hexane and analysed using chromatographic columns filled with W/HP chromosome sorbent impregnated with Silar 5 cp liquid phase and analysed on an HRGC 5300 chromatograph at 140-250°C and temperature increase by 2°C per minute. The identification of individual fatty acids was carried out in accordance with Sigma-Aldrich standards. The content of each fatty acid was expressed as a percentage of the total amount. The mass fraction of essential amino acids was determined by liquid chromatography using an automatic analyser T-339 (T 339, Czech Republic) at the O.V. Palladin Institute of Biochemistry (Ukraine). The protein hydrolysis of *C. gariepinus* meat was carried out at 110°C for 24-36 hours. For this purpose, samples of crushed meat weighing 1-5 mg were mixed with 6N hydrochloric acid. Identification of individual amino acids was carried out based on Sigma-Aldrich standards. The content of the tryptophan amino acid was determined at the V. Dokuchaev Kharkiv National Agrarian University according to DSTU 4507:2005 (2008) method. Crushed fish meat was decomposed by alkaline hydrolysis to determine tryptophan with the conversion of the amino acid to free form, its isolation by column ion exchange

chromatography with Post-column derivatisation with ninhydrin. The mineral composition was studied at the Ukrainian Research Institute of Alcohol and Food Biotechnology according to DSTU 7525:2014 (2015). The mineral composition was investigated at the Ukrainian Research Institute of Alcohol and Food Biotechnology in accordance with DSTU ISO 11885:2005, by inductively coupled plasma atomic emission spectrometry; the content of heavy metals was determined by atomic absorption spectrometry; the mineralisation of samples was carried out according to DSTU 7670:2014.

Results

Investigation of the amino acid composition of C. gariepinus meat protein in comparison with other freshwater fish

An assessment of the compliance of the amino acid composition of *C. gariepinus* meat protein with FAO/WHO recommendations and its comparative characteristics with those of other freshwater fish are provided in Table 1.

Table 1. *Compliance of the amino acid composition with meat protein of C. gariepinus and other freshwater fish, g/100 g of protein*

Name of EAC	Name of fish				Ideal protein according to FAO/WHO (Dietary Ref. 2017)
	*C. gariepinus**	*C. carpio* (Bal-Prylypko *et al.*, 2018)	*C. idella* (Bal-Prylypko *et al.*, 2018)	*H. molitrix* (Bal-Prylypko *et al.*, 2018)	
Protein content, in % of the total chemical composition	16.80	15.60	17.10	18.70	
AAE9, incl.	48.4	50.38	45.09	32.60	27.70
VAL	4.8	6.47	4.19	2.24	3.90
ILE	4.3	4.71	4.90	3.68	3.00
LEU	9.9	10.58	8.80	7.38	5.90
MET+CYS	4.4	2.94	2.97	1.13	2.20
THR	4.3	5.29	4.60	2.63	2.30
PHE + TOUR	7.7	7.64	7.96	5.63	3.80
TRP	0.8	1.06	0.9	Traces	0.60
LYS	10.1	11.17	10.29	7.23	4.50
HIS	2.1	0.52	0.48	2.68	1.50

Notes: *– results of the author's own research
Source: developed by the author

Analysis of the data in Table 1 shows that the total amount of essential amino acids in the proteins of catfish meat in the conditions of aquaculture in Ukraine exceeds their recommended value in ideal protein by 74.72% (48.40 vs. 27.70 g/100 g of protein). In carp – by 81.87% (50.38 vs. 27.70 g/100 g of protein), in grass carp – by 62.77% (45.09 vs. 27.70 g/100 g of protein), in silver carp – by 17.68% (32.60 vs. 27.70 g/100 g of protein). The results obtained allow estimating the biological value of protein based on the amino acid score assessment of the protein value of *C. gariepinus* in terms of amino acid speed compared to this indicator in freshwater fish such as carp *C. carpio*, grass carp *C. idella*, and silver carp *H. Molitrix* shown in Figure 1.

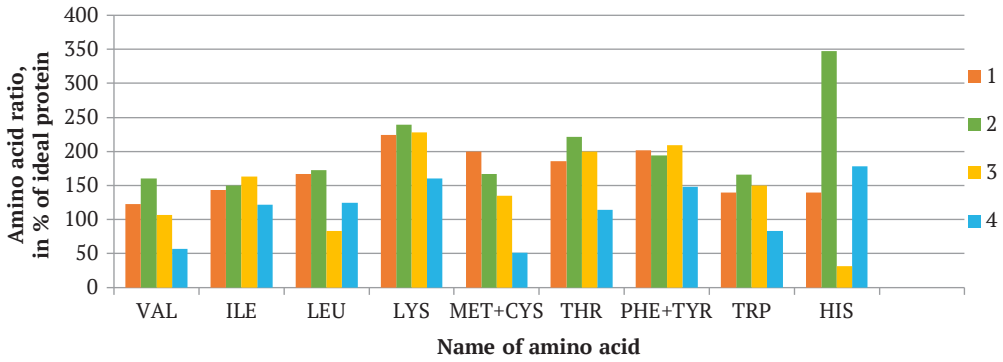

Figure 1. Protein amino acid composition of the main commercial freshwater fish of Ukraine
Notes: 1 – C. gariepinus; 2 – C. carpio; 3 – C. idella; 4 – H. Molitrix
Source: developed by the author

As can be seen from the figure, the scores of all AAE9 in meat protein *C. gariepinus* exceeds 100%, which characterises its high biological value. The highest rate for lysine was determined – 224%. This amino acid belongs to the aliphatic, the group of acids that ensure the growth of the body, takes part in the transport of fatty acids, and helps to reduce the level of triglycerides. Meat proteins of *C. sagrio, C. idella, H. Molitrix* also contain a high amount of this acid, the rate of which is 239, 228, and 160 %, respectively. The decrease in the rate of essential amino acids in catfish meat is found in the following sequence: LYS (224%), PHE+TYR (202%), MET+CYS (200%), LEU (167%), ILE (143%), TRP I HIS (140%), VAL (123%). In other freshwater fish, the tendency to decrease the speed of AAE(9) is different: in carp, HIS – 347, LIS – 239, THR – 221, PHE+TYR – 194, LEU – 173, MET+CYS – 167, TRP – 166, VAL – 160, ILE – 150; in grass carp, LYS – 228, PHE+TYR – 209, IKE – 163, TET+CYS – 135, VAL – 107, LEU – 83, HIS – 32; in silver carp JIS – 178, LYS – 160, PHE+TYR – 148, LEU – 125, ILE – 122, THR – 114, TRP – 83, VAL – 57, MET+CYS – 51, %, respectively.

The protein of carp and catfish meat is also complete in contrast to the protein of grass carp and silver carp, in which limiting amino acids are determined, the rate of which is as follows: HIS – 32% and LEU – 83%; TRP – 83%, MET+CYS – 51% and VAL – 57%. Assessment of the biological value of lipids in *C. gariepinus in comparison with other freshwater fish.* Results of studies of the fatty acid composition of lipids in *C. gariepinus* meat in comparison with these indicators of this fish species obtained in central Europe and carp are presented in Table 2.

Table 2. *Comparative characteristics of fatty acid composition of meat lipids in C. gariepinus from various aquaculture conditions and carp, in % of the total amount of fatty acids*

Fatty acids	Acid code	Name of fish			FAO/WHO recommendations (Dietary Reference Values..., 2017)
		*C. gariepinus**	*C. gariepinus* (Krogdahl *et al.*, 2022)	*C. carpio* (Bal-Prylypko *et al.*, 2018)	
Saturated, incl.		32.61	30.50	27.52	30
F12DO	12:0	-	0.03	0.23	
F14DO	14:0	2.69	2.87	1.75	
F15DO	15:0	0.93	0.25	0.31	
F16DO	16:0	21.93	21.76	18.39	

Table 2. Continued

Fatty acids	Acid code	Name of fish			FAO/WHO recommendations (Dietary Reference Values..., 2017)
		*C. gariepinus**	*C. gariepinus* (Krogdahl *et al.*, 2022)	*C. carpio* (Bal-Prylypko *et al.*, 2018)	
F17DO	17:0	-	0.38	0.83	
F18DO	18:0	7.06	5.02	6.01	
F20DO	20:0		0.19		
Monounsaturated, incl.		40.52	36.33	49.07	60
F14D1	14:1	-	0.08	-	
F15D1	15:1	-	0.02		
F16D1	16:1	6.89	0.67	7.32	
F16D1CN9	16:1 cis9	-	4.69	-	
F17D1	17:1	-	0.14	0.06	
F18D1	18:1			4.86	
F18D1CN9	18:1 cis9	31.09	28.08	35.99	
F20D1	20:1		2.35	0.54	
F22D1	22:1	2.54	0.21	0.30	
F24D1	24:1	-	0.09	-	
PFA, incl.		21.87	29.99	11.44	10
F14D2	14:2	-	0.05	-	
F16D2	16:2	-	0.08	-	
F18D2N6	18:2	10.99	19.79	4.86	
F18D2TCON	18:2	-	0.14	-	
F18D3N6	18:3	-	1.85	-	
F18D3N3	18:3	2.18	0.6	4.91	
F18D4	18:4	-	0.72	-	
F20:2D2	20:2	3.95	0.20	0.32	
F20:3D3	20:3	-	0.48	-	
F20:4D4	20:4	0.53	0.21	-	
F20:4D4N6	20:4	-	-	0.36	
F20:5D5N3	20:5	1.37	3.09	0.56	
F22:5D5	22:5	0.46	0.57	-	
F22:6D6N3	22:6	2.39	2.21	0.43	
Unidentified		5.08	3.18	11.97	

Source: developed by the author

The results of the comparative characteristics show that the sum of saturated fatty acids of lipids of catfish grown in aquaculture conditions in Ukraine is slightly higher than the recommendations of FAO/WHO and amounts to 32.61 against 30% of the total amount of fatty acids. The mass fraction of monounsaturated fatty acids (MFA) is 32.61% less and the sum of polyunsaturated fatty acids (PFA) is 118.7% more than the FAO/WHO recommendations (Fats and fatty acids in human nutrition, 2010). Among saturated fatty acids, a high level of palmitic acid was observed both in lipids of catfish from the aquaculture conditions in Ukraine and from other aquaculture conditions of this species – 21.93; 21.76% (Krogdahl *et al.*, 2022) and freshwater carp – 18.39%, respectively. For monounsaturated fatty acids (MFA) in the lipids of catfish meat and other freshwater fish, the dominance of oleic acid (F18DICN9) 18:1 ω-9: 31.09 % – in catfish lipids in Ukraine aquaculture; 28.08% – in catfish in other aquaculture conditions; and 35.99% – in carp lipids were determined. The

amount of polyunsaturated fatty acids (PFA) in catfish lipids in aquaculture conditions in Ukraine is more than twice the amount recommended by FAO/WHO and equals 21.87 against 10%. A high mass fraction of these acids was also found in catfish lipids under other aquaculture conditions – 29.99%. In freshwater carp fish, the content of these acids is closer to the recommended amount. Among the polyunsaturated fatty acids of catfish lipids, the largest mass fraction was determined for linoleic acid (F18D2N6) 18:2 ω-6. In the conditions of catfish aquaculture in Ukraine, this acid amounts to 10.99, in other conditions – 19.79 (Krogdahl *et al.*, 2022) and in carp – 4.86% (Bal-Prylypko *et al.*, 2018), respectively.

Assessment of the biological value of fish meat lipids based on the ratio of individual classes and certain fatty acids in accordance with the ideal lipid (Tsypriyan *et al.*, 2007) and the FAO/WHO recommendations (Fats and fatty acids..., 2010) are shown in Table 3.

Table 3. *Assessment of the biological value of lipids in catfish meat and other freshwater fish*

Name of lipid type	Fatty acid ratio				
	SFA : MFA : PFA	PFA : SFA	F18D2N6 : F18D1CN9	F18D2N6 : F18D3N3	Σ ω-6 : Σ ω-3 (Fats and fatty acids ...2010)
	(Tsypriyan *et al.*, 2007)				
Ideal lipid	1 : 1 : 1	0.2 – 0.4	>0.25	>7	10 – 5
*C. gariepinus**	1.49 : 1.80 : 1	0.67	0.35	5.04	1.8 : 1
C. gariepinus (Krogdahl *et al.*, 2022)	1.98 : 1.80 : 1	0.98	0.70	7.71	3.39 : 1
C. carpio (Bal-Prylypko *et al.*, 2018)	2.40 : 4.28 : 1	0.41	0.13	0.98	0.9 : 1.0

Source: developed by the author

Analysis of the data in Table 3 shows that in catfish meat lipids in all aquaculture conditions, the ratio of saturated (SFA) to monounsaturated (MFA) and polyunsaturated (PFA) fatty acids does not correspond to the ideal lipid indicators due to the excess of the mass fraction of SFA and MFA and the amount of PFA by 1.49 and 1.80 (under the conditions of aquaculture in Ukraine) and by 1.98 and 1.80 times (under other aquaculture conditions) (Krogdahl *et al.*, 2022), respectively. The PFA : SFA ratio in catfish lipids under all aquaculture conditions is higher than in the ideal lipid and is 0.67 and 0.98 versus 0.2-0.4 in the ideal lipid. In carp lipids, this indicator is consistent with the ideal lipid – 0.41. The ratio of fatty acids F18D2N6 : F18D1CN9 in catfish lipids under various aquaculture conditions is higher than in the ideal lipid: in catfish from aquaculture of Ukraine, this indicator is 0.35 against >0.25 in the ideal lipid, in carp – less than twice (0.13). As for the indicator F18D2N6 : F18D3N3, in the ideal lipid it is >7 and is consistent only with catfish lipids in the aquaculture of another country (7.71); in the aquaculture of Ukraine – 5.04 against >7. The ratio of the sum of fatty acids ω-6: ω-3 has recently been given considerable attention due to their functional and metabolic significance in the regulation of lipid metabolism (Fats and fatty acids ..., 2010; Sharma & Agnihotri, 2020). According to the results of studies, the ratio of these acids does not coincide with the ideal lipid, but it indicates a high mass fraction of ω-3 fatty acids, which are particularly deficient in the human diet. In an ideal lipid, this ratio is 10 : 5, in catfish in the

conditions of aquaculture in Ukraine – 1.8 : 1, and in the conditions of aquaculture in another country – 3.39 : 1. Carp lipids in this indicator can also be attributed to biologically valuable due to the high content of fatty acids of the ω-3 family, namely, almost on a par with acids of the ω-6 family (0.9 : 1.0).

Investigation of the mineral composition of C. gariepinus meat in the conditions of aquaculture in Ukraine.

Table 4 shows the content of mineral elements in *C. gariepinus* meat and its compliance with the daily requirement of an adult person.

Table 4. *Characteristics of the mineral composition of meat of C. gariepinus, mg/100 g of meat*

Name of mineral element	*C. gariepinus*	Daily requirement (Tsypriyan *et al.*, 2007)
K	343 ± 15	2,500
Na	42.1 0.7	1,300
Mg	23.24 0.7	400
Fe	0.23 0.02	15.00
Z	0.4 0.02	12.00
Se	0.014 0.002	0.055
P	208 15	700-4,000

Source: compiled by the authors

According to the findings, the content of a single mineral element in the composition of *C. gariepinus* meat cannot cover the daily requirement of an adult (Tsypriyan *et al.*, 2007), however, is of interest as an additional source of essential macro- and micro-elements. In terms of the content of heavy metals such as Pb and Cd and the radionuclide ^{90}Sr, catfish meat meets safety requirements (Codex general..., 2009) (Table 5).

Table 5. *Content of heavy metals and radionuclides in the meat of C. gariepinus (n = 3, p < 0.05)*

Indicator	Meat *of C. gariepinus*	Acceptable levels (Codex general..., 2009)
Heavy metals, mg/100 g		
Pb	Not detected	1.0
Cd	Not detected	0.2
Radionuclides, Bq/kg		
^{90}Sr	0.039±0.001	100

Source: developed by the author

The heavy metals Pb and Cd are not detected in the meat of *S. gariepinus*, and the content of the radionuclide ^{90}Sr is at a low level. Thus, according to the indicators under study, channel catfish meat is safe in the conditions of aquaculture in Ukraine.

Discussion

During 2021-2023, the important contribution of fisheries and aquaculture to food security and nutrition of the population in the 21st century was increasingly recognised, as it has provided an increased supply of aquatic animals to global markets. Food products from aquatic organisms are one of the most popular food groups in the world. This is conditioned by the features of such products, which are a source of essential and non-essential elements of nutrition, namely, easily digestible proteins with all proteinogenic amino acids, monounsaturated fatty acids ω-9, polyunsaturated fatty acids ω-6 and ω-3, vitamins, macro- and micro-elements. Therefore, the world has determined an annual increase in the level of consumption of

fish products, which in the future will be more than 20-22 kg per year. Fish raw materials and products are more closely related to the recommendations of domestic and international organisations to ensure the daily human need for high-quality and health-improving nutrition. However, no product made from any raw material can fully meet these needs (Mamndeyati & Tidi, 2023). Therefore, in the future, innovative technologies for the development of poly-component food products will be developed based on studies of all indicators of the quality and safety of raw materials, mathematical modelling of the recipe composition of products that would correspond to or be close to the recommended values to meet the needs of the human body. That is why the obtained data on the nutritional value of catfish meat from aquaculture in Ukraine are important for developing recommendations for improving its processing technologies and creating health-improving nutrition products.

In recent years, aquaculture of the *Clarias gariepinus* catfish of the *Clariidae* family has been developing in Ukraine, which was emphasised by U.E. Sharylo *et al*. (2020) and M.V. Zadorozhnii (2023), and this type of fish is in great demand among the population for the production of various culinary products. However, until the next time, data on nutritional value are limited only to materials regarding the chemical composition and some technological characteristics of meat. Thus, I. Bal *et al.* (2023a) established that organoleptic characteristics of fresh clariid catfish meet the requirements of the standard; in terms of mass composition, the largest share belonged to the carcass – 58.07 ± 2.40%, the fillet was 43.68 ± 2.00%, the last mass fraction of 20.01 ± 2.73% is accounted for by the head, bones, viscera, and fins.

According to I.M. Bal *et al.* (2023b), nutritional value of *C. gariepinus* is determined by a high fat content (26.2 ± 1.32%), which is not consistent with the data of this indicator in catfish from natural conditions and is higher than in aquaculture conditions in Nigeria. According to S.O. Okonkwo *et al.* (2020), catfish meat, both in aquaculture and in vivo, is low in fat (12.0 ± 1.4-12.9 ± 2.8%), this may be conditioned by the weight of the fish samples under study (200 g against 989.0 and 1,450 g in the conditions of aquaculture in Ukraine). The protein content of catfish meat from the conditions of aquaculture in Ukraine exceeds this indicator in fish from other countries and living conditions, which determined the highest energy value of its meat (506.7 ± 7.1 vs. 492.2 ± 7.2 kcal). These data once again highlight the influence of growing conditions and feed on the chemical composition of fish meat. In accordance with the recommended norms of physiological needs for the ratio of protein, fat, and carbohydrates in the daily diet as 1:1:4 (Order of the Ministry of Health of Ukraine No. 1073, 2017) the results of current research and literature sources on the chemical composition of catfish meat do not coincide. The protein content of channel catfish meat is 2.5 and 2.85 times higher than fat (Folch *et al.*, 2023; Bal *et al*., 2023a).

Meat protein of catfish in the conditions of aquaculture in Ukraine is characterised by its biological value, which is determined by the high content of essential amino acids (AAE9). The total amount of these acids is 48.40 against the ideal protein content of 27.70 g/100 g of protein, that is, 74.29% higher. The qualitative and quantitative composition of AAE9 catfish meat protein is consistent with the literature data of this indicator in other freshwater fish. Thus, in the studies by L. Bal-Prylypko *et al*. (2018) the protein of carp and crass carp meat was determined to be 50.38 and 45.09 g per 100 g of these acids. Thus, channel catfish meat protein can be recommended as a source of biologically valuable animal protein in the human diet. Regularities in the composition of AAE9 in catfish and other freshwater fish meat have also been established, which are manifested in the high content of LYS (the ratio of this acid is 224% in

catfish and 160 to 239% in other freshwater fish (Suleiman *et al*., 2023).

Lipids are produced, transported, and recognised by the coordinated action of numerous protein-binding enzymes and receptors. Therefore, a comprehensive analysis of lipids is crucial for understanding their impact on the nutritional value and technological properties of fish meat. The fatty acid composition of lipids is a very important indicator of the biological value of raw materials. As previously determined, the total amount of saturated fatty acids (SFA) in catfish lipids is slightly higher than the FAO/WHO recommendation, amounts to 32.61% versus 30% of lipids, and is a typical feature for other freshwater fish. Thus, in the lipids of catfish from other aquaculture conditions, the sum of these acids is set at 30.50%, in carp – 27.52 %. Among this class of fatty acids, a high content of palmitic acid F16D0 was determined – 21.93%. A similar dependence was obtained in the study of catfish meat lipids in other aquaculture conditions – 21.76% (Krogdahl *et al*., 2022) and in lipids of freshwater fish: 18.39% in carp and 24.40% in grass carp (Bal-Prylypko *et al*., 2018). Palmitic acid can simultaneously bring benefits and harm for human health, namely, positively affect the condition of the skin, take part in the synthesis of important fatty acids for humans, and support cellular functions, as noted by J.K. Grant *et al*. (2024). However, in large quantities, this acid can contribute to the deterioration of brain function, the appearance of excess weight, and cause the development of cardiovascular diseases, as noted by F.M. Sacks *et al. (*2017).

The total amount of monounsaturated fatty acids (MFA) in channel catfish lipids under aquaculture conditions in Ukraine is 33.34% less than the recommended amount (Fats and fatty acids..., 2010), which is consistent with this indicator in the main commercial freshwater fish and catfish under other aquaculture conditions. The researchers determined a total amount of MFA in the lipids of catfish aquaculture in another country is at the level of 36.33%, which is 39.45% less than recommended by FAO/WHO. The level of the sum of these acids in carp lipids is closer to their balanced content and is 49.07% (18.34% less). A characteristic feature of fatty acids of this class is the dominance of oleic acid F18DICN9 both in the lipids of catfish aquaculture of Ukraine, other aquaculture conditions, and lipids of freshwater fish. In studies of the fatty acid composition of catfish lipids in aquaculture conditions in another country, 28.08% of this acid was found (Krogdahl *et al*., 2022), in Carp-35.99% (Bal-Prylypko *et al*., 2018). Oleic acid ω-9 is not classified as essential (Grant *et al*., 2024), because it can be produced by the human body from unsaturated fatty acids and is not necessary in the diet. However, the positive effect of this acid on the duration and quality of human life, activation of lipid metabolism, and promotion of the penetration of active components into the stratum corneum of the skin has been shown. Therefore, a balanced intake of this acid is recommended.

The total amount of polyunsaturated fatty acids (PFA) exceeds the FAO/WHO recommendation by more than two times in the lipids of catfish aquaculture of Ukraine and is 21.87% against 10 (Table 2). In other aquaculture conditions, the content of these acids in catfish lipids is three times higher – 29.99% (Krogdahl *et al*., 2022). In carp lipids, the amount of PFA meets the recommendations and is 11.44% (Bal-Prylypko *et al*., 2018). In the first place in terms of quantity is linoleic acid F18D2N6 (10.99%). In the fatty acid composition of catfish lipids from other aquaculture conditions, a high content of this acid was also determined – 19.79% (Krogdahl *et al*., 2022). The lipid profile of freshwater fish is characterised by its low level: 4.86% was determined in carp, 10.66% in grass carp, and 4.54% in silver carp (Bal-Prylypko *et al*., 2018). With a sufficiently high mass fraction of polyunsaturated fatty acids (PFA) – (20.87 vs. 10% recommended), only the 1.8:1 ratio of ω-6/ω-3 fatty acids indicates

the biological value of catfish meat lipids. The ratio of certain classes and individual fatty acids in an ideal lipid proposed by V.I. Zsyprian *et al.* (2007) is declarative and until further notice, experimental confirmation of these data is very limited. The effect of the ω-6/ω-3 fatty acid ratio on nutritional value has been studied to the greatest extent. This indicator has recently received considerable attention due to the participation of these acids in the regulation of lipid metabolism (Sharma & Agnihotri, 2020; Chen *et al.*, 2023). PFA deficiency of the ω-3 and ω-6 families disrupts metabolic processes in the human body, which can cause serious diseases. Low levels of essential fatty acids eicosapentaenoic (F20 : 5d5n3) – 1.37% and docosahexaenoic (F22 : 6d6n3) – 2.39% are typical for freshwater fish. Thus, in the lipids of carp, grass carp, and silver carp, these acids are present in a minimum amount: F20 : 5D5N3 – 0.56; 0.57; 1.47%, respectively; F20 : 5D5N3 – 0.43; 0.82; 0.35% (Bal-Prylypko *et al.*, 2018). Recently, these acids have received considerable attention in the human diet and are recommended for the prevention and treatment of cardiovascular and many other diseases, as indicated by P. Sharma & N. Agnihotri (2020). It was established that the use of sufficient amounts of these acids prevents the occurrence of atherosclerosis, coronary diseases, and stimulates the immune system. These acids have been shown to have anticholesterogenic and anti-lipogenic effects. The source of much-needed PFA of the ω-3 and ω-6 families is a variety of marine and oceanic species (Manson *et al.*, 2019; Menchynska *et al.*, 2021). Therefore, based on these data, it can be recommended to improve catfish meat processing technologies by enriching pasty products with fats from marine fish species to meet the daily human need for essential fatty acids F20 : 5D5N3 and F22 : 6D6N3. The technology of these products allows modelling their nutritional value with specified properties for almost all factors.

The importance of providing a person's daily needs with mineral elements is conditioned by their participation in many metabolic processes, so the results of the studies on these indicators and their agreement with the recommended values are important for evaluating the nutritional value of catfish meat. Low levels of K, Na, Mg, Fe, Z, Se, and P were found (Table 5), which cannot meet a person's daily need for these nutritional factors. Similar characteristics of the mineral composition of meat were noted by L. Bal-Prylypko *et al.* (2018) in freshwater fish. However, raw materials from freshwater fish can be used as an additional source of mineral elements. Catfish meat meets the safety requirements by the content of heavy metals such as Pb and Cd, and radionuclide ^{90}Sr, and is consistent with the data of these indicators for other freshwater fish of aquaculture in Ukraine.

Thus, according to such indicators of nutritional value as the qualitative and quantitative composition of essential amino acids, clariid catfish meat in the conditions of aquaculture in Ukraine meets the recommendations for protein usefulness. The lipid component for the content of essential fatty acids requires the design of multicomponent food products by enriching catfish meat with lipids from marine aquatic organisms to provide the human diet with essential fatty acids F20 : 5D5N3 and F22 : 6D6N3.

Conclusions

Aquatic food products make an important contribution to food security and nutrition, are in high demand among the Ukrainian population, and are among the most popular food groups. Over the past few decades, Ukraine has been farming *Clarias gariepinus*, a catfish that is in great demand. However, the lack of systematic studies of the nutritional value of its meat limits the improvement of processing technologies.

The biological value of catfish meat proteins is determined by the content of all essential amino acids, the sum of which is 74.72% higher than in the ideal protein according to

the recommendations of FAO/WHO. The ratio of all essential amino acids is above 100% and indicates the absence of limiting ones. The composition of fatty acids and lipids of catfish meat is typical for freshwater fish and this species grown in other aquaculture conditions. A high content of palmitic acid – 21.93%, oleic acid – 31.09% and linoleic acid – 10.99% was determined. The biological value of lipids is determined by the ratio of fatty acids of the ω-6/ω-3 family as 1.8:1 at the recommended 10:5, which indicates the possibility of using lipids of this fish to regulate lipid metabolism and as a source of fatty acids of the ω-3 family that are particularly deficient in the human diet. The content of macronutrients K, Na, Mg, Fe, Z, Se, and P is significantly less than the daily requirement of an adult, but their presence in catfish meat can be an additional source of them when consumed. Catfish meat is safe in terms of the content of heavy metals Pb, Cd and the radionuclide ^{90S}r.

Thus, the data on the nutritional value of *Clarias gariepinus* meat, grown in aquaculture in Ukraine, were obtained, namely, the biological value of protein and lipid components, the content of some essential mineral elements, heavy metals and ^{90}Sr radionuclide. The totality of these data indicates a high biological value of proteins due to the qualitative and quantitative content of essential amino acids, the speed and sum of which exceeds the FAO/WHO recommendations for an ideal protein. Lipids are characterised by a low content of polyunsaturated fatty acids and almost no particularly valuable fatty acids EPA and DHA. However, the lipid value of this type of fish is determined by the ratio of fatty acids of the ω-6/ω-3 families as 1.8 : 1 with the recommended 10:5. Given the deficiency of ω-3 fatty acids in the adult diet, catfish lipids are of interest as a source of these acids. However, the nutritional value of any fish and other raw materials does not meet the recommendations for health-improving nutrition. Undoubtedly, the *C. gariepinus* is in great demand among the population of Ukraine. Therefore, promising areas for further research will be associated with the development of multicomponent paste products, the formulation of which is planned to be enriched catfish meat with polyunsaturated fatty acids such as eicosapentaenoic and dogosahexaenoic from marine aquatic organisms.

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Conflict of Interest

None.

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Харчова цінність кларієвого сомику в умовах аквакультури України

Іван Баль

Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0007-1608-5263

Анотація. Харчова цінність сировини визначається сукупністю показників, які характеризують біологічну цінність білку, ліпідів, мінерального складу та безпеки. Тому їх дослідження у м'ясі одного із об'єктів аквакультури України – кларієвого сомику є актуальним. Мета роботи полягала у дослідженні біологічної цінності білку, ліпідів, мінерального складу, безпеки м'яса сомику при вирощуванні в Україні і оцінки цих показників у відповідності до рекомендацій ФАО/ВООЗ. Амінокислотний склад білку визначали методом іонообмінної рідино-колоночної хроматографії на автоматичном аналізаторе Т 339 (Чехія); жирнокислотний склад ліпідів - на газовом хроматографі HRGC 5300 («Carlo Erba», Італія). Мінеральний склад м'яса досліджували методом атомно-емісійної спектрометрії з індуктивно-зв'язаною плазмою; вміст важких металів – методом атомно-абсорбційної спектрометрії. Дослідження амінокислотного складу білку визначило присутність усіх незамінних амінокислот у кількості суттєво перевищеної у ідеальному білку у відповідності до рекомендацій ФАО/ВООЗ, що свідчить про високу біологічну цінність. Жирнокислотний склад ліпідів є типовим для прісноводних риб та ліпідів сомику із інших умов аквакультури. Біологічна цінність ліпідів м'яса сомику визначається співвідношенням жирних кислот родин ω-6/ω-3 як 1,8:1,0 при рекомендованому 10:5, що свідчить про можливість використання ліпідів цієї риби у якості джерела особливо дефіцитних у раціоні людини жирних кислот ω-3. Низький рівень полі ненасичених жирних кислот та відсутність незамінних жирних кислот ейкозапентаєнової (ЕПК) та докозагексаєнової (ДГК) кислот дає підставу формувати дизайн біологічно цінних продуктів з м'яса сомику шляхом його збагачення ліпідами морських гідробіонів. Практична значимість результатів досліджень полягає в отриманні оригінальних даних щодо харчової цінності м'яса одного із об'єктів аквакультури України, визначені ступеню задоволення добової потреби людини при його споживанні та розробки рекомендацій щодо раціонального використання

Ключові слова: м'ясо сомику; амінокислоти незамінні; жирні кислоти; показники безпеки; важкі метали; радіонукліди

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Physical and mathematical modelling of the process of cooking minced meat with spelt flour and champignon mushrooms

Larisa Bal-Prylypko*
Doctor of Technical Sciences, Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-9489-8610

Mykola Nikolayenko
PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-2213-4985

Mikhailo Mushtruk
PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-3646-1226

Marina Nazarenko
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-8598-0420

Ludmila Beyko
PhD in Technical Sciences, Associate Professor
Ternopil Ivan Puluj National Technical University
46001, 56 Ruska Str., Ternopil, Ukraine
https://orcid.org/0000-0001-6211-8010

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*Corresponding author

Abstract. The introduction of additives of plant or animal origin into meat products is currently a steady trend in food technologies due to the possibility of obtaining unique properties of products and reducing their cost, which justifies the relevance of the conducted research. The purpose of the study was to build a mathematical algorithm that can determine the regularities of changes in the main parameters of the process of preparing minced meat semi-finished products with vegetable additives, which would help to establish the trends in the development of technical and technological efficiency of mechanisation of the system of fine grinding of raw materials for the production of sausage products. The addition of spelt flour and mushrooms as ingredients to the minced meat mass was investigated, which allows, together with reducing the cost of production of cooked sausage products, significantly improving the organoleptic quality indicators of products, reducing their caloric content and extending the shelf life for consumption. The wild variety of spelt used in this scientific work as an alternative to its cultivated varieties has significantly less allergic activity and, accordingly, a lower proportion of gliadins, which form the basis of wheat gluten; which justifies the practical significance of the study. A microstructural analysis of minced meat of control and experimental samples of boiled sausages was performed, which revealed that the latter category of meat product is characterised by increased density and elasticity due to the inclusion of spelt microparticles in the vacuole of the meat fraction. According to the results of experimental studies, using the "dimension analysis" method and the Federman-Buckingham theorem, it was possible to obtain a criterion equation for the process of heat and mass transfer under conditions of intensive mechanical mixing. These process characteristics were described using the Euler, Fourier, and Sherwood criteria. The compiled function contains the main factors of external influence on raw materials and their physical and mechanical characteristics, which allows adequately assessing the diffusion processes in the technological environment and creating the recommended range when designing technical and technological support for obtaining high-quality food products

Keywords: spelt; shear stress; minced meat mass; similarity theory; similarity numbers; diffusion; cooked meat products

Introduction

Currently, there is a steady trend of increasing the population's demand for meat products, which leads to a partial reorientation of meat processing enterprises to the production of combined meat products containing additives of plant and animal origin. One of the main priorities of the national policy in the field of healthy nutrition is a revolutionary restructuring of technologies to create completely new, qualitatively different food products that will meet the requirements of modern consumers and will have a targeted adjustment of chemical composition and functional characteristics. L.V. Bal-Prylypko *et al*. (2022) found that the eating habits of the country's population as a whole and its various regions are characterised by critically low levels of protein, vitamins, minerals, dietary fibre, and other vital components. According to the latest research, a revolutionary potential in the development of a new market for meat products through the creation of enriched and innovative combined products has been noted. This means using food additives and replacing some of the raw meat with plant components to achieve a more balanced composition. This approach will not only reduce the shortage of meat products, but also contribute to the development of new technologies in the food industry.

For a long time, the question of the possibility of providing the latest varieties of products with health-improving and medicinal properties remained for these recipes, which led to the development of the *FOSHU* (*Foods for Special Health Use*) concept in Japan in 1991. Based on the results of experimental studies by L.D. Díaz *et al*. (2020), it was found that in many countries the food market of meat products received quite a large number of products that became known under the brand of "functional" and focused primarily on consumers with special needs. Their purpose is to provide basic nutritional needs while simultaneously having a positive effect on the physiological state of a person, in particular, to normalise the concentration of cholesterol in the blood and the composition of the bacterial flora of the intestine, strengthen the immune system, give the product anti-inflammatory properties, prolong the active period and overall life expectancy.

Seven main types of additives characterised by therapeutic and preventive properties of ingredients of functional products, namely, dietary fibre; minerals; vitamins; antioxidants; polyunsaturated fatty acids; probiotics and prebiotics, have been consistently used at Ukrainian enterprises. In addition, to improve the conditions for preparing products for consumption, for hydration of dietary fibre concentrates, the formulations contain treated water, the quality of which is subject to strict requirements by the national standard for drinking water (DSTU 7525:2014, 2014).

It is common practice to add dietary fibre to the products, which is necessary for the normal functioning of the digestive tract, normalisation of metabolic processes that are not broken down by human digestive enzymes: cellulose, hemicellulose, and lignin. A.K. Das *et al.* (2020) argue that the need for dietary fibre is a consequence of the evolution of the human gastrointestinal tract, which since ancient times has consumed mainly fibre-rich plant foods recommended by Western diets, normalising the daily requirement of which from 14 to 30 g, depending on the age of the person. V. He *et al*. (2022) found that dietary fibre and whole grains include a unique range of bioactive components, among which starch compounds occupy a special place. It is worth noting that these starchy substances remain resistant to enzymes that work in the gastrointestinal tract (Takač *et al.*, 2021).

As reported by S.K. Gill *et al*. (2021), the growing demand for the use of recipes for meat products with vegetable additives justifies the importance of the presented research object, the need to develop effective models for describing, evaluating and predicting the dynamics of changes in the characteristics of this product, which confirms relevance and prospects for the development of mathematical modelling methods shown in the paper. Therefore, the purpose of the study was to improve the production technology of cooked sausage products and the process of cooking minced meat with admixtures of spelt flour and champignons by applying similarity theory and modelling methods using the "dimension theory" method, developing a physical and mathematical model of the studied process of compiling the heat and mass transfer equation and graphoanalytical analysis of dependencies between the main parameters of the process.

To achieve this goal, the following main tasks were set: to analyse the current trends in the development of the meat industry regarding the use of vegetable proteins and enzymes in the production of semi-finished products; comprehensive studies of the functional and technological properties of plant additives in meat semi-finished products; to develop an improved technology for the production of meat semi-finished products with the addition of, in particular, spelt flour and mushrooms; to develop a physical and mathematical model of the process of cooking minced meat; to draw up an equation of heat and mass transfer of the process under study and determine the relationships between its main parameters.

The scientific hypothesis of this study is as follows: the development of a mathematical model of the minced meat preparation process is based on the analysis of the factor space, which reveals experimentally obtained physical and mechanical characteristics of the minced meat weight and the driving forces of the process, the dependencies between which were replaced by dependencies between similarity numbers that can adequately describe the process under study.

Literature Review

Many modern studies are increasingly focusing on the use of various additives of animal and vegetable origin in meat products. E.B. Rimm *et al*. (2022) argue that the lipids contained in the vast majority of seafood are rich in polyunsaturated fatty acids, docosahexaenoic, and eicosapentaenoic acids, which are present only in this type of raw material, making marine raw materials the basis for multicomponent functional food systems.

M.J. Keenan *et al*. (2009) concluded that dietary fibre in meat mixes stabilises the structure and increases the ability of minced meat to retain water in an amount that is 5-30 times their own weight due to the content of cellulose, hemicellulose, and lignin in them. S.K. Gill *et al*. (2021) proved that the body's main source of dietary fibre is legumes and cereals, whole grains, vegetables, fruits, and nuts. It is important to note that dietary fibre is divided into soluble and insoluble. Soluble fibre can be found in foods such as vegetables, fruits, and nuts, while insoluble fibre is mostly found in whole grains.

S. Guerra *et al*. (2021) proved that pectin is a valuable component of plant additives, which is included in the basic structure of fruit cells and green parts of plants. Pectin gels create the basis of the walls of the stomach and intestines, eliminate acute physical effects, significantly reducing inflammation of the mucous membrane. The addition of pectin contributes to the effective elimination of incorporated radionuclides from the body, as noted by V.P. Vasyliv *et al*. (2021), in particular, biogenic toxins, cholesterol, bile acids, urea, bilirubin, serotonin; increases immunity and post-radiation recovery of blood enzyme elements, improves the antioxidant activity of blood and liver tissues. Chitin, as a natural biological polymer found in fungi, in particular, champignons or yeast, performs the protective and resisting function of cells; effectively binds lipids, reducing the activity of fat absorption processes in the intestine, is necessary for the growth of hair and nails, according to L. Vyerchenko *et al*. (2019). G. Caio *et al*. (2020) conducted a study that used seeds of cereals such as wheat, rye, barley in sausage products, which allowed increasing the starch content to 4%, which leads to a reduction in production costs and allows simultaneously enriching the minced mixture with dietary fibre. However, it is important to consider that the high content of gluten in these additives can cause genetic diseases, such as celiac disease, which occurs in a certain part of the population, which ranges from 0.2% to 6%, depending on the region of the world.

The scientific manuscript by T. Pintado & S. Cofrades (2020), described a series of experiments on adding legumes to meat products, which were characterised by a significant content of essential amino acids and minerals, which allowed increasing the biological value of meat mixtures by 15-20% and the energy value by 3-5%. L.J. Deleu *et al*. (2020) proved that the spelt grain contains up to 24% protein against 12-13% in ordinary winter wheat, and gluten up to 53% compared to conventional varieties with a minimum amount of gluten, so it can be recommended for inclusion in the diets of gluten allergy sufferers. In contrast to the usual varieties of cultivated wheat, spelt protein is characterised by an increased content of most essential amino acids and unsaturated fatty acids (Allai *et al*., 2022). D.R. Shah *et al*. (2020) noted that the use of spelt as a starchy additive to minced meat avoids the need to introduce

dietary fibre into the composition due to their high grain content (10.7%). When spelt is consumed, the body receives vital trace elements such as B vitamins, potassium, zinc, manganese, minerals and vitamins that help improve the body's immune system and lower blood cholesterol (Jančić *et al.*, 2022).

Thus, the use of spelt flour in the composition of the meat products under study can significantly improve the content of essential acids, vitamins, and valuable trace elements in the product, creating competition for traditionally used dietary fibre, justifying the prospects of the developed recipe.

Materials and Methods

Studies of boiled meat products of control and experimental samples were carried out using raw materials, the classification of which is presented in Table 1.

Table 1. *List of raw materials for conducting experimental studies*

No.	Experimental samples
1	red and white meat of broiler chickens (DSTU 3143:2013, 2014)
2	pink salmon caviar (DSTU 8096:2015, 2017)
3	skimmed milk powder (DSTU 4273:2015, 2016)
4	dried crushed champignons (DSTU ISO 7561-2001, 2003)
5	spelt flour (DSTU 46.004-99, 1999)
6	nori algae (DSTU 5013:2008, 2009)
7	olive oil (DSTU 5065:2008, 2009)
8	refined sunflower oil (DSTU 4492:2017, 2019)
9	drinking water (DSTU 7525:2014, 2014)
10	table salt (DSTU 3583:2015, 2017)
11	white sugar according to (DSTU 4623:2023, 2023)

Source: developed by the authors

The moisture binding capacity (MBC) was determined by the amount of water released from 300 g of the sample after pressing three times for 10 minutes with a 1 kg load. *Plasticity* was determined by pressing the sample sample after determining the MBC parameter. The calculation was performed using the spot area formed by the crushed sample when it was pressed on filter paper with a static load of 1 kg for 10 minutes. The *penetration coefficient* of the finished products was determined by the depth of immersion of the needle indenter into the test sample. Maximum shear stress τ_m was determined using the plasticity values and penetration numbers obtained from studies of the corresponding samples (Table 2).

Table 2. *Functional and technological indicators of control and experimental samples of boiled sausages*

Indicator	Control of TU U 10.1-37792346-002:2021,%	Experimental sample No. 1	Experimental sample No. 2	Experimental sample No. 3
Content of hydrated spelt flour in minced meat, %	–	5.0	7.0	8.0
Content of champignon mushrooms in minced meat, %	–	1.5	2.0	3.0
Plasticity X, cm^2/g	7.80	8.44	8.66	8.79
Penetration, Pa	1,609.06	1,660.86	1,769.36	1,766.44

Source: developed by the authors

Modelling was performed using the second Federman-Buckingham similarity theory and the "dimension theory" method, which allows processing the obtained experimental data in the form of a criterion equation (Palamarchuk *et al.*, 2021).

The following calculation methods were used to calculate the similarity criteria required for the study.

The Euler criterion can be determined by the equation:

$$Eu = \frac{P}{\rho \cdot S \cdot \upsilon^2}, \quad (1)$$

where P – resistance of the medium, H; S – area of the force contact action, m^2; ρ – density of the food mass; υ – speed of the product flow in the bowl of the mincer

The Sherwood Criterion Sh is typically calculated as

$$Sh = \beta \cdot \ell / D, \quad (2)$$

where ℓ – characteristic size under the conditions of the mass exchange under study, which can be identified with the average particle size of the dispersed phase, which can be taken for the cutting process: $\ell = 0.4\ mm$; D – diffusion coefficient, which can be accepted for minced meat masses $D = 0.5 \cdot 10^{-9}\ m^2/s$.

The mass transfer coefficient can be determined by the following ratio:

$$\beta = \frac{\Pi_v}{\Delta C \cdot S}, \quad (3)$$

where Π_υ – volumetric process performance, kg/m^3; ΔC – difference in spelt concentrations in developed and traditional technologies, %

The plasticity value can be determined by the equation:

$$X = \frac{S}{m} = \frac{S \cdot g}{m \cdot g} = \frac{S \cdot g}{P} = \frac{g}{\tau_m}. \quad (4)$$

The diffusion Fourier number can be determined by the equation:

$$\mathrm{Fo}_\partial = \frac{D \cdot t}{\ell^2}, \quad (5)$$

where t – processing time of a single product load: for research conditions, the cutting time – t=8 min

Statistical evaluation of the results was performed using standard methods using statistical software Statgraphics Centurion XVII (StatPoint, USA) – multivariate analysis of variance (MANOVA), LSD test. Statistical processing was performed in Microsoft Excel 2016 in combination with XLSTAT. The values were estimated using the mean value and standard deviations.

Results and Discussion

When choosing the most acceptable meat raw materials from the standpoint of physiological value, the content of the most consumed types of meat – beef, pork, and chicken – of constituent proteins (18.9%, 16.4%, 20.3%, respectively) and fats (12.4%, 27.8%, 13.1%, respectively) was considered. Chicken has the advantage of being the closest in these respects to beef, which is in acute shortage in the diet. However, due to the relatively lower content of macro- and micro-elements in it, the search for additives that would compensate for this shortcoming of chicken has become a subject of further study, given that the ongoing decline in the supply of raw meat requires the use of protein-rich plant-based ingredients to make up for the lack of protein. Therefore, it is effective to use vegetable proteins as a substitute for traditionally used wheat flour for wild spelt flour, enriched with dietary fibre, minerals and fatty acids, and to enrich the taste and smell with the addition of crushed mushrooms.

The main factors of the process of preparing a mixture of beef, pork, and chicken with the presented vegetable additives are the density of products ρ, maximum shear stress τ_m, changes in the concentration of spelt flour and champignons in products ΔC, value of the diffusion coefficient D and the mass recovery coefficient in the technological mass β, product processing time in the mincer t, kinematic characteristics of the process, in particular, the speed of product flow promotion in the mincer bowl υ and its rotation speed ω.

Considering the presented factor space and the features of the course of the process under

study, the following criteria or similarity numbers can be noted that define it:

➢ *Euler number Eu as a measure of the ratio of pressure forces and head velocity;*

➢ *Sherwood number Sh, as a measure of the ratio of the intensity of convective and diffusion flows at the interface of separation of interacting phases;*

➢ *the Fourier number is diffuse, as a measure of the ratio of the mass of a substance transmitted by diffusion and local ripples in a non-stationary flow.*

At the first stage of the calculation, the parameters of the process under study presented above are decomposed into dimensions in Table 3.

Table 3. *Basic design parameters of the mincing process*

No.	List of parameters of the process under study	Dimension
1	Product density ρ, kg/m^3	$kg \cdot m^{-3}$
2	Processing time for a single product load t, s	s
3	Maximum shear stress τ_m, Pa	$kg \cdot s^{-2} \cdot m^{-1}$
4	Diffusion coefficient D, m^2/s	$m^2 \cdot s^{-1}$
5	Average particle size of the dispersed phase ℓ, m	m
6	Speed of product flow in the mincer bowl υ, m/s	$m \cdot s^{-1}$
7	Mass transfer rate in load weight β, m/s	$m \cdot s^{-1}$
8	Free fall acceleration g, m/s^2	$m \cdot s^{-2}$

Source: developed by the author

The presented similarity criteria determine the main physical, mechanical and rheological factors of the process.

Equation (1) is modified to determine the Euler criterion in the form:

$$Eu = \frac{P}{\rho \cdot S \cdot \upsilon^2} = \frac{\tau_m}{\rho \cdot \upsilon^2}, \quad (6)$$

where P – resistance of the medium, N; S – area of force contact, m^2; $\tau_m = \frac{P}{s}$ – maximum shear stress, Pa; υ – speed of the product movement in the mincer bowl: $\upsilon = \frac{2\omega R}{k_{on}} = \frac{\pi \cdot n_s \cdot R}{15 k_{on}}$; R – geometric size of the mincer bowl (Fig. 1); n_s, ω – rotation speed and angular velocity of the mincer bowl: can be adopted n_s within n_s = 8-20 rpm; k_{on} – coefficient of driving force consumption when moving minced meat to overcome the resistance of the knife mechanism: can be taken within the limits of k_{on} = 1.5-2.0.

The speed of the product flow is defined as

$$\upsilon = \frac{2\omega R}{k_{on}} = \frac{\pi \cdot n_s \cdot R}{15 k_{on}} = \frac{3.14 \cdot 15 \cdot 0{,}233}{15 \cdot 1{,}7} = 0.43 m/s.$$

The product density can be taken within ρ = 1,100 - 1,180 kg/m^3

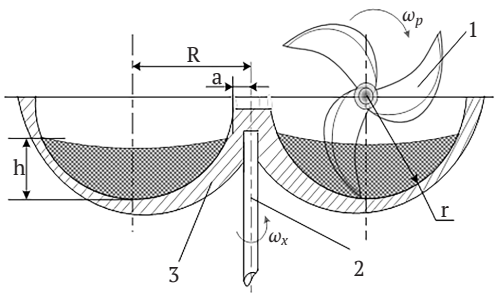

Figure 1. Diagram of a mince cutter for fine mincing

Notes: 1 – cutting mechanism, 2 – bowl drive shaft, 3 – mincer bowl

Source: developed by the author

When determining the mass transfer coefficient, equation (3) is transformed as:

$$\beta = \frac{\Pi_v}{\Delta C \cdot S} = \frac{m}{t \cdot S \cdot \Delta C \cdot \rho} = \frac{m \cdot g}{t \cdot S \cdot \Delta C \cdot g \cdot \rho} = \frac{\tau_z}{t \cdot \Delta C \cdot g \cdot \rho}, \quad (7)$$

where g = 9.81 m/s^2 – free fall acceleration; $\tau_z = m \cdot g/S = P/S$.

When determining plasticity, equation (4) is transformed as follows:

$$X = \frac{S}{m} = \frac{S \cdot g}{m \cdot g} = \frac{S \cdot g}{P} = \frac{g}{\tau_m}. \quad (8)$$

Then when using (8):

$$\tau_m = \frac{g}{X}. \quad (9)$$

Using that the penetration index is proportional to the shear stress of the minced meat mass τ_G, penetration coefficient Q determined from the dependency:

$$Q = \frac{P}{h^2} = \tau_m \cdot k_{pr}, \quad (10)$$

where k_{pr} – proportionality coefficient; h – depth of indenter depth in the mass of minced meat under a certain load P, which was determined from experimental studies

Then when using (6):

$$\tau_m = \frac{Q}{k_{pr}}. \quad (11)$$

Given a fairly large number of factors that determine the process, the relationship between them will be replaced by the dependencies between the presented similarity criteria. To do this, the dimension matrix is compiled using Table 4.

Table 4. *Dimension matrix of the investigated process of vibrational mixing of sausage mince ingredients*

Parameters	ρ, kg/m^3	υ, m/s	τ_m, H/m^2 kg/(m·s^2)	t, s	β, s/m
M, kg	1		1		
L, m	-3	1	-1		1
T, s		-1	-2	1	-1
Power coefficients	ε	n	m	α	

Source: developed by the author

In general, the relationship between the presented parameters can be written as a function:

$$\beta = f(\rho, \upsilon, \tau_m, t).$$

Based on the dimension matrix compiled in Table 2, the presented function is rewritten as a power series:

$$\beta = K \cdot \tau \mathrm{m}\ \mathrm{m} \cdot \rho\varepsilon \cdot \upsilon n \cdot t\alpha, \quad (12)$$

where K – constant coefficient.

For a given factor space, where we have 6 variables, by the π theorem, the number of dimensionless components is 6 - 3 = 3. This corresponds to the number of similarity criteria selected, such as the Sherwood, Fourier, and Euler numbers.

In Table 3, the dimension matrix can be represented as a system of equations for the power coefficients of the mass transfer equation (11).

Equation (11) provides

$$\begin{cases} n + \varepsilon = 0 \\ n - m - 3\varepsilon - l = 1 \\ -n - 2m + \alpha = -1. \end{cases} \quad (13)$$

$$\varepsilon = -\mathrm{m}. \quad (14)$$

From the term of equations (13) and (14):

$$0 = -3m - 3\varepsilon + \alpha. \quad (15)$$

From equation (15):

$$n = \alpha - 2m + 1. \quad (16)$$

From equation (16):

$$\alpha = 3m + 3. \quad (17)$$

Given equation (10)

$$\beta = \rho^{-m} \cdot \upsilon^{(\alpha-2m+1)} \cdot t^{(3m+3\varepsilon)} \cdot \tau^{m}. \quad (18)$$

Given equation (2)

$$\frac{\beta \cdot \ell}{D} = Sh = \frac{\ell}{D} \cdot \left[\frac{\tau_m}{\rho \cdot \upsilon^2}\right]^{m} \cdot t^{(3m+3\varepsilon)} \cdot \upsilon^{(\alpha+1)}. \quad (19)$$

Given equation (6)

$$Sh = Eu^{m} \cdot \upsilon^{(\alpha+1)} \cdot t^{\alpha} \cdot \frac{\ell}{D}. \quad (20)$$

Given equation (1)

$$Sh = Eu^{m} \cdot \mathrm{Fo}_{\partial}{}^{\alpha} \cdot \left[\frac{\upsilon}{D}\right]^{(\alpha+1)} \cdot \ell^{3}. \quad (21)$$

Then the general expression of the mass transfer equation of the process under study takes the form:

$$Sh = Eu_{m} \cdot \mathrm{Fo}_{\partial}{}^{\alpha} \cdot \mathrm{K}; \quad (22)$$

$$K = \left[\frac{\upsilon}{D}\right]^{(\alpha+1)} \cdot \ell^{3}. \quad (23)$$

Using the data in Table 4 and the method of graphoanalytical estimation of power functions, a graph of the function $Sh = f(Eu)$ was constructed; this function is linear, the graph of which consists of the abscissa axis and the angle φ (Fig. 2). To obtain initial data during the graphoanalytical analysis of the process under study, the values of the above-mentioned Fourier, Sherwood, and Euler criteria, and the mass flow coefficient, were determined using the corresponding equations (1, 2, 3, 5, 6) according to experimental data obtained based on the results of the conducted studies (Table 3).

Then the value of the first power coefficient is $m = tg\varphi = tg72° = 3.08$

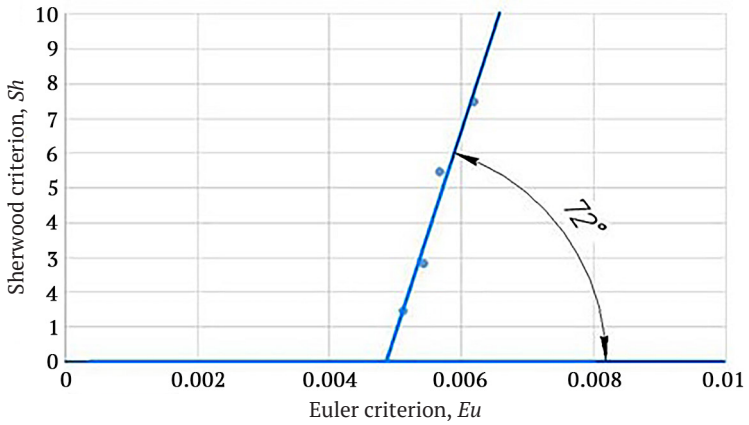

Figure 2. Function graph $Sh = f(Eu)$

Source: developed by the authors

Table 5. *Values of similarity criteria for the process of minced meat preparation*

Process parameter	Control of TU U 10.1-37792346-002:2021,%	Experimental sample No. 1	Experimental sample No. 2	Experimental sample No.3
Penetration number, Pa	1,609.06	1,660.86	1,769.36	1,766.44
Content of hydrated spelt flour and mushrooms in minced meat ΔC	-	0.065	0.09	0.11
Maximum shear stress τ_m, *kPa*	1.26	1.16	1.13	1.12
Minced meat density ρ, kg/m^3	1,100	1,110	1,130	1,180
Diffusion coefficient ***D, m²/s***		$0.5 \cdot 10^{-9}$		

Table 5. Continued

Process parameter	Control of TU U 10.1-37792346-002:2021,%	Experimental sample No. 1	Experimental sample No. 2	Experimental sample No.3
Particle size of the dispersed phase ℓ, *m*	$1 \cdot 10^{-3}$	$0.8 \cdot 10^{-3}$	$0.6 \cdot 10^{-3}$	$0.4 \cdot 10^{-3}$
Processing time *t, s*		480		
Speed of flow in the mincer bowl υ, m/s		0.43		
Mass transfer rate in load weight β, *m/s*	$3.74 \cdot 10^{-6}$	$3.42 \cdot 10^{-6}$	$2.37 \cdot 10^{-6}$	$1.83 \cdot 10^{-6}$
Sherwood criterion, *Sh*	7.4712	5.4739	2.8386	1.4608
Euler criterion, *Eu*	0.0062	0.0057	0.0054	0.0051
Fourier criterion, Fo_d	0.240	0.375	0.667	1.500

Source: developed by the authors

Using the previous calculation methodology, the function graph was plotted using the data from Table 4. From this graph, the angle γ (Fig. 3) of its slope to the abscissa axis was found and the value of the second power coefficient was determined by the equation:

Table 6. *Calculated data for determining power coefficients*

Process parameter	Control of TU U 10.1-37792346-002:2021,%	Experimental sample No. 1	Experimental sample No. 2	Experimental sample No.3
Dimensionless component Fo_d^{α}	0.130	0.246	0.560	1.786
Dimensionless component Eu^m	$1.574 \cdot 10^{-7}$	$1.201 \cdot 10^{-7}$	$1.05 \cdot 10^{-7}$	$8.776 \cdot 10^{-8}$
Dimensionless component Sh/Eu^m	$4.75 \cdot 10^{7}$	$4.56 \cdot 10^{7}$	$2.7 \cdot 10^{7}$	$1.66 \cdot 10^{7}$
Dimensionless component $\frac{Sh}{Eu^m \cdot Fo_o^{\alpha}}$	$3.65 \cdot 10^{8}$	$1.85 \cdot 10^{8}$	$4.83 \cdot 10^{7}$	$9.32 \cdot 10^{6}$
Parameter *K*	$5.14 \cdot 10^{12}$	$2.63 \cdot 10^{12}$	$1.11 \cdot 10^{12}$	$3.29 \cdot 10^{11}$

Source: developed by the authors

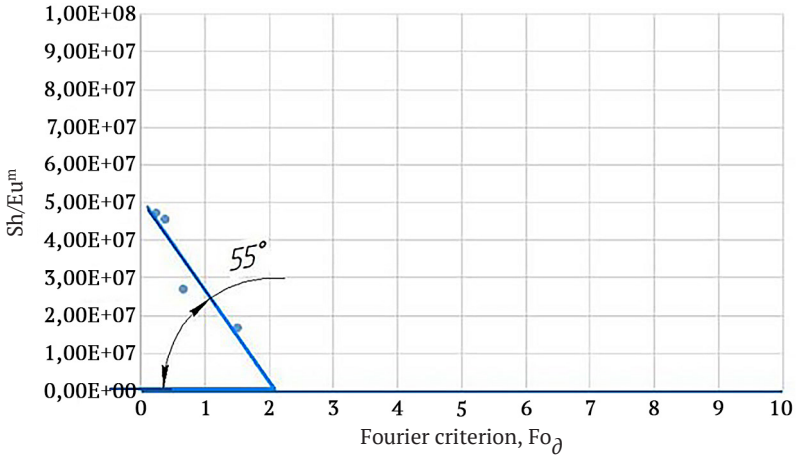

Figure 3. Function graph $\frac{Sh}{Eu^m} = f(\mathrm{Fo}_d)$

Source: developed by the authors

The next step was to plot the function $\frac{Sh}{Eu^{m} \cdot Fo_d{}^{\alpha}} = f(K)$ (Fig. 4). Using the data from Table 4, the process constant K was determined.

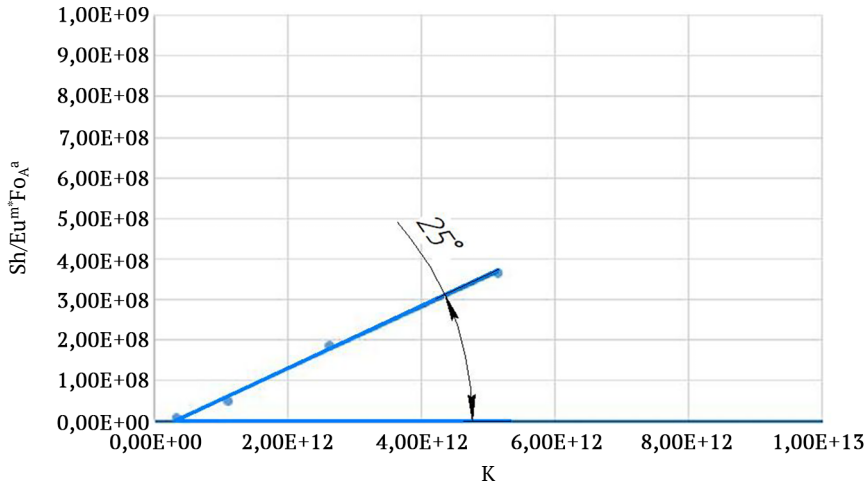

Figure 4. Function graph $\frac{Sh}{Eu^{m} \cdot Fo_d{}^{\alpha}} = f(K)$

Source: developed by the authors

Thus, the criterion equation of the process of vibrational mixing of the ingredients of the studied process was finally determined in the form of

$$Sh = Eu^{m} \cdot Fo_d{}^{\alpha} \cdot K = Eu^{3,08} \cdot Fo_d{}^{1.43} \cdot \left[\frac{v}{D}\right]^{2.43} \cdot \ell^{3};$$

$$K = \left[\frac{v}{D}\right]^{(\alpha+1)} \cdot \ell^{3};$$

$$\frac{\beta \cdot \ell}{D} = \left[\frac{\tau_m}{\rho \cdot v^2}\right]^{3.08} \cdot \left[\frac{D \cdot t}{\ell^2}\right]^{1.43} \cdot \left[\frac{v}{D}\right]^{2.43} \cdot \ell^{3};$$

The presented mass transfer equation illustrates the dominant effect of the fine grinding process on the change in the concentration of spelt flour and champignons in production ΔC. This effect is determined by the value of the diffusion coefficient D, the particle size of the dispersed phase, and the mass flow coefficient in the loading mass β. Using equation (26) and the developed programme, the recommended set of operating mode parameters for the process of fine grinding in the production of cooked sausages is established, considering the above factors.

The paper by J.M. Ramos-Diaz *et al*. (2022) described an experiment aimed at creating a recipe for minced meat for semi-finished poultry products with the addition of porcini mushrooms. The main approach was to identify the optimal combination of ingredients to create a balanced meat mix. Various types of meat, dairy products, and herbal supplements were used in the model recipes. The use of turkey and chicken fillet provided complete animal proteins, and partial replacement of fatty meat raw materials with milk fat was carried out to reduce fat content. Additionally, the researchers developed a technology for making sausage products with the addition of vegetable ingredients for frying and indicated the main technological parameters of the production and heat treatment process. They also investigated the rheological properties of minced meat, such as adhesion, viscosity, and shear structural and mechanical properties. However, the researchers should substantiate in more detail the use of meat offal and dairy ingredients to stabilise protein and fat in the meat mixture,

and prove that replacing the main meat raw materials with vegetable ones will allow obtaining high-quality sausages for grilling. In addition, the researchers did not perform sensory analysis of the finished product after heat treatment, which may be an important step in determining its quality.

The study by K. Chen *et al*. (2022) investigated promising developments for the meat processing industry – the production of dry snack products, in particular, meat chips. The main purpose of the study was to investigate the functional and technological characteristics of minced meat systems consisting of beef and seafood. These systems were designed to be improved with special food additives to increase quality and properties. The study showed that minced meat systems were high in protein (30.0-34.8%), lipids (2.2-3.7%), and carbohydrates (0.8-2.5%). Systems with the addition of seafood were characterised by a high ability to retain moisture (74.52-90.3%), which indicates their properties during drying. However, the researchers did not consider a number of important rheological parameters, such as maximum shear stress and dynamic viscosity, nor did they perform an organoleptic assessment. To improve the results obtained, it may be useful to conduct mathematical modelling based on these indicators.

H. Eshgarf *et al*. (2021) investigated the thermophysical properties of model dissected masses based on meat and fish with a functional additive. The influence of the multiplicity of grinding and additive concentration on the ratio between frozen (free) and non-frozen (bound) water and optimal technological parameters for the production of semi-finished products was determined. It was found that a functional vegetable additive in minced meat of split meat and fish products contributes to an increase in the proportion of undemanding moisture at temperatures up to -18°C. For double grinding, the rational value of the additive should be considered 25%, and for triple grinding – up to 30%. But it is not clear why the researchers did not analyse the factors that limit the introduction of additives, and what organoleptic characteristics of the finished products they studied while maintaining the high moisture retention capacity of the semi-finished product.

The purpose of the study by M. Nasiru *et al*. (2021) consisted in establishing the relationship between prescription components and production parameters of a new type of meat product. The paper offered solutions to the problem of creating a model recipe for a meat product with a high content of dietary fibre in a composite mixture. The goal was to develop mathematical tools that could serve as a basis for evaluating the component composition and parameters of cooking semi-finished meat products with specified structural and technological characteristics. The features of cooking semi-finished meat products using a composite mixture containing unconventional vegetable raw materials were revealed. The researchers developed a mathematical model that considers the dependence of the quality of finished meat semi-finished products on the number of components in the recipe and cooking conditions. They also determined the optimal dosage of the composite mixture and the values of the cooking parameters.

However, a comprehensive study of the mechanisms of development of structural and technological effects in ready-made meat systems under various conditions of their production process was not presented. The main finding was a model describing nonlinear relationships between the structural parameters of a semi-finished meat product and technological indicators from the conditions of the production process, in particular, temperature. To clarify the study, the researchers should analyse the dosage of the components of the composite mixture, explain the purpose of their introduction, which is aimed at improving the physical properties of the meat product that they enrich.

Common varieties of cereals widely used in the food industry have significantly lower content of dietary fibre, essential amino acids, and unsaturated fatty acids compared to wild spelt. The use of spelt as a substitute for traditional cereal varieties in food can help increase the consumption of dietary fibre and other useful components of food, which was determined by O. Kochkodan *et al*. (2020).

L.V. Bal'-Prylypko *et al*. (2018) argue that adding pectin to food may prove to be an effective method of removing harmful compounds such as biogenic toxins and radionuclides from the body, especially after exposure. Such techniques can improve the function of the immune system and contribute to the overall state of human health, but to confirm the results of these studies, the researchers need to present the results of organoleptic and physicochemical properties of the finished product.

Thus, replacing traditional food components with spelt and using pectin as a supplement may prove to be effective strategies for improving a person's eating habits and overall health, as confirmed by scientific research.

Conclusions

The developed formulation allowed simultaneously increasing the protein content in the minced meat composition by replacing wheat flour containing 11-12% protein with spelt flour, where the protein content reaches 20-22%; and also reducing the allergic danger due to the fact that the gluten of spelt flour contains significantly less highly allergic gliadin present in traditional wheat flour in fairly large quantities. To compile a mathematical algorithm that relates the main parameters of the process of preparing minced meat, the choice of Froude, Euler, Fourier and Sherwood similarity criteria was substantiated, which allowed estimating the forces of inertia and weight, pressure and head velocity, intensity of convective and diffusion flows at the interface of interacting phases, and intensity of the mass transfer process in the process of minced meat preparation.

When using graph-analytical methods, a mathematical model was compiled in the form of a mass transfer equation containing the ratio between such process parameters as product density ρ, coefficient of dynamic viscosity of the process medium μ, maximum shear stress τ_m, change in the concentration of methylcellulose in raw materials ΔC, value of the diffusion coefficient D and the mass transfer coefficient in the load mass β. Using the compiled criterion equation and the developed programme, the main graphical relationships between the presented parameters were revealed, which allowed creating a recommended number of operating mode parameters for the studied process of preparing minced meat and sausage production technology using a food additive based on spelt flour and champignon mushrooms.

The developed mathematical algorithm based on the results of physical and mathematical modelling allowed optimising the product formulation, analysing the nutritional value of minced meat and other multicomponent mixtures, developing new products and analysing their impact on health at a new level; this significantly expands the potential of process, technological and organisational aspects of designing new food products with a combined formulation, considering a wide range of mechanical and heat and mass transfer factors; thereby significantly increasing their competitive ability in the industrial food production market. A promising area for further research is to determine the effect of various ratios between spelt flour, mushrooms, and other ingredients on the taste, texture, and nutritional properties of minced meat using mathematical modelling.

Acknowledgements

None.

Conflict of Interest

None.

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Фізико-математичне моделювання процесу приготування фаршу із домішками спельтового борошна та грибів печериці

Лариса Баль-Прилипко

Доктор технічних наук, професор
Національний університет біоресурсів і природокористування
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-9489-8610

Микола Ніколаєнко

Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-2213-4985

Михайло Муштрук

Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-3646-1226

Марина Назаренко

Аспірант
Національний університет біоресурсів і природокористування
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-8598-0420

Людмила Бейко

Кандидат технічних наук, доцент
Тернопільський національний технічний університет імені Івана Пулюя
46001, вул. Руська, 56, м. Тернопіль, Україна
https://orcid.org/0000-0001-6211-8010

Анотація. Введення до м'ясопродуктів домішок рослинного або тваринного походження складає на теперешній час стійку тенденцію у харчових технологіях через можливості отримати унікальні властивості продукції та зниження її собівартості, що обгрунтовує актуальність проведених досліджень. Метою статті є побудова математичного алгоритму, що дозволяє визначити закономірності зміни основних параметрів процесу приготування фаршу м'ясних напівфабрикатів із рослинними домішками, що дозволить визначити тенденції розвитку технічної та технологічної ефективності засобів механізації системи тонкого подрібнення сировини для виготовлення ковбасних виробів. Досліджено застосування у якості інгредієнтів до фаршевої маси використовують домішки спельтового борошна та грибів печериці, що дозволяє разом із зниженням собівартості виробництва вареної ковбасної продукції, значно покращити органолептичні показники якості продуктів, зменшити їхню калорійність та подовжити терміни придатності до споживання. Дикорослий різновид спельта, що використовується у даній науковій роботі як альтернатива її культурним сортам, володіє значно меншою алергійною активністю та відповідно меншою часткою гліадинів, які складають основу пшеничного глютену або клейковини; що обгрунтовує практичну цінність роботи. Був виконаний мікроструктурний аналіз фаршу

контрольного та дослідних зразків варених сосисок виявив, що остання категорія м`ясного продукту характерна підвищеними щільністю та пружністю завдяки включенню мікрочасток спельти у вакуолі м`ясної фракції. Згідно з результатами експериментальних досліджень, використанням методу «аналізу розмірностей» та теореми Федермана-Букінгема вдалося отримати критеріальне рівняння для процесу тепломасообміну в умовах інтенсивного механічного перемішування. Дані процесні характеристики були описані при допомозі критеріїв Ейлера, Фур'є та Шервуда. Складена функція містить основні фактори зовнішнього впливу на сировину та її фізико-механічні характеристики, що дозволяє адекватно оцінити процеси дифузії у технологічному середовищі та сформувати рекомендований ряд при проектуванні технічного та технологічного забезпечення для отримання якісної харчової продукції

Ключові слова: спельта; напруга зсуву; фаршева маса; теорія подібності; числа подібності; дифузія; варені м'ясопродукти

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Features of goat behaviour depending on the temperature and humidity index

Oleksandra Hranat*
Master of Sciences
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0001-1299-0764

Nataliia Bogdanova
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-4634-9609

Vasyl Turynskiy
Doctor of Agricultural Sciences
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-0312-694X

Abstract. The temperature and humidity index (THI) is one of the most critical environmental factors, because it affects the body's thermoregulation and the overall productivity of goats. The study aimed to identify the relationship between the behavioural reactions of goats of different breeds and changes on the temperature and humidity index in the premises. The study used methods of time slices and recording of behavioural manifestations of goats. It was found that with a THI of 69-74%, the intensity of animal movement was high, but when the THI increased to 81%, activity sharply declined. After an extended stay in THI of 75-81%, goats find it quite challenging to restore average activity indicators. The animals were in the comfort zone (THI = 69-74%) and showed a moderate to weak approach to the feed table. With THI of 75-81%, goats showed interest; however, they did not consume feed. Animal rest positively correlates with such indicators as THI,

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*Corresponding author

r = from +0.40 (Saanen) to +0.49 (Alpine); movement in the pen, r = +0.62 and +0.66; approach to the feed table r = +0.32 and +0.31; and urination r = +0.16 and +0.12, respectively. A sharp increase in the rest frequency was detected at 76-81% THI. After normalising THI, animals also rested more frequently, which may be a consequence of heat stress. At the optimal level of THI (up to 74%), the frequency of goat rest decreased over a long period of time. A positive statistically insignificant correlation was established between THI and animal movement in the pen, r = from +0.19 (Saanen) to + 0.39 (Alpine). The movement of animals in the pen positively correlates with feed consumption, r = from +0.30 (Saanen) to +0.34 (Alpine), and negatively with the rumination process in animals, r = from -0.23 (Alpine) to -0.68 (Saanen). It was found that goats of the Saanen breed are more dependent on THI than the Alpine breed. The study's results should be considered when regulating the microclimate on premises for dairy goats and male goats

Keywords: ambient temperature; goats; animal behaviour; feed consumption; rumination

Introduction

Ukraine is currently developing goat breeding on a new, modern technical and technological basis, which, along with the development of other livestock sectors, is a key to filling the market with products and ensuring the country's food security. The success of modern industrial farms mainly depends on creating comfortable conditions for animals. By definition of V.V. Nedosekov *et al*. (2021), animal welfare is based on criteria such as feeding, environment, health, behaviour, and mental state. That is why the organisation of optimal conditions for keeping animals, in particular the microclimate – one of the most important factors of animal welfare – is important.

The welfare of animals kept in extensive conditions generally depends on the influence of climatic factors (heat, cold, humidity, etc.). Research conducted by I.A. Pomitun *et al*. (2021) confirms that long-term exposure to sub- and above-normal temperatures affects not only the behavioural responses of animals, but also affects the further development of animals and the manifestation of their reproductive ability. In particular, it was found that temperature stresses can affect the physiological processes and ability of animals to reproduce. For animals that are constantly kept indoors, air conditioning, optimal livestock density, the type of floor and the availability of bedding are important factors of physical comfort. Insufficient ventilation, even at low ambient temperatures, can cause shortness of breath and stress, especially in pregnant animals. According to C.M. Dwyer (2022), when the livestock density is less than 1 m^2 per animal, their aggression and motor activity increase, as evidenced by competition for the best places to lie down. In specialised enterprises, the methods and systems of keeping are significantly changing, individual care for animals is decreasing, and the utilisation rate of technological machines and equipment is increasing. Therefore, according to R. Mylostyvyi & O. Chernenko (2019), A. Lykhach & V. Lykhach (2023), the technical environment requires a detailed study of the life manifestations of farm animals, including goats (Yıldırır *et al*., 2019). This means that it is important to adapt technologies so that they consider the natural needs of animals and do not cause stress or inconvenience to them. Studies are conducted to find out what aspects of keeping affect the physiology, behaviour, and productivity of animals. G. Zobel *et al*. (2019) suggest that goats have acquired certain cognitive functions in the course of evolution. Goats have developed natural behaviours that affect how they feed and interact in the herd.

However, according to C.M. Dwyer (2022), in the context of intensive production technologies, goats are not able to independently meet their needs for providing sufficient feed and water, since they are completely dependent on humans. According to A.L. Goetsch *et al*. (2022), the eating behaviour of goats is determined by such important factors as indoor microclimate parameters, the level of animal productivity, the size of the technological group, the balance of the diet and the feeding regime. Animals, like humans, are capable of experiencing pain and suffering. Therefore, for example, the behaviour of goats during feed consumption may be an important marker for early detection of various diseases in them. Also relevant are studies on the relationship between the rank of dominance and feed consumption; features of herd behaviour and animal productivity. The study of these aspects helps to better understand the needs of animals and optimise their living conditions.

The temperature regime, as a factor of influence on animals, is one of the most critical, because it affects the thermoregulation of the body and the productivity of goats in general. In this regard, the purpose of the study – analyse the activity indicators of goats of different breeds and identify the relationship between behavioural responses of animals and changes in the temperature regime in the room.

Materials and Methods

The study was conducted in 2023 on the number of goats of Saanen (male goats, n = 7, females, n = 14) and Alpine (male goats, n=7, females, n = 14) breeds in the conditions of the farming enterprise "Tetiana-2011" of the Kyiv Region. Among the goats that were simultaneously kept in the herd, analogue groups were formed, considering the age, live weight, and productivity of the animals (Table 1).

Table 1. *Goat productivity indicators, M ± m*

Group	Breed	Number of animals, units	Live weight, kg	Average daily milk yield, kg
1 – dairy goats	Saanen	14	59.6 ± 0.42	2.63 ± 0.08
2 – dairy goats	Alpine	14	59.9 ± 0.53	2.77 ± 0.12
3 – male goats	Saanen	7	75.0 ± 0.44	-
4 – male goats	Alpine	7	75.3 ± 0.36	-

Source: developed by the author

All animals were kept in the same stall conditions and fed the same type of feed. The diet included haylage of perennial grasses, hay, straw, and concentrated feed. Goats consumed feed from the feed table three times a day. Total nutritional value of the diet adjusted considering the energy requirements of lactation, based on 1 kg of goat milk (4% fat) – 5.2 MJ EE and 45-70 g DP.

Two methods were used to conduct the planned research.

The first was the time slice method (Danchuk *et al*., 2020), observations were carried out three times a day, every 6 hours, for an hour. The behaviour of goats after milking and after feeding was recorded. Observations were carried out for a month, with stable keeping of goats at different ambient temperatures. Hot weather changed for a period of prolonged rains with a cold snap. The average temperature in the room was 22.6 ± 0.83°C (min – 18, max – 30). Temperature and humidity index (THI) – 71.2 ± 0.88 (min – 67, max – 81). THI categories were defined by L.R. Hahn *et al*. (2009).

The second was a method for recording individual behavioural manifestations of goats (Danchuk *et al*., 2020). During the observation, only cases of the necessary motor activity or behaviour of animals were recorded. The results obtained by this method did not allow judging the overall distribution of time by

different types of motor activity of animals, but they determined the frequency, duration, sequence, and direction of behavioural reactions of interest to the researcher. A system of abbreviations was used to collect data and record individual acts of goat behaviour. The following behavioural acts of goats were recorded: movement of animals along the pen – M, approach to the feed table – Af, feed consumption – F, rumination – Rm, rest – R, defecation – D, urination – U.

Considering abbreviated records of animal behavioural acts, the information was entered in the primary data processing protocol. The primary data was then processed and transferred to the final data processing protocol. Standing and lying down were taken as a state of rest; and any movement, searching for and consumption of feed, and fighting were taken as motor activity. Thus, by setting the number (+) and (-) during the follow-up period, the time spent on movement and rest was determined. The intensity of goat movement was calculated as the ratio between the rate of movement in the pen and the sum of animal activity indicators per day.

The mean values (M) for groups and their limits, the statistical error of the average (± m) and the value of correlation coefficients (r) were determined as an indicator of assessing the relationship between goat behavioural responses and changes in the temperature regime in the premises. The bioethical requirements of the Law of Ukraine No. 3447-IV (2006) were followed during animal manipulations.

Results and Discussion

In the course of research, according to THI indicators, the following factors are considered: the following safety categories: optimal – up to 74%; preventive – 75-78%; dangerous – 79-83%; extremely dangerous – more than 84%. It was found that with a sharp increase in temperature, the intensity of goat movement decreased (Fig. 1). With a THI of 69-74%, the intensity of animal movement was high, but when the THI increased to 81%, there was a sharp decline in activity. It is worth noting that the goats reacted more stably to a gradual increase or decrease in temperature. They probably had some time to adapt to changing environmental conditions. When there were sudden changes in temperature, the activity of goats changed abruptly.

Normally, the movement intensity indicator should be 1, that is, an indicator of the movement of animals in the pen must be equal to the sum of all animal activity during observation.

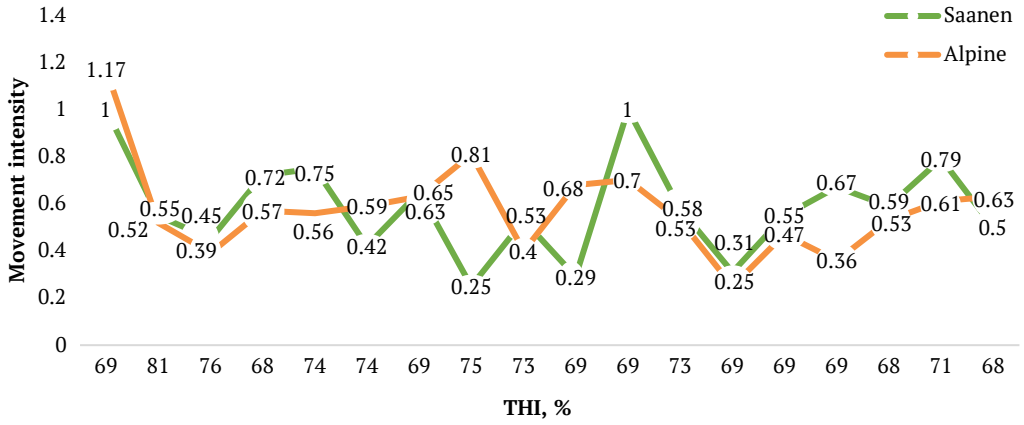

Figure 1. Movement intensity of all groups of animals, in accordance with the THI, %
Source: developed by the author

The approach to the feed table is not an indicator of feed consumption. This indicator was recorded on the condition that the animal approached the feed table, but did not eat (Fig. 2).

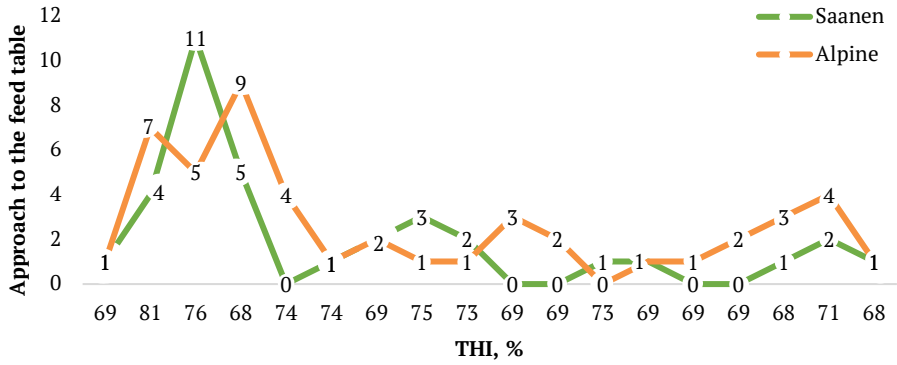

Figure 2. Approach to the feed table of all groups of animals, in accordance with THI, %
Source: developed by the author

Analysis of the data obtained shows that being in the comfort zone (THI = 69-74%) the animals showed a moderate to weak approach to the feeding table. However, during the period of a sharp increase in temperature, animals approached the feed table often. There was no definite correlation between feed consumption and the approach of animals to the feed table, depending on -0.09 (Alpine breed) to +0.23 (Saanen breed).

Observations have shown that at THI 75-81% (warning / dangerous), goats showed interest however, there was no feed consumption. The animals either stood for a certain time near the feed table, or sniffed the feed and left. These approaches were repeated every 10-15 minutes. This indicates that animals cannot focus only on their feed intake and often change their activities. This behaviour can also indicate the quality of feed. In any case, the animals felt uncomfortable. At THI up to 74%, less amount of "idle" approaches to the feed table was recorded. The data show a more stable behaviour of Alpine goats compared to Saanen goats (Fig. 3). It was recorded that the animals approached the feed table exclusively to consume feed.

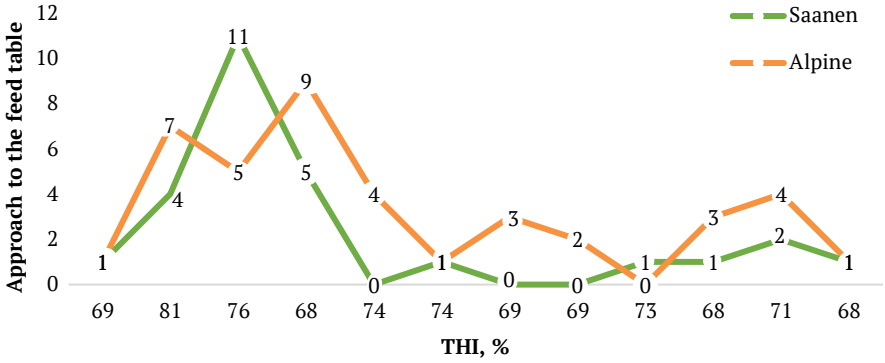

Figure 3. Approach to the feed table of dairy goats, according to THI, %
Source: developed by the author

Male goats showed a similar response to temperature rise, but it should be noted that it was less intense than goats (Fig. 4). The graph shows the difference in response to the stimulus between the breeds under study. Saanen male goats sharply increased the activity of the approach to the feed table, while Alpine male goats, on the contrary, reduced it.

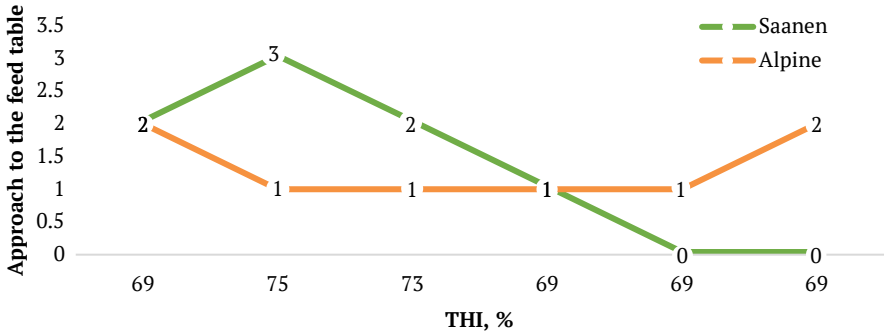

Figure 4. Approach to the feed table of groups of male goats, according to THI, %
Source: developed by the author

As noted by R.M. Reshma Nair *et al*. (2021), under stress, animals reduce metabolic activity, in particular rumen activity. Thus, it is predicted that at high THI values, the experimental animals will chew less time, delaying this process for the night, or a cooler period, when the ambient temperature will be optimal and comfortable for maintaining the normal functioning of their digestive system. That is why the frequency of feed consumption indicator is important when evaluating the behaviour of goats at different temperatures.

Observation data (Fig. 5) confirm the results obtained by R.M. Reshma Nair *et al*. (2021). Goats consumed food often and for a short period of time precisely because of the elevated THI. This conclusion was made based on the results of the analysis of the data shown in Fig. 2 and Fig. 5.

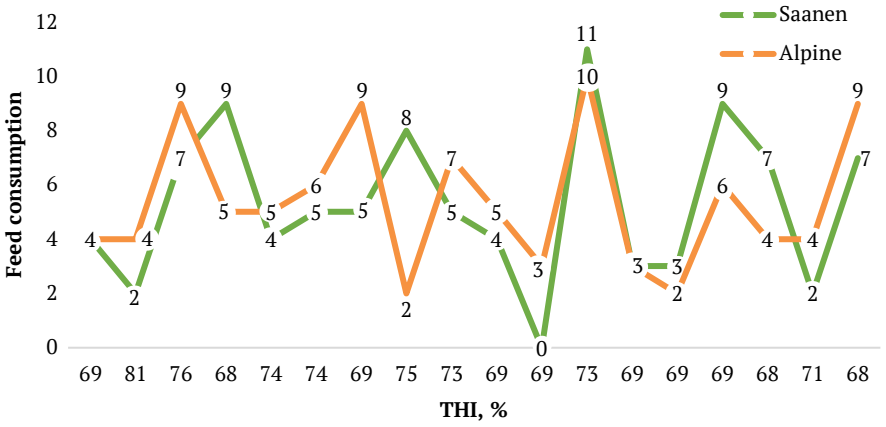

Figure 5. Feed consumption of all experimental groups of animals, according to THI, %
Source: developed by the author

In the course of the study, it was revealed such pattern: when THI 76-81%, both the maximum approaches to the feed table without feed consumption and the maximum frequency of feed consumption were simultaneously observed in animals. That is, the animals quickly changed their activities, moved a lot, and generally spent less time consuming feed than, for example, at normal temperatures, when the frequency of approach to the feed table was the lowest, and the frequency of feed consumption was the highest. Thus, it can be concluded that at THI of 69-73%, the animals approached the feed table exclusively for feed consumption and stayed there for a longer time.

Analysing the data in Fig. 6, it is worth noting that no significant difference was found between the breeds. Saanen and Alpine goats showed almost identical trends in feed consumption depending on the changes in THI.

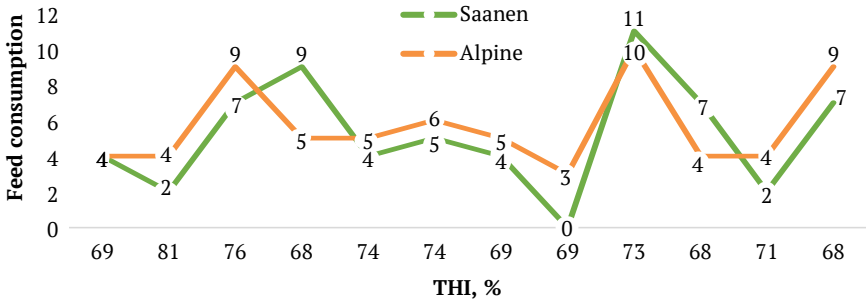

Figure 6. Feed consumption of groups of dairy goats, according to THI, %
Source: developed by the author

However, unlike dairy goats, male goats (Fig. 7), observed a significant difference in the response to THI of 75% (warning). Saanen male goats had an increased frequency of feed consumption, while Alpine male goats had a significant decrease. A minor and statistically insignificant correlation was established between THI and animal feed consumption (r = +0.06).

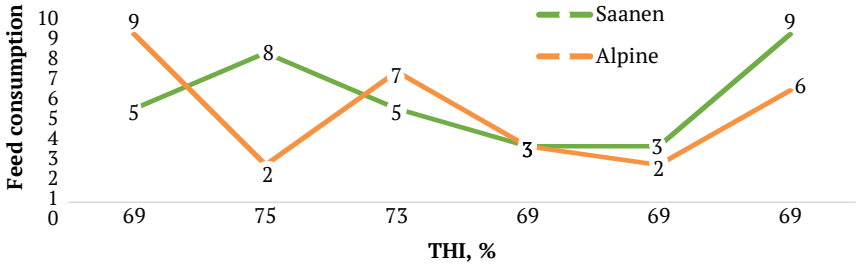

Figure 7. Feed consumption of goat groups, according to THI, %
Source: developed by the author

Given the features of ethological studies, the main object of which is live animals, it is quite difficult to predict their activity during the experiment. Notably, the act of defecation in animals occurred at optimal THI values (69-74%). A low and insignificant correlation was established between THI and the frequency of defecation (r = +0.21).

A small positive statistically insignificant correlation was found between THI and urination in goats. For the entire goat population under study, the correlation coefficient was +0.08.

There was also no correlation between the approach to the feed table and urination – from -0.19 (Saanen breed) to +0.35 (Alpine breed); between feed consumption and urination – from -0.07 (Alpine breed) to +0.21 (Saanen breed).

At THI of 81%, a decrease in the frequency of chewing in animals was detected (Fig. 8), while goats showed relative calmness. At THI of 68-75%, high rates of rumination were recorded. Although THI of 75 % is considered a warning category for animals, according to the observations, it did not have a significant effect on the reduction of rumination frequency. However, at THI of 76%, a sharp decrease in the rumen activity was observed. The correlation coefficients between THI and rumination were found to be low and statistically insignificant, ranging from -0.16 (Alpine breed) to +0.07 (Saanen breed). In addition, all the animals abruptly reacted to the change in THI. This may indicate a rather low recovery rate after heat shock.

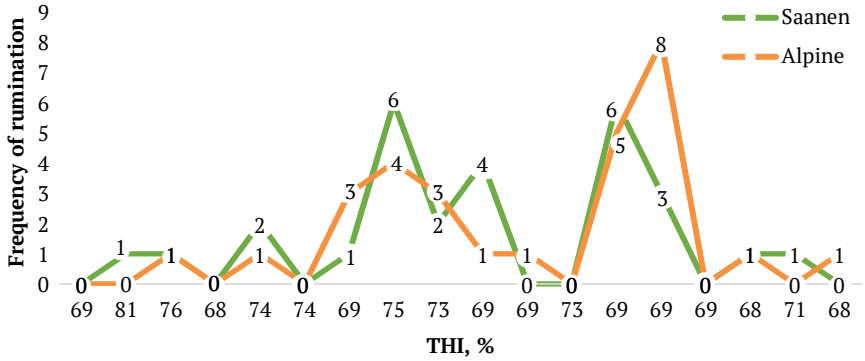

Figure 8. Frequency of rumination in all animal groups, according to THI, %
Source: developed by the author

Goats of the studied breeds reacted almost equally to changes in THI, however, there were some differences (Fig. 9). The reaction of Saanen goats was more intense and coincided with temperature changes compared to Alpine goats. Overall, Alpine goats were quite passive in responding to changes THI and in general, they had low rumen activity.

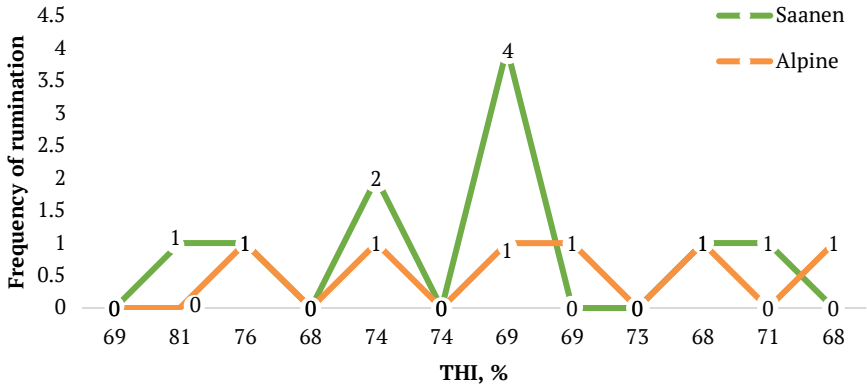

Figure 9. Frequency of rumination in dairy goats, according to THI, %
Source: developed by the author

There was no significant difference between the frequency of rumination in male goats of both breeds (Fig. 10). The only significant difference was observed at THI of 69%, when male goats of the Saanen breed showed an average level of rumination frequency, and in male goats of the Alpine breed it increased sharply.

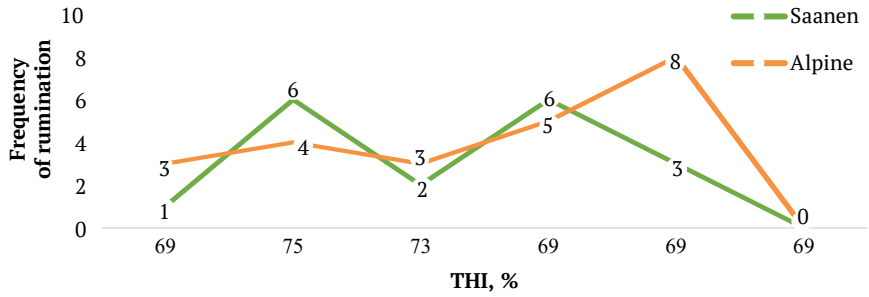

Figure 10. Frequency of rumination in male goats, according to THI, %
Source: developed by the author

Rest of animals is an important indicator of their overall comfortable condition. When animals often change their position, they cannot relax – this indicates the presence of discomfort. Rest positively correlated with such indicators as THI, r = from +0.40 (Saanen) to +0.49 (Alpine); movement in the pen, r = +0.62 and +0.66; approach to the feed table, r = +0.32 and +0.31 and urination, r = +0.16 and +0.12, respectively. That is, with all the parameters associated with animal movement. When the animal is uncomfortable lying down, it moves to another place in search of a more comfortable one. Therefore, it is necessary to analyse the frequency of rest only considering the indicators of the frequency of movement in the pen. It was predicted that in a state of discomfort, with high THI indicators, animals will have a simultaneous increase in both the activity of movement in the pen and the frequency of rest.

Studies have revealed a sharp increase in the frequency of rest at THI of 76-81% (Fig. 11). After normalisation of temperature, there was also an increased frequency of rest in animals, which may be a consequence of heat stress. Then, over a long period of time, at the optimal THI (up to 74%), the frequency of animal rest decreased.

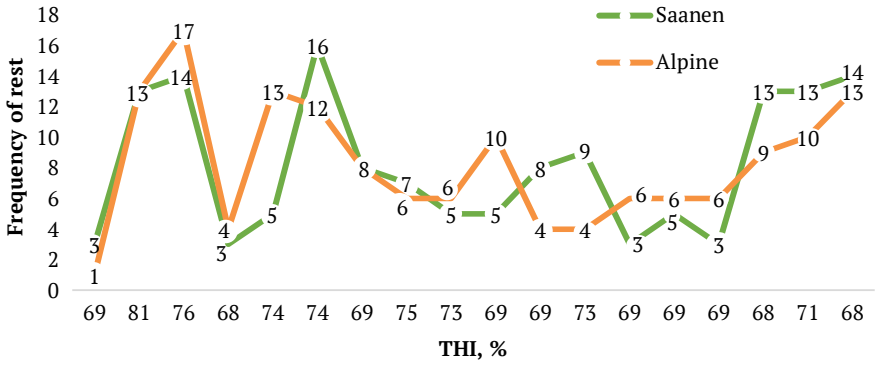

Figure 11. Frequency of rest of all animal groups, according to THI, %
Source: developed by the author

However, it is not possible to definitively confirm the effect of temperature on the increase in the frequency of rest based on the data obtained. At the end of the observations, a similar peak of activity was detected, but at the optimal temperature (THI of 68-71%). Therefore, for a more accurate assessment of the impact of this index on animal rest, it is necessary to extend the duration of experiments to have a greater volume of data. A positive statistically insignificant correlation was established between THI and animal movement in the pen, r = from +0.19 (Saanen) to + 0.39 (Alpine). The movement of animals in the pen positively correlated with feed consumption, r = from +0.30 (Saanen) to +0.34 (Alpine) and negatively with rumination, r = from -0.23 (Alpine) to -0.68 (Saanen). The movement of animals in the pen is the main indicator of their activity. The movement of animals is an important parameter of their comfortable state and normally occurs constantly with breaks for food consumption, rest, etc. Therefore, to determine the state of discomfort of animals, it is advisable to describe it together with an indicator of the opposite activity of animals, namely, rest.

As already noted, sharp changes in the activity of animals were recorded during the observations. The goats took a recumbent position to rest, but after a short time (from 3 to 5 minutes) they got up and changed their place to lie down. This phenomenon was repeated. This frequency of position changes may indicate discomfort in animals, they are not able to relax and rest. Quite often, in the process of finding the best place to rest, animals showed aggression and struggle for places to lie down, especially near drinkers and walls. It was found that animals of the studied breeds reacted differently to the change in THI (Fig. 12). Animals of the Saanen breed demonstrated more rapid changes in the frequency of movement in the pen, unlike Alpine breed.

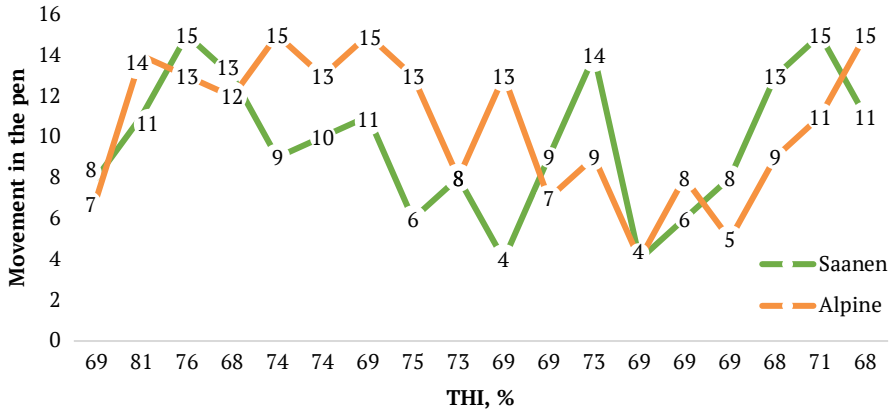

Figure 12. Frequency of movement in the pen of all groups of animals, according to THI, %
Source: developed by the author

However, it is not possible to highlight the dependence of animal movement in the pen and THI indicators, this pattern is not observed on the graph. It was suggested that at high values of THI, both indicators (movement in the pen and rest) will have equally high activity indicators. Comparing graphs of these indicators (Fig. 11, 12), in general, identical peaks at THI 75-81 % can be distinguished. Subsequently, when the temperature regime was normalised, the separation of the values of these parameters was observed. The level of

rest of animals decreased simultaneously with a decrease in the activity of movement of animals in the pen (Saanen breed) and there was a decrease in the frequency of rest with high indicators of movement in the pen (Alpine breed). Thus, it can be assumed that animals of Saanen breeds are more dependent on temperature and respond to an increase in THI – by increasing the activity and frequency of position changes, and on normalisation of THI – by general calming (extending the rest time and reducing movement in the pen).

The study analysed the activity indicators of goats of different breeds depending on changes in the room temperature regime. The negative impact of high temperature on animal productivity was observed during the introduction of farm animals from temperate climates to warm climates and during the first attempts to increase the milk productivity of animals in subtropical regions (Berman, 2012). Exploring the problems of global warming, M. Cheng *et al*. (2022) concluded that extreme climate change has a negative impact on the rate of increase in livestock population, their productivity, reproductive function, morbidity, and mortality.

According to S.B. Romo-Barron *et al*. (2019), the thermal effect on sheep productivity and well-being is most noticeable when the air temperature decreases below 12°C (lower threshold) or increases above 25-31°C (upper threshold), when the thermoregulation mechanisms significantly deviate from the norm. Behavioural responses to heat stress in sheep are manifested, depending on its severity and duration, by a permanent or temporary decrease in motor activity and by seeking shaded areas. According to I.A. Pomitun *et al*. (2021), the optimal air temperature on the day of insemination of ewes (13-26°C) contributed to the emergence of poliovulation and better fertilisation of eggs, as evidenced by the output of lambs born as part of twins and triplets and a 7.3% higher multiplicity of ewes against animals whose insemination occurred at elevated temperatures.

Research W.H.E.J. van Wettere *et al.* (2021), conducted using ecological Chambers, proved the negative effect of high temperatures (≥32°C) on the components of sheep fertility (estrus, fertilisation, embryo survival, and lambing). The influence of the above temperatures is especially noticeable 5 days before and 5 days after estrus. Heat stress for 5 days before estrus reduces the fertilisation rate by almost 60%. It was also found that prolonged exposure to high temperatures (32-41°C) during pregnancy of sheep reduces the weight of lambs at birth, their viability, thus increasing neonatal mortality.

Environmental parameters and physiological responses of animals are the starting point for mathematical modelling of their impact on animal development and manifestation of their productivity. R. Mylostyvyi & O. Chernenko (2019), investigated the relationship between the parameters of the thermal environment and the milk productivity of cows in the hot period. The integral indicators of the cowshed's microclimate state were the temperature and humidity index (THI) and the temperature and humidity index in the cowshed hangar type (THI_{CHT}). The researchers found a weak correlation between sun exposure and daily milk yield at r = -0.2, between relative humidity and daily milk yield at r = +0.4, and between relative humidity and milk fat content at r = +0.2. The correlation between daily milk yield, milk fat, milk protein content and, wind strength r = -0.2 to 0.4. Between daily milk yield, milk fat and milk protein content, and air temperature r = -0.2 to 0.5 ($p < 0.05$).

As noted by R.M. Reshma Nair *et al*. (2021), domestic goats are an ideal subject for climate change research. Anatomical, physiological, and behavioural features of goats help them adapt to different environmental conditions. According to N. Koluman (2023), during periods of drinking water scarcity, goats voluntarily reduce their dry food intake. R.M. Reshma Nair *et al*. (2021) report that when exposed to high temperatures, goats are able to concentrate urine, thus maintaining the body's water

balance. In turn, N. Maksimović *et al*. (2023) found that the heart rate in goats with limited access to water decreases, further slowing down the metabolic rate to conserve water and compensate for the reduction in animal food intake.

However, according to S. Hamzaoui *et al*. (2013), goats are not heat-resistant during lactation. They show certain changes in productivity due to heat stress, namely, a decrease in milk yield and a change in the chemical composition of milk. However, there is also a decrease in feed consumption. In goats, the maximum appetite was shown at the ambient temperature range from 0°C to +10°C, then it was gradually lost when the temperature rose to +40°C. Under heat stress, goats' rectal temperature (+0.58°C), respiratory rate (+48 breaths/min), water consumption (+77%), and water evaporation (+207%) increased.

A.A.K. Salama *et al*. (2020) also confirm that heat stress causes noticeable changes in thermophysiological properties in dairy goats, including an increase in rectal temperature and respiratory rate, along with a decrease in feed intake (by 28%) and milk yield (by 21%). In turn, A. Contreras-Jodar *et al*. (2018) found that heat stress not only negatively affected the milk production levels of Murciano-Granadina goats and their eating behaviour, but also led to changes in the immune system and increased susceptibility to diseases. Using the THI index, a decrease in feed intake (by 29.8%), milk yield (by 8%), protein content (12%) and fat content (13%) in milk was found in goats exposed to heat stress.

HA. Yamani & N. Koluman (2020), investigated how rising ambient temperatures affect milk production in Saanen, Alpine, and Boer goats. According to their data, milk yield in goats decreased with an increase in the value of THI. Overall, THI was 70.097% in the spring season and 82.65% in the summer season. It is recorded that for every 1 unit of increase in THI, there is a decrease in milk yield by 1%. THI values of 75-78% cause stress, and THI values of 70% or less are comfortable for animals.

S.V. Chumak *et al*. (2021) found that the presence of Saanen goats under THI conditions of more than 65% affected some chemical indicators of goat's milk. In particular, there was a decrease in fat content by 29%. There were no differences in protein and lactose concentrations. A decrease in the fat/protein ratio in goat's milk by 27% and dry matter by 9% was observed during the month. The concentration of urea nitrogen in milk decreased by 60%. There was a significant increase in the number of somatic cells almost three times, which confirms the presence of a stress response from the mammary gland.

Sharp fluctuations in the intensity of movement of animals are always a signal of violation of their comfortable conditions, which is confirmed by observations of M. Yıldırır *et al*. (2019) and research data. Animals become restless, constantly move, aggression increases, or vice versa, they become passive. The hierarchy of goats in the herd also affects their behaviour and feed intake ($p \leqslant 0.005$). Low-ranking goats have a higher feeding frequency ($P < 0.001$). The duration of rest (lying down and standing) decreases in goats of medium- and low-rank ($P = 0.001$). Competitive behaviour increases ($P = 0.001$) in medium-and low-rank goats.

Summarising the results of this study, it should be noted that with a sharp increase in temperature, the intensity of movement of Saanen and Alpine breeds decreased. With THI indicators of 69-74%, the intensity of animal movement was high, but with an increase to 81%, there was a sharp decline in activity. It was also found that after a long stay in THI conditions, 75-81% of goats find it quite difficult to restore normal activity indicators.

Thus, the analysis of scientific sources and the present research indicate that THI is a good indicator of detecting heat stress in animals. Therefore, it is advisable to consider this indicator when regulating the microclimate in premises for dairy goats.

Conclusions

It was found that at THI values of 69-74%, the intensity of animal movement was high. When increasing THI up to 81%, there was a sharp decline in activity. After a long stay in THI of 75-81%, animals had significant difficulty in restoring normal activity levels. Being in the comfort zone (THI = 69-74%) the animals showed a moderate to weak approach to the feed table. At THI of 75-81% (warning / dangerous), goats showed interest however, there was no feed consumption. There was no definite correlation between feed consumption and the approach of animals to the feed table, depending on -0.09 (Alpine breed) to +0.23 (Saanen breed).

At THI of 69-73%, animals approached the feed table exclusively for feed consumption and stayed there for a longer time. At THI of 76-81%, animals simultaneously showed both the maximum approaches to the feed table without feed consumption and the maximum frequency of feed consumption. A minor and statistically insignificant correlation was established between THI and animal feed consumption (r = +0.06). A small positive statistically insignificant correlation was found between THI and urination in goats (r = +0.08). No correlation was found between the approach to the feed table and urination – from -0.19 (Saanen breed) to +0.35 (Alpine breed); between feed consumption and urination – from -0.07 (Alpine breed) to +0.21 (Saanen breed).

A decrease in the frequency of rumination was found in animals at THI of 81%, while goats exhibited relative calmness. At THI of 68-75%, high rates of rumination were recorded. At THI of 76%, a sharp decrease in the rumen activity was observed. Low statistically insignificant correlation coefficients were found between THI and ruminant performance in animals, ranging from -0.16 (Alpine breed) to +0.07 (Saanen breed). Rest was positively correlated with such indicators as THI, r = from +0.40 (Saanen) to +0.49 (Alpine); movement in the pen, r = +0.62 and +0.66; approach to the feed table r = +0.32 and +0.31, and urination r = +0.16 and +0.12, respectively.

A sharp increase in the frequency of rest was detected at THI of 76-81 %. After normalisation of temperature, an increase in the frequency of rest in animals was also observed, which may be a consequence of heat stress. At the optimal level of THI (up to 74%), over a long period of time, the frequency of goat rest decreased. A positive statistically insignificant correlation was established between THI and animal movement in the pen, r = from +0.19 (Saanen) to + 0.39 (Alpine). The movement of animals in the pen positively correlates with feed consumption, r = from +0.30 (Saanen) to +0.34 (Alpine), and negatively with the rumination process in animals, r = from -0.23 (Alpine) to -0.68 (Saanen). It was found that animals of the Saanen breed in the conditions of the farm "Tetiana-2011" were more temperature-dependent and responded to an increase in THI by increasing activity and frequency of position changes, and to the normalisation of THI – by general calmness (lengthening of rest time and reduction of movement in the pen). In order to better understand the algorithm of behaviour of dairy goats under intensive technology, it is advisable to conduct similar studies in the future, subject to an increase in the number of experimental animals and the duration of observation.

Acknowledgements

None.

Conflict of Interest

None.

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Особливості поведінки кіз залежно від температурно-вологісного індексу

Олександра Гранат

Магістр
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0001-1299-0764

Наталія Богданова

Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-4634-9609

Василь Туринський

Доктор сільськогосподарських наук, професор
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-0312-694X

Анотація. Температурно-вологісний індекс (THI) є одним з найбільш критичних факторів середовища, адже впливає на терморегуляцію організму та продуктивність кіз в цілому. Мета дослідження – виявити взаємозв'язок між поведінковими реакціями кіз різних порід зі зміною температурно-вологісного індексу у приміщенні. У дослідженні використано методи часових зрізів і реєстрації поведінкових проявів кіз. Виявлено, що за показників THI 69-74 % інтенсивність руху тварин була високою, однак при підвищенні THI до 81 %, відбувався різкий спад активності. Після тривалого перебування в умовах THI 75-81 % козам досить важко відновлювати нормальні показники активності. Перебуваючи у зоні комфорту (THI = 69-74 %) тварини демонстрували помірний та слабкий підхід до кормового столу. При THI 75-81 % кози проявляли інтерес до кормового столу, однак споживання корму не відбувалося. Відпочинок тварин позитивно корелює з такими показниками як THI, r = від +0,40 (Зааненські) до +0,49 (Альпійські); рух по загону, r = +0,62 і +0,66; підхід до кормового столу r = +0,32 і +0,31 та сечовипускання r = +0,16 і +0,12 відповідно. Виявлено різке підвищення частоти відпочинку при THI 76-81 %. Після нормалізації THI також спостерігали підвищену частоту відпочинку у тварин, що може бути наслідком теплового стресу. За оптимального THI (до 74 %), упродовж тривалого періоду, частота відпочинку кіз зменшувалася. Встановлено позитивну статистично недостовірну кореляцію між THI та рухом тварин по загону, r = від +0,19 (зааненські) до +0,39 (альпійські). Рух тварин по загону позитивно корелює із споживанням корму, r = від +0,30 (Зааненські) до +0,34 (Альпійські) та негативно з жуйним процесом у тварин, r = від -0,23 (Альпійські) до -0,68 (Зааненські). Виявлено, що кози Зааненської породи більш залежні від THI ніж Альпійської. Результати дослідження доцільно враховувати під час регулювання мікроклімату в приміщеннях для дійних кіз і цапів

Ключові слова: температура навколишнього середовища; цапи; поведінка тварин; споживання корму; румінація

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Behavioural patterns of boars by breed depending on age, season, and type of ventilation

Oleksandr Deschenko*
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-2185-2689

Anna Lykhach
Doctor of Agricultural Sciences
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-0472-6162

Abstract. An important tool for improving the productive characteristics of pigs, including boars, is a thorough study of their behavioural patterns and reactions to compliance with housing conditions, which serves as an indicator of the protocol for assessing the welfare of this sex group in commercial pig farms. The purpose of the experiment was to identify the influence of age, season of the year, and type of ventilation on the duration of behavioural acts of boars by breeds to establish their behavioural patterns in industrial technology. The experiment involved 18 boars of the Large White, Landrace, and Duroc breeds. The boars selected for the experiments were clinically healthy and divided into two groups of 9 animals each. The control group of boars was kept in a room with a transverse ventilation system, and the animals of the experimental group were kept in geothermal air supply conditions for a year. In the process of visualising the behaviour parameters of boars of different breeds, it was found that: the duration of rest was significant ($P < 0.001$) affected by 49.1-67.6% – age, 10.9-23.2% – season of the year, 0.1-3.0% – type of ventilation; the duration of movement during the day was significant ($P < 0.001$) affected by 44.7-68.0% – age, 9.1-28.5% – season of the year, 0.5-3.2% – type of ventilation; the duration of admission feed and water were significant affected ($P < 0.001$) by 49.7-71.9% – age, 7.9-25.9% – season of the year, 0.1-2.4% – type of ventilation. A behavioural act that prevailed in duration and frequency ($P < 0.001$), especially

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*Corresponding author

in the summer-autumn period, was rest, which increased in time with age from 72.3% to 76.4%, regardless of the breed, season of the year, and type of ventilation. In summer and autumn, the transverse air supply system visualised abnormal apathetic behaviour during rest in animals (lying on their sides, stomach, eyes closed, without any reactions to indifferent stimuli, and the time that boars spent on stereotypical behaviour (head banging, jumping and licking the bars of the cage) increased by 3% ($P < 0.95$) and in the "position of sitting dog" by 2% ($P < 0.95$). The results obtained allow introducing the use of ethological factors in industrial pig production to increase boar sperm production, and identify individuals with behavioural deviations to develop ways to assess welfare and integrate them into production

Keywords: pigs; rest; movement; feed and water intake; welfare; three-factor variance analysis

Introduction

According to the convincing opinion of J.J. McGlone *et al.* (2020), who published the peer-reviewed section of the textbook "Animal Reproduction in Veterinary Medicine" in the public domain, the successful development of pig production technologies is a case in maintaining and restoring the number of animals as raw materials for processing enterprises. Results of long-term research by A. Lykhach *et al.* (2023) confirm the fact that in Ukraine, most commercial pig farms keep boars to maintain successful pig breeding technologies and profitable management of the pig industry in general. Practical experience shows that for cost-effective pork production in pig farms, the main factor is effective artificial insemination of sows with the criterion of evaluating boars according to their qualitative and quantitative parameters of sperm production, which was the focus of experiments by S. Kondracki *et al.* (2021). In turn, the synthesis of sperm in boars depends on a number of factors, in particular: age, breed, intensity of use, time of year, ventilation system in the premises, type of higher nervous activity, signs of individual behavioural complex, etc., and is confirmed by the conclusions of I. Zapryanova & R. Malinova (2019), I. Michos *et al.* (2021), W.L. Flowers (2022).

Despite various technological challenges, Ukraine is adopting and implementing a number of highly innovative technologies with the use of energy efficiency in livestock facilities, in particular pig breeding, to combine intensive systems of pork production technology, which are operated with minimal costs, maximum production capacity in compliance with sanitary and hygienic requirements for keeping pigs of different sex and age groups and the transformation of the energy system of livestock premises at the expense of alternative fossil resources in the agricultural sector, in particular, geothermal energy. However, the use of geothermal energy (Kwak *et al.*, 2021) in pork production will reduce the impact of the industry on the environment, harmonise the compliance of conditions for keeping pigs with the biological needs of industrial-type sites (Kim *et al.*, 2023), as provided for by the legislation of Ukraine and the European Union (Council Directive 2008/120/EC, 2008; Order of the Ministry for Development of Economy No. 224, 2021).

Natural regulatory and temperature conditions for the development of pig breeding are not observed in every region of Ukraine. For example, data from the Ukrainian Hydrometeorological Centre of the State Emergency Service of Ukraine indicate that the average peak summer temperature in Ukraine in 2023 was +33°C, and in the southern area of the country, such as Zaporizhzhia, Kherson, Mykolaiv, Odesa regions, the peak summer temperature in August was recorded at +38°C (Ukrainian

Hydrometeorological Centre, 2023). In this regard, a long period of hot weather in these regions has a significant impact on the technology of the pig industry and its profitability in general. Therefore, pig production technology, at least in these regions, requires a clear energy-efficient environmental control system that not only adapts to hot environmental conditions, but also eliminates the effects of heat generated by pigs. However, processing large amounts of fresh air on hot summer days will inevitably lead to put up in the energy consumption of the cooling system, so a high-quality cooling system must provide an appropriate balance between air quality and energy consumption (Hu *et al.*, 2023).

Since the body temperature of pigs is a homeostatic value, and their productive characteristics increase if they are kept in the temperature comfort zone (Gourdine *et al.*, 2021), then as soon as the environment becomes hot and humid, the thermoregulation mechanism is triggered in pigs: reducing feed intake, slowing down the growth rate, developing heat stress, which is harmful to health and even leads to death (Liu *et al.*, 2022; Niu *et al.*, 2024).

An important strategy for improving the efficiency of the pig industry is to research the features of behaviour indicators of different breeds and production groups of pigs, which allows explaining and predicting their functional manifestation, and improving performance responses in the conditions of industrial technology, as noted by J.L. Gourdine *et al.* (2021). From the search results available, it was found that the behaviour of boars remains insufficiently researched, especially depending on age, breed, season of year or type of ventilation, compared with the behaviour of lactating sows, rearing piglets, or fattening pigs. In addition, the process of learning about the behaviour of boars is complicated by significant differences in the ways of keeping them in both sustainable and industrial pig breeding. Currently, the legitimate way to keep boars is individual, since the group method often shows stereotypical and homosexual behaviour, and acute and chronic aggression (Haigh & O'driscoll, 2019). Since visualisation of the behaviour of boars is an important tool for obtaining the necessary information about the compliance of conditions of keeping with the biological needs of animals and, as a result, an indicator of ensuring the welfare of the latter, the purpose of the experiment was to establish the influence of age, season of year and type of ventilation system on the duration of behavioural acts of boars in the context of breeds and, as a result, the establishment of their behavioural patterns in industrial technology.

Materials and Methods

Experimental studies were conducted during 2021-2023 at the Ukrainian breeding farm PrJSC "Plemzavod Stepnoy" Zaporizhzhia Region. In total, 18 boars of Large White, Landrace, and Duroc breeds were used in the experiment (Fig. 1).

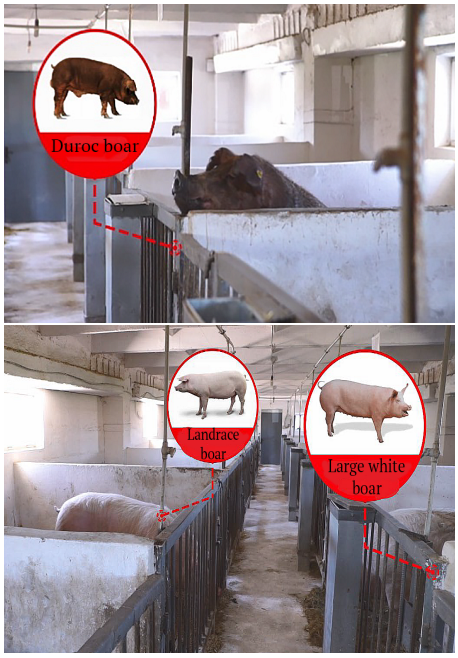

Figure 1. Breeds of boars kept on the farm
Source: photo by the authors

Boars were kept on bedding in individual pens with an area of 7 m^2, on a concrete floor with heat and moisture insulation. The boars of different breeds selected for the experiments were clinically healthy. The pigsty was equipped with forced transverse and geothermal ventilation with electronic control. Boars were fed individually with granulated complete mixed feed "Eber" at 2.8-3.0 kg of feed per animal/day with a nutritional value: crude protein content – 202,630 g/kg and metabolic energy of 12,406 MJ/kg. The composition of 1 kg of granulated feed produced by LLC "PC Alternativa" included the following ingredients (%): corn (20,000), wheat (18,355), wheat bran (25,000), soybean cake (22,645), sunflower meal (10,000), Aminomix Eber (4,000), (quality certificate according to the Technical Conditions DSTU 4508:2005). The feed was provided twice a day, at 8:00 am and 04:00 pm. The boars had constant access to drinking water from nipple drinkers. The microclimate parameters at the premises corresponded to Department Norms for Technological Design – Agro-Industrial Complex – 02.05 "Pig-breeding enterprises (complexes, farms, small farms)" (2005). The conditions of feeding, watering, keeping, care, prevention and treatment were in accordance with the European legislation on the protection of animals and their comfort (Council Directive 2008/120/EC (2008); Council Directive 2010/63/EC (2010) and Order of the Ministry for Development of Economy, Trade and Agriculture of Ukraine No. 224 (2021). The treatment of boars in the experiment fully met the requirements of bioethical standards for proper treatment of animals approved by the Bioethical Commission of the National University of Life and Environmental Sciences of Ukraine (007/2021).

A control group of boars with 3 animals of each breed was kept in the house by a transverse ventilation system with wall-mounted supply valves (1), wall-mounted exhaust fans (2), and an automated microclimate control system (3) (Fig. 2). Air entered the room through wall-mounted valves, and the speed of the exhaust fans and the opening of the valves were controlled by a computerised microclimate monitoring system.

1 2 3

Figure 2. Structural elements of transverse ventilation in the premises for boars of different breeds from the control group

Source: photo by the authors

The design features of the ventilation system (Fig. 3) in the house where the boars of the experimental group were kept, 3 animals of each breed, is the organisation of air circulation using a geothermal system: air inflow from the environment was carried out through an air intake shaft (1), then the air passed through an underground tunnel – air duct (2), where it was additionally heated in winter or cooled in summer due to soil energy before entering the house directly through the lower ventilation racks (3), which were evenly located near the

exhaust fans of the shafts that release air to the outside, and the functioning of the entire system was organised and controlled by a microclimate control device (4).

(1) (2) (3) (4)

Figure 3. Structural elements of geothermal ventilation in the premises for boars of different breeds from the experimental group

Source: photo by the authors

Both experimental groups of boars kept in house with different ventilation systems had identical construction, were made of the same building materials, and were equally spatially located relative to the prevailing wind rose. The number of cages in both buildings was the same, with an identical area and similar system for water and feed distribution, manure removal was carried out by horizontal TSN-3 conveyors and remote conveyors on tractor trailers.

During the experiment, the timing of behavioural acts of boars of different breeds was monitored using Full HD 1080p video recorders (with a maximum resolution of 1920x1080, 30 fps) with AVI recording format. In total, behavioural acts (rest, movement, food and water intake for 24 hours) were studied by visual observations in boars aged 6, 12, and 24 months of the following breeds: Large White, Landrace, Duroc. The assessment of behavioural acts of boars of each breed was measured in absolute terms as the number of minutes spent on the performance of a particular behavioural act during the day.

When analysing the influence of the age group, type of ventilation, and season of the year on the duration of rest, movement, and feed and water intake of pigs, the algorithm of three-factor variance analysis (with fixed factors) was used. In addition to the influence of the main factors, estimates of the variance ratio are also calculated for combinations of second-level factors ("age group" × "type of ventilation", "age group" × "season of the year", and "type of ventilation" × "season of the year"), and for combinations of third-level factors ("age group" × "type of ventilation" × "season of the year").

For each main factor and all their possible combinations, an estimate of the strength of the factor/combination influence was calculated (h^2) as the ratio of the corresponding sum of squares (*SS*) to the total sum of squares of the entire dispersion complex, expressed in %. Three-factor analysis of variance was performed separately for pigs of three breeds (Large White, Landrace, and Duroc). Group estimates of the arithmetic mean and its 95 confidence interval (95% CI) were also calculated for each combination of main factors. All calculations were performed using the *STATISTICA* software suite (*StatSoft Inc.*) based on the algorithms given in the manual (Kramarenko *et al.*, 2019).

Results and Discussion

According to the conducted studies, it was found that in Large White boars, regardless of the type of ventilation, the duration of rest increases with age; although in winter the rest is shorter than in other periods of the year (Table 1).

Table 1. *Duration of the main behaviour parameters of boars of the Large White breed, depending on age, season of the year, and type of ventilation, min* $\bar{X} \pm S_{\bar{x}}$

Behaviour parameter	Transverse ventilation				Geothermal ventilation			
	winter	spring	summer	autumn	winter	spring	summer	autumn
6 months and older								
Rest	837.5 ± 0.43	870.4 ± 1.30	856.5 ± 0.58	873.6 ± 0.38	864.9 ± 0.34	872.7 ± 0.87	879.5 ± 2.46	871.8 ± 0.61
Movement	516.3 ± 0.37	495.1 ± 0.37	510.0 ± 0.38	494.2 ± 1.00	496.3 ± 1.30	494.2 ± 0.91	484.3 ± 2.53	493.7 ± 3.13
Feed and water intake	86.4 ± 0.84	74.7 ± 0.98	73.6 ± 0.63	72.8 ± 0.48	78.9 ± 0.60	73.2 ± 1.17	76.4 ± 0.84	74.6 ± 1.66
12 months and older								
Rest	855.6 ± 3.83	967.2 ± 2.05	1,024.8 ± 3.14	993.4 ± 1.76	946.4 ± 2.33	951.2 ± 1.25	1,010.5 ± 1.30	960.4 ± 2.07
Movement	501.8 ± 0.77	407.2 ± 2.24	361.4 ± 5.99	382.4 ± 5.90	432.4 ± 2.24	428.6 ± 0.57	380.7 ± 1.11	418.7 ± 1.61
Feed and water intake	82.9 ± 2.70	65.6 ± 1.65	53.8 ± 2.40	64.2 ± 1.31	61.2 ± 0.66	60.0 ± 0.40	48.8 ± 0.20	60.9 ± 0.74
24 months and older								
Rest	935.4 ± 7.92	946.1 ± 7.10	1,048.3 ± 0.50	945.6 ± 1.01	980.5 ± 1.20	996.7 ± 0.69	1,026.1 ± 1.14	993.4 ± 0.77
Movement	436.2 ± 1.84	429.7 ± 2.16	345.3 ± 3.46	427.7 ± 1.84	392.3 ± 0.93	381.4 ± 1.27	365.8 ± 1.54	384.3 ± 3.39
Feed and water intake	68.4 ± 1.11	64.2 ± 1.29	46.4 ± 0.97	66.7 ± 0.48	67.2 ± 1.11	61.9 ± 0.55	48.1 ± 0.54	62.3 ± 0.73

Source: developed by the authors

Based on the obtained data, it was found that the complex of behavioural acts in boars visualises an age-related decrease movement from 15%, regardless of their breed, season of the year, and ventilation system in the premises. According to A. Lykhach *et al*. (2023), boars are characterised by a behavioural stereotypical feature that becomes quite long with age – the "position of sitting dog", which accounts for about 12% of their rest time. The results of the studies coincide with the conclusions of the US and French researchers – S.P. Parois *et al.* (2017), the object of their study was pregnant and lactating sows. These researchers note that the behavioural strategy for dealing with stress is to reduce overall movement, as a result of which lactating sows reduced standing and sitting from 18% to 11.6% of the time of day and increased, respectively, rest, and barren sows – spent time in a state of lying down to 70%. In the experiment, the longest rest period was recorded in boars aged 24 months and older with the use of a transverse ventilation system in summer, which is 72.8% of the time. Similar data was obtained by S. Rohrmann & S. Hoy (2005) in three sperm processing centres in Germany, where 78 boars rested 81.0% of the 24 hours.

The results of a three-factor analysis of variance indicate the presence of a significant (in all cases $P < 0.001$) influence of the main factors on the duration of rest (Table 2).

Table 2. *Results of a three-factor dispersion analysis of the influence of the age group, type of ventilation, and season of the year on the duration of rest of Large White boars*

Source of variance	SS	df	MS	F	P	h^2, %
Age (1)	533,250.4	2	266,625.2	4,705.2	< 0.001	65.7
Ventilation (2)	20,835.4	1	20,835.4	367.7	< 0.001	2.6
Season (3)	125,575.9	3	41,858.6	738.7	< 0.001	15.5
1×2	2,535.2	2	1,267.6	22.4	< 0.001	0.3
1×3	72,001.6	6	12,000.3	211.8	< 0.001	8.9
2×3	22,145.0	3	7,381.7	130.3	< 0.001	2.7
1×2×3	25,202.2	6	4,200.4	74.1	< 0.001	3.1
Error	9,519.8	168	56.7			1.2
Total	811,065.5	192				100.0

Notes: SS – sum of squares of deviations; df – number of degrees of freedom; MS – middle square; F – variance ratio; R – probability level; h2 – the strength of the factor's influence

Source: developed by the authors

The most significant impact on the duration of rest was observed for the indicators age (65.7%) and the season of the year (15.5%), while the impact of the type of ventilation was the lowest (2.6%). Among the combinations of factors of the first and third levels, the highest strength of influence, as might be expected, was noted for the combination "age group" × "season of the year" (8.9%). On the other hand, quite a significant influence was recorded for the combination of all three main factors, that is, "age group" × "type of ventilation" × "season of the year" (3.1%), and for the combination "type of ventilation" × "season of the year" (2.7%). The results of three-factor analysis of variance indicate the presence of a significant (in all cases $P < 0.001$) influence of the main factors on the duration of movement (Table 3).

Table 3. *Results of a three-factor dispersion analysis of the influence of the age group, type of ventilation, and season of the year on the duration of movement of Large White boars*

Source of variance	SS	df	MS	F	P	h^2, %
Age (1)	382,542.9	2	191,271.4	3,946.7	< 0.001	68.0
Ventilation (2)	7,989.0	1	7,989.0	164.8	< 0.001	1.4
Season (3)	72,542.4	3	24,180.8	499.0	< 0.001	12.9
1×2	7,558.3	2	3,779.1	78.0	< 0.001	1.3
1×3	41,367.2	6	6,894.5	142.3	< 0.001	7.3
2×3	17,091.6	3	5,697.2	117.6	< 0.001	3.0
1×2×3	25,739.5	6	4,289.9	88.5	< 0.001	4.6
Error	8,141.8	168	48.5			1.4
Total	562,972.6	192				100.0

Source: developed by the authors

As with the duration of rest, the most significant effects on the duration of movement were observed for the age group (68.0%) and season (12.9%), while the effect of ventilation type was relatively low (1.4%). Among the combinations of factors, the highest influence on the duration of movement was registered for the combination "age group" × "season of the year" (7.3%). On the other hand, a fairly significant influence was observed for the combination of all three main factors, i.e.: "age group" × "type of ventilation" × "season of the year" (4.6%), and for the combination "type of ventilation" × "season of the year" (3.0%). The results of a three-factor analysis of variance indicate the presence of a significant (in all cases $P < 0.001$) influence of the main factors on the duration of feed and water intake (Table 4).

Table 4. *Results of a three-factor dispersion analysis of the influence of the age group, type of ventilation, and season of the year on the duration of feed and water intake of Large White boars*

Source of variance	SS	df	MS	F	P	h^2, %
Age (1)	13,861.4	2	6,930.7	669.8	< 0.001	49.7
Ventilation (2)	491.2	1	491.2	47.5	< 0.001	1.8
Season (3)	7,217.7	3	2,405.9	232.5	< 0.001	25.9
1×2	7,84.4	2	392.2	37.9	< 0.001	2.8
1×3	2,538.6	6	423.1	40.9	< 0.001	9.1
2×3	869.8	3	289.9	28.0	< 0.001	3.1
1×2×3	377.1	6	62.8	6.1	< 0.001	1.4
Error	1,738.4	168	10.3			6.2
Total	27,878.7	192				100.0

Source: developed by the authors

As with the duration of rest and the duration of movement, the most significant effect on the duration of feed and water intake was observed for the age group (49.7%) and the season of the year (25.9%), while the effect of the type of ventilation was also very low (1.8%). Among the combinations of factors, the highest strength of influence on the duration of feed and water intake was registered for the combination "age group" × "season of the year" (9.1%). On the other hand, quite a significant influence was noted for the combination of factors "type of ventilation" × "season of the year" (3.1%) and "age group" × "type of ventilation" (2.8%).

Thus, the greatest influence on the duration of various behaviour parameters of Large White boars was noted for the main factor "age group". Its role in determining the duration of rest or movement was significantly higher than for the duration of feed and water intake. In the second place, according to the proportion of variability on the duration of various behaviour indicators of Large White boars, was the influence of the main factor "season of the year". However, the opposite situation was established here – its effect on the duration of feed and water intake was almost twice as high as on the duration of rest or movement. As for the combination of factors, the greatest impact was observed either for the combinations "type of ventilation" × "season of the year" and "age group" × "type of ventilation" × "season of the year" (for the duration of rest and movement), or for combinations "age group" × "season of the year", "type of ventilation" × "season of the year" and "age group" × "type of ventilation" (for the duration of feed and water intake).

Considering the estimates of the arithmetic mean (± 95% CI) of the duration of rest in different groups of Large White boars, depending on the age group, type of ventilation, and season of the year, the following patterns can be noted. At the age of 6 months and older, for Large White boars, the duration of rest for geothermal ventilation almost did not differ in different seasons of the year, while for transverse ventilation it was the same in spring and autumn, but differed significantly from the estimates for winter and summer.

The duration of rest increased in animals aged 12 and 24 months. An increase in the duration of rest at the age of 12 months for geothermal ventilation was noted for animals in summer and autumn. With the transverse type of ventilation, boars of the same breed had an increase in the duration of rest – in summer and autumn. For animals aged 24 months, two patterns of dependence of the duration of rest on the type of ventilation were established. The first pattern was observed during the autumn-winter-spring period of the year, but boars spent more time resting in premises with geothermal ventilation than during transverse ventilation. The second pattern was observed for animals of the same breed in summer, since for them the duration of rest, on the contrary, was significantly higher with transverse ventilation than with geothermal ventilation.

The duration of movement at the age of 6 months for Large White boars did not differ much in different seasons of the year with geothermal ventilation. But with the transverse type of ventilation, it grew – in summer and winter. Overall, movement duration was significantly reduced in animals aged 12 and 24 months. At the age of 12 months, it was highest in the autumn-winter-spring period of the year and significantly lower in the summer with geothermal ventilation. With transverse ventilation, the duration of movement increased significantly for animals in winter, but decreased almost proportionally in spring, summer, and autumn. For boars aged 24 months, two patterns of dependence of the duration of movement on the type of ventilation were also established. The first pattern was observed during the autumn-winter-spring period of the year, but for geothermal ventilation, this behavioural act was significantly reduced compared to the transverse type of ventilation. The second pattern was observed for boars in summer, where the duration of movement, on the contrary, was significantly higher with geothermal ventilation than with transverse ventilation.

For boars aged 6 months, the duration of feed and water intake almost did not differ in different seasons of the year, both with geothermal ventilation and with transverse ventilation. With the exception of the winter season, when this behaviour was significantly higher with transverse ventilation type. Overall, the duration of feed and water intake decreased in animals aged 12 and 24 months. At the age of 12 months, the duration of feed and water intake was almost the same in spring and autumn for both types of ventilation systems. In winter, the duration of feed and water intake was significantly higher with transverse ventilation, and in summer, this behaviour parameter was the lowest with both geothermal ventilation and transverse ventilation, although it tended to increase with transverse ventilation. At the age of 24 months, the duration of feed and water intake was lowest in summer and autumn and was the same for both geothermal and transverse ventilation. In spring, the duration of this behaviour was higher, and in winter even higher, however, the duration of feed and water intake of boars in these seasons also did not differ with different types of ventilation.

It is worth noting that a similar analysis of variance was performed by S.V. Zhyzhka (2021) in the dissertation paper on the reproductive qualities of sows in conventional ventilation and negative pressure air supply in different seasons of the year. Thus, the researcher established the probable strength of the influence

of the indoor ventilation system on the number of piglets at weaning by 3.38% ($P < 0.05$), the weight of the piglets' nest at weaning by 5.95% ($P < 0.01$), and the absence of this factor on number and weight of piglets. The season of year factor had a significant effect on nest weight at weaning 26.58% ($P < 0.001$), sow multiple fertility 3.47% ($P < 0.01$), number of piglets at weaning 2.38% ($P < 0.01$), and piglet survival before weaning 1.87% ($P < 0.05$). The significant influence of this factor on the size of piglets has not been established. The interaction of these factors had little effect on the weight of the piglets' nest at weaning.

The time spent on parameters of the behaviour of boars of the Landrace breed, depending on age, season of the year and type of ventilation, is shown in Table 5. The results of the behavioural range of boars of the Landrace breed indicate that the predominant behaviour in terms of duration and frequency in this breed, as well as Large White and Duroc breeds, is a stationary state, which is visualised at pig farms as behaviour in a state of rest. However, in the course of observation, it was noticed that boars of the Landrace breed, differing in a more excitable type of higher nervous activity when kept with a transverse type of air ventilation, spent up to 3% ($P < 0.95$) of the time on stereotypical behaviour, which manifested itself in the form of head banging and licking the cage grate, especially in the hot summer and autumn, which is consistent with the study by I. Petak *et al*. (2010), identified a similar phenomenon from 13 studied behavioural complexes of sire boars. J.W. Ross *et al.* (2015) suggest that this behaviour of pigs is a consequence of heat stress, where extreme heat in the summer months of the year is likely to affect both pork production and welfare of pigs. According to V. Miclea *et al.* (2016), the behavioural complex of boars has a significant impact on their sperm production. Most animals without heat stress showed stable sexual reflexes, and they were awarded 5 points. In turn, ejaculates were collected from the same boars twice a week in the spring for two years and it was noted that ejaculates were characterised by age and breed-appropriate volume, concentration and mobility, and could be processed into the largest number of doses for insemination. This had an obvious positive economic effect. However, the researchers found that age affected the quality of ejaculate in young boars, with the exception of a few animals that had reduced sexual reflexes.

Table 5. *Duration of the main behaviour parameters of boars of the Landrace breed, depending on age, season of the year, and type of ventilation, min* $\bar{X} \pm S_{\bar{x}}$

Behaviour parameter	Transverse ventilation				Geothermal ventilation			
	winter	spring	summer	autumn	winter	spring	summer	autumn
6 months and older								
Rest	832.4 ± 1.71	868.9 ± 0.93	904.3 ± 7.18	871.3 ± 1.41	896.3 ± 7.02	873.3 ± 0.82	900.4 ± 7.80	875.3 ± 2.33
Movement	517.6 ± 0.57	498.2 ± 9.09	442.8 ± 5.57	493.8 ± 1.31	469.8 ± 3.00	495.6 ± 0.40	466.8 ± 7.45	494.5 ± 1.93
Feed and water intake	90.1 ± 0.41	72.9 ± 0.67	92.9 ± 0.23	74.9 ± 0.30	73.9 ± 1.35	71.1 ± 0.56	72.8 ± 1.08	70.2 ± 0.40
12 months and older								
Rest	862.2 ± 4.87	898.6 ± 16.27	1,021.4 ± 0.90	929.3 ± 10.61	929.3 ± 10.61	939.8 ± 3.98	967.5 ± 6.67	965.4 ± 1.99
Movement	498.9 ± 0.69	475.6 ± 8.47	366.5 ± 4.37	449.1 ± 7.29	436.4 ± 1.87	418.3 ± 3.08	408.9 ± 4.03	414.5 ± 1.01
Feed and water intake	78.9 ± 1.25	65.8 ± 1.60	52.1 ± 2.09	61.6 ± 1.04	65.6 ± 1.18	54.2 ± 1.03	58.4 ± 0.25	60.1 ± 0.61

Table 5. Continued

Behaviour parameter	Transverse ventilation				Geothermal ventilation			
	winter	spring	summer	autumn	winter	spring	summer	autumn
	24 months and older							
Rest	934.8 ± 7.64	954.6 ± 5.47	1,010.1 ± 0.44	956.4 ± 4.15	938.6 ± 8.38	965.1 ± 9.20	1,021.0 ± 2.01	951.3 ± 10.02
Movement	446.8 ± 4.58	429.3 ± 2.17	380.0 ± 5.20	431.8 ± 1.31	442.3 ±v11.96	414.5 ± 4.87	369.8 ± 1.95	410.7 ± 5.16
Feed and water intake	58.4 ± 0.97	56.4 ± 1.35	49.8 ± 1.06	51.8 ± 1.19	59.1 ± 0.77	60.4 ± 1.22	49.2 ± 0.67	67.0 ± 1.59

Source: developed by the authors

The results of the three-factor analysis of variance indicate the presence of a significant (in all cases: $P < 0.001$) influence of the main factors on the duration of rest (Table 6).

Table 6. *Results of a three-factor variance analysis of the influence of age group, type of ventilation, and season of the year on the duration of rest of Landrace boars*

Source of variance	*SS*	*df*	*MS*	*F*	*P*	h^2, %
Age (1)	27,3483.6	2	136,741.8	368.7	< 0.001	49.1
Ventilation (2)	16,474.3	1	16,474.3	44.4	< 0.001	3.0
Season (3)	129,346.5	3	43,115.5	116.3	< 0.001	23.2
1×2	6,512.0	2	3,256.0	8.8	< 0.001	1.2
1×3	16,872.9	6	2,812.1	7.6	< 0.001	3.0
2×3	25,016.1	3	8,338.7	22.5	< 0.001	4.5
1×2×3	27,408.6	6	4,568.1	12.3	< 0.001	4.9
Error	62,302.1	168	370.8			11.2
Total	557,416.1	192				100.0

Source: developed by the authors

The most significant effect on rest duration was observed for the age group (49.1%) and season of the year (23.2%), while the effect of ventilation type was the lowest (3.0%). Among the combinations of factors of the second and third levels, the highest strength of influence was noted for the combination "age group" × "type of ventilation" × "season of the year" (4.9%), and "type of ventilation" × "season of the year" (4.5%).

The results of three-factor analysis of variance indicate the presence of a significant (in all cases: $P < 0.001$) influence of the main factors on the duration of movement (Table 7).

Table 7. *Results of a three-factor variance analysis of the influence of age group, type of ventilation, and season of the year on the duration of movement of Landrace pigs*

Source of variance	*SS*	*df*	*MS*	*F*	*P*	h^2, %
Age (1)	165,723.5	2	82,861.7	407.1	< 0.001	44.7
Ventilation (2)	12,034.9	1	12,034.9	59.1	< 0.001	3.2
Season (3)	105,796.7	3	35,265.6	173.3	< 0.001	28.5
1×2	4,132.5	2	2,066.3	10.2	< 0.001	1.1
1×3	8,966.4	6	1,494.4	7.3	< 0.001	2.4
2×3	21,805.4	3	7,268.5	35.7	< 0.001	5.9
1×2×3	18,363.1	6	3,060.5	15.0	< 0.001	4.9

Table 7. Continued

Source of variance	*SS*	*df*	*MS*	*F*	*P*	h^2, %
Error	34,191.4	168	203.5			9.2
Total	371,013.8	192				100.0

Source: developed by the authors

Similarly, as with respect to the duration of rest, the most significant effect on the duration of movement was observed for the age group (44.7%) and the season of the year (28.5%), and the influence of the type of ventilation was low (3.2%). Among the combinations of factors of the second and third levels, the highest strength of influence on the duration of movement of boars of the Landrace breed, and in the previous case, was noted for the combination of "age group" × "type of ventilation" × "season of the year" (4.9%) and "type of ventilation" × "season of the year" (5.9%). The results of a three-factor analysis of variance indicate the presence of a significant (in all cases: $P < 0.001$) influence of the main factors on feed and water intake (Table 8).

Table 8. *Results of a three-factor dispersion analysis of the influence of the age group, type of ventilation, and season of the year on the duration of feed and water intake of Landrace boars*

Source of variance	*SS*	*df*	*MS*	*F*	*P*	h^2, %
Age (1)	14,892.1	2	7,446.1	826.2	< 0.001	55.7
Ventilation (2)	632.2	1	632.2	70.2	< 0.001	2.4
Season (3)	2,123.0	3	707.7	78.5	< 0.001	7.9
1×2	1,980.2	2	990.1	109.9	< 0.001	7.4
1×3	3,056.1	6	509.3	56.5	< 0.001	11.4
2×3	969.9	3	323.3	35.9	< 0.001	3.6
1×2×3	1,589.7	6	265.0	29.4	< 0.001	5.9
Error	1,514.0	168	9.0			5.7
Total	26,757.1	192				100.0

Source: developed by the authors

As with the duration of rest and duration of movement, the most significant effect on the duration of feed and water intake was observed for the age group (55.7%). But the assessment of the strength of the influence of the season of the year was significantly lower than for the previous two behaviour indicators of Landrace pigs (7.9%). The effect of the type of ventilation was also relatively low (2.4%). Among the combinations of factors, the highest strength of influence on the duration of movement was recorded for the combination "age group" × "season of the year" (11.4%) and "age group" × "type of ventilation" (7.4%).

Consequently, the greatest influence on the duration of various behaviour parameters of Landrace boars was observed for the main factor "age group". Its role in determining the duration of rest or movement, in contrast to other boars of the Large White breed, was lower than for the duration of feed and water intake. In the second place, according to the proportion of variability on the duration of various indicators of boar behaviour, was the influence of the main factor "season of the year". But here the opposite situation was established – its effect on the duration of feed and water intake of Landrace boars was significantly lower than on the duration of rest or movement. As for the combination of factors, the greatest influence was observed for the "type of ventilation" combinations × "season of the year" (for the duration of rest and movement), and for "age group" × "season of the year" and "age group" × "type of

ventilation" (for the duration of feed and water intake). Ultimately, for all behaviour indicators of Landrace boars, a significant influence was also noted for the combination of third-level factors, that is, "age group" × "type of ventilation" × "season of the year".

Estimation of the arithmetic mean (± 95% CI) of the duration of rest in different groups of boars of this breed depending on the age group, type of ventilation, and season of the year shows that at the age of 6 months for Landrace animals, the duration of rest with geothermal ventilation was almost the same in different seasons of the year, while with the transverse type of ventilation the highest estimates of this behavioural trait were obtained for the summer season, slightly lower – in spring and autumn, and finally the shortest duration of rest was observed in winter. A significant influence of the type of ventilation on the duration of rest was noted only in winter. Overall, the duration of rest increased in animals aged 12 and 24 months. At the age of 12 months, for Landrace animals, the duration of summer rest with transverse ventilation significantly increased compared to geothermal ventilation, while during the remaining seasons of the year, on the contrary, it significantly decreased. Especially, this decline was also noted in winter. At the age of 24 months, during the autumn-winter-spring period, the duration of rest of boars did not significantly differ, while during the summer season it was significantly higher, but, again, did not depend on the type of ventilation.

An estimate of the arithmetic mean (± 95% CI) duration of movement in different groups of Landrace boars, depending on the age group, type of ventilation and season of the year, indicates that at the age of 6 months, the duration of movement did not significantly differ in spring and autumn with both geothermal and transverse ventilation. Overall, movement duration tended to decrease in animals aged 12 and 24 months. At the age of 12 months, the duration of movement of boars of this breed was almost the same in different seasons of the year with geothermal ventilation. Although in winter it was still slightly higher than in summer. But with transverse ventilation, the duration of movement of Landrace pigs significantly increased during all seasons of the year, except for summer. At the age of 24 months, the duration of movement was almost independent of the type of ventilation, and to a greater extent depended on the season of the year. It was lowest in summer, grew during the spring and autumn seasons, and peaked in winter.

Estimation of arithmetic means (± 95% CI) of the duration of feed and water intake in different groups of Landrace boars depending on age group, type of ventilation and season of the year shows that at the age of 6 months the duration of this behaviour was the same among Landrace boars in all seasons of the year with geothermal ventilation. While with transverse ventilation, it increased significantly in winter and summer, or, conversely, remained unchanged during spring or autumn. Overall, the duration of feed and water intake tended to decrease in animals aged 12 and 24 months. At the age of 12 months, with geothermal ventilation, the duration of feed and water intake in boars was greatest in winter. With transverse ventilation, on the contrary, there was a significant off-season differentiation in the duration of feed and water intake; it was lowest in animals during the summer, highest in spring and autumn, and finally reached its maximum in winter. The significant influence of the type of ventilation was observed in all seasons of the year, except autumn. At the age of 24 months, the duration of feed intake during the summer season was lowest with both types of ventilation. Significant differences for boars kept under different types of ventilation were observed in the autumn: with geothermal ventilation, the duration of feed and water intake in this season was the highest, while with transverse ventilation – as low as in summer. The type of ventilation did not affect the duration of feed

and water intake of Landrace boars in winter and did not significantly affect them in autumn.

The study by M.B. Shpetnyi (2019) is somewhat consistent with the conducted experiments, and according to the results of the analysis of variance, it was found that the main economic useful features were significantly affected by the type of lattice floor in the piglet rearing machine – 9.7-13.6%, while the time of year affected the same features by 3.5-5.6%, and their combined interaction by 2.9-4.9%. The time spent on behaviour parameters of boars of the Duroc breed, depending on age, season of the year and type of ventilation, is shown in Table 9.

Table 9. *Duration of the main behaviour parameters of boars of the Duroc breed, depending on age, season of the year, and type of ventilation, min* $\bar{X} \pm S_{\bar{x}}$

Behaviour parameter	Transverse ventilation				Geothermal ventilation			
	winter	spring	summer	autumn	winter	spring	summer	autumn
6 months and older								
Rest	905.3 ± 1.10	911.2 ± 1.48	976.4 ± 5.51	966.2 ± 1.91	926.1 ± 0.64	937.7 ± 1.10	949.2 ± 6.78	940.1 ± 3.66
Movement	472.3 ± 5.96	468.2 ± 4.21	408.4 ± 0.96	414.2 ± 0.97	453.2 ± 5.66	453.1 ± 3.38	443.1 ± 3.66	441.1 ± 1.88
Feed and water intake	62.12 ± 0.55	60.0 ± 0.46	55.9 ± 0.99	59.5 ± 0.89	60.5 ± 0.50	59.1 ± 0.52	57.9 ± 0.52	58.9 ± 0.35
12 months and older								
Rest	862.6 ± 4.83	922.5 ± 9.38	1,069.4 ± 4.84	984.4 ± 2.76	964.9 ± 5.91	960.4 ± 3.91	985.2 ± 7.12	966.7 ± 1.66
Movement	489.2 ± 2.29	442.8 ± 8.80	327.9 ± 6.40	396.8 ± 2.46	406.7 ± 0.93	414.3 ± 1.42	400.0 ± 3.14	416.9 ± 0.97
Feed and water intake	88.3 ± 0.90	74.3 ± 0.59	42.0 ± 0.65	58.6 ± 0.50	68.3 ± 0.25	65.4 ± 0.82	52.9 ± 0.72	56.0 ± 0.46
24 months and older								
Rest	1,065.8 ± 2.94	1,064.5 ± 1.23	1,100.7 ± 2.97	1,072.6 ± 2.01	1,068.6 ± 8.38	1,049.6 ± 0.71	1,050.3 ± 6.79	1,042.1 ± 1.54
Movement	342.9 ± 7.71	337.5 ± 4.28	319.0 ± 4.04	332.5 ± 3.46	334.6 ± 4.04	354.1 ± 6.45	359.0 ± 4.82	364.8 ± 6.82
Feed and water intake	31.0 ± 0.33	38.8 ± 1.22	20.4 ± 0.26	35.3 ± 1.29	36.5 ± 0.42	35.0 ± 0.53	30.4 ± 0.38	33.4 ± 0.50

Source: developed by the authors

Visualisation of behavioural acts of Duroc boars depending on the season of the year and the type of ventilation parameters that in animals aged 24 months, the duration of time for rest ranged from 72.3% to 76.4%, considering the phlegmatic temper of representatives of this breed. During rest, the animals lay on their sides, stomachs, with their eyes closed, sometimes not responding to any indifferent stimuli in the house where they were kept, especially in the hot season. Such indifference, according to D.M. Broom & A. Fraser (2007) refers to abnormal apathetic behaviour, which in this study was observed in boars of the Duroc breed with a transverse air ventilation system. In addition, boars of this breed showed stereotypical behaviour in the form of jumping on the cage grid – up to 1% (Fig. 1) and the "position of sitting dog" – 2% ($P < 0.95$), which is consistent with the experiments conducted by I. Petak *et al*. (2010) and in their case, this figure was 3% ($P < 0.99$).

The results of a three-factor analysis of variance indicate the presence of a significant ($P \leq 0.001...0.003$) influence of the main factors on the duration of rest (Table 10).

Table 10. *Results of a three-factor dispersion analysis of the influence of the age group, type of ventilation and season of the year on the duration of rest of Duroc boars*

Source of variance	*SS*	*df*	*MS*	*F*	*P*	h^2
Age (1)	560,717.4	2	280,358.7	2,013.2	< 0.001	67.6
Ventilation (2)	1,233.7	1	1,233.7	8.9	0.003	0.1
Season (3)	90,471.7	3	30,157.2	216.6	< 0.001	10.9
1×2	8,933.9	2	4,467.0	32.1	< 0.001	1.1
1×3	52,316.7	6	8,719.4	62.6	< 0.001	6.3
2×3	65,405.7	3	21,801.9	156.6	< 0.001	7.9
1×2×3	26,650.5	6	4441.7	31.9	< 0.001	3.2
Error	23,395.3	168	139.3			2.8
Total	829,124.9	192				100.0

Source: developed by the authors

The most significant effect on the duration of rest for Duroc boars was observed for the age group (67.6%) and the season of the year (10.9%), while the influence of the type of ventilation was very low (0.1%). Among the combinations of factors of the second level, the highest strength of impact was noted for the combinations "type of ventilation" × "season of the year" (7.9%) and "age group" × "season of the year" (6.3%). The results of three-factor analysis of variance indicate the presence of a significant (in all cases: $P < 0.001$) influence of the main factors on the duration of movement (Table 11).

Table 11. *Results of a three-factor dispersion analysis of the influence of age group, type of ventilation, and season of the year on the duration of movement of Duroc boars*

Source of variance	*SS*	*df*	*MS*	*F*	*P*	h^2
Age (1)	341,522.3	2	170,761.1	1081.0	< 0.001	64.9
Ventilation (2)	2,653.0	1	2,653.0	16.8	< 0.001	0.5
Season (3)	48,134.6	3	16,044.9	101.6	< 0.001	9.1
1×2	4951.9	2	2,476.0	15.7	< 0.001	0.9
1×3	35,051.4	6	5,841.9	37.0	< 0.001	6.7
2×3	51,467.6	3	17,155.9	108.6	< 0.001	9.8
1×2×3	15,771.8	6	2,628.6	16.6	< 0.001	3.0
Error	26,538.6	168	158.0			5.0
Total	526,091.2	192				100.0

Source: developed by the authors

As with the duration of rest, the most significant effect on the duration of movement of Duroc boars was observed for the age group (64.9%) and the season of the year (9.1%), while the influence of the type of ventilation was significantly low (0.5%). Among the combinations of factors of the second level, the highest force of influence on the duration of movement was also registered for the combinations "type of ventilation" × "season of the year" (9.8%) and "age group" × "season of the year" (6.7%). The results of a three-factor analysis of variance indicate the presence of a probable (in all cases: $P < 0.001$) influence of the main factors on the duration of feed and water intake (Table 12).

Table 12. *Results of a three-factor dispersion analysis of the influence of the age group, type of ventilation, and season of the year on the duration of feed and water intake of Duroc boars*

Source of variance	*SS*	*df*	*MS*	*F*	*P*	h^2, %
Age (1)	35,502.9	2	17,751.4	4,986.0	< 0.001	71.9
Ventilation (2)	47.0	1	47.0	13.2	< 0.001	0.1
Season (3)	5,974.2	3	1,991.4	559.3	< 0.001	12.1
1×2	477.2	2	238.6	67.0	< 0.001	1.0
1×3	4,234.9	6	705.8	198.2	< 0.001	8.6
2×3	1,275.4	3	425.1	119.4	< 0.001	2.6
1×2×3	1,238.6	6	206.4	58.0	< 0.001	2.5
Error	598.1	168	3.6			1.2
Total	49,348.3	192				100.0

Source: developed by the authors

As with rest and movement time, the most significant effect on feed and water intake for Duroc boars was observed for age group (71.9%) and season (12.1%), while the effect of ventilation type was also very low (0.1%). Among the combinations of the second-level factors, the highest strength of influence on the duration of feed and water intake of Duroc boars was observed for the combination "age group" × "season of the year" (8.6%).

Thus, the greatest influence on the duration of various behaviour indicators of Duroc pigs was noted for the main factor "age group". Its role in determining the duration of feed and water intake was higher than for the duration of rest and movement. The season of the year to the greatest extent determined the variability of the duration of feed and water intake. The combination of factors "age group" × "season of the year" played an important role in shaping the duration of all behaviour indicators of Duroc boars, while the combination "type of ventilation" × "season of the year" was essential for determining the length of rest and movement. Ultimately, the combination of all three factors under study also influenced the development of behavioural responses of Duroc boars in this experiment. According to A. Lopez Rodriguez *et al.* (2017), the change in the indicators of various forms of behaviour of boars, which is genetically determined, is influenced by the design features of the pen, seasonal effects, indoor microclimate, age, and especially elevated temperature (heat stress), increasing to 34.5°C within 8 hours and 31°C – 16 hours daily for 90 days provoked low movement, increased rest, and also reduced fertility compared to a similar group of boars kept at 23°C.

An estimate of the arithmetic mean (± 95% CI) duration of rest indicates that at the age of 6 months in boars in summer and autumn with transverse ventilation, this indicator was higher with the transverse type of ventilation, and, on the contrary, lower in winter and spring than with the geothermal type. In general, the duration of rest increased in animals at the age of 12 and, especially, at the age of 24 months. At the age of 12 months, the highest duration of rest with transverse ventilation was observed during the summer season and significantly decreased during the autumn, spring and winter seasons, respectively. The difference between different seasons of the year in terms of the duration of rest was probable and this range of off-season variability was about 200 minutes. The type of ventilation (geothermal or transverse) did not affect the duration of rest only during the autumn. At the age of 24 months, the probable effect of the type of ventilation was observed only during the summer – with transverse ventilation, the duration of rest was significantly higher than with geothermal ventilation.

An estimate of the arithmetic mean (± 95% CI) of the duration of movement indicates that

at 6 months of age in the summer and autumn, with transverse ventilation, this behaviour parameter was lower, and in the winter and spring, on the contrary, higher than with geothermal ventilation. Overall, the duration of movement decreased in animals at the age of 12 and, especially, at the age of 24 months. At the age of 12 months, the highest duration of movement with transverse ventilation was observed during the winter, while this feature took lower values during the spring, autumn, and summer seasons, respectively. The difference between different seasons of the year in terms of movement duration was significant and this range was almost 160 minutes. Ultimately, the type of ventilation (geothermal or transverse) had little effect on the duration of movement only during the autumn; for the remaining seasons, the differences between different types of ventilation were very pronounced. At the age of 24 months, the duration of boars' movement did not depend on the type of ventilation during the winter and spring. While, during the summer and autumn, their duration of movement significantly decreased with transverse ventilation type.

Estimates of the arithmetic mean (± 95% CI) of the duration of feed and water intake at the age of 6 months indicate that neither the type of ventilation nor the season of the year affected this behaviour. At the age of 12 months, these indicators were slightly higher, and at the age of 24 months, on the contrary, significantly lower than at the age of 6 months. At the age of 12 months, the highest duration of feed and water intake with transverse ventilation was observed during the winter, and this trait took lower values during the spring, autumn, and summer seasons, respectively. The difference between seasons of the year in terms of the duration of feed and water intake was significant and its range between seasons was almost 50 minutes. The type of ventilation (geothermal and transverse) did not affect the duration of feed and water intake, again, only during the autumn. At the age of 24 months, the duration of boars' feed and water intake with geothermal ventilation was almost the same throughout all seasons of the year, although it differed significantly between the winter and summer. With transverse ventilation, the duration of feed and water intake was almost the same. The duration of this type of behaviour of Duroc boars was significantly lower only during the summer. Based on the conducted experiment, models of behaviour of boars of three breeds were established depending on the age group, season of the year, and type of ventilation, which in the conditions of industrial pig breeding will increase the reserves of ethological strategies to put up performance responses, introduce methods for assessing welfare, and their integration into production.

Conclusions

Based on the results of the experiment in the conditions of an industrial pork production enterprise, behavioural patterns of boars in the context of breeds depending on the age, season of the year, and type of ventilation were established. Thus, the duration of rest is significant ($P < 0.001$) influenced by: in boars of the Large White breed, 65.7% – age, 15.5% – season of the year, 2.6% – type of ventilation; in boars of the Landrace breed, 49.1% – age, 23.2% – season of the year, 3.0% – type of ventilation; in boars of the Duroc breed, 67.6% – age, 10.9% – season of the year, 0.1% – type of ventilation. Accordingly, the duration of movement was significant ($P < 0.001$) affected by: in Large White boars 68.0% – age, 12.9% – season of the year, 1.4% – type of ventilation; in Landrace boars 44.7% – age, 28.5% – season of the year, 3.2% – type of ventilation; in Duroc boars 64.9% – age, 9.1% – season of the year, 0.5% – type of ventilation. In turn, the duration of feed and water intake was significant ($P < 0.001$) affected by: in Large White boars 49.7% – age, 25.9% – season of the year, 1.8% – type of ventilation; in Landrace boars 55.7% – age, 7.9% – season of the

year, 2.4% – type of ventilation; in Duroc boars 71.9% – age, 12.1% – season of the year, 0.1% – type of ventilation.

Regardless of the breed, season of the year, and type of ventilation, the predominant behavioural act in terms of duration (72.3-76.4%) at $P < 0.001$ and frequency (especially in the summer-autumn period) during the day, was rest, which increased in time with age (6-12-24 months). During rest with the transverse air supply system, the animals showed abnormal apathetic behaviour, which was manifested in lying on their sides or stomach, with their eyes closed, without any reactions to indifferent stimuli in the room for their maintenance, especially in hot periods of the year, which is a manifestation of heat stress in animals. Boars, when kept with transverse air ventilation, spent up to 3% ($P < 0.95$) of their time on stereotypical behaviour, which was manifested in the form of head banging, jumping, and licking the cage grate and the "position of sitting dog" – 2% ($P < 0.95$), especially in the hot periods of summer and autumn.

The conducted study is useful for ethological monitoring of compliance of keeping conditions with the biological needs of boars, and for pig breeders it opens up ways to develop strategies for identifying individuals with behavioural and performance abnormalities as an element of animal welfare assessment and a way to combat heat stress.

Prospects for further studies are to research the relationship of sexual behaviour of boars with qualitative and quantitative signs of their sperm productivity, depending on the breed, age, season of the year, and type of ventilation.

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Conflict of Interest

None.

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Поведінкові патерни кнурів у розрізі порід залежно від віку, сезону року і типу вентиляції

Олександр Дещенко

Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-2185-2689

Анна Лихач

Доктор сільськогосподарських наук
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-0472-6162

Анотація. Важливим інструментом підвищення продуктивних ознак свиней, у тому числі кнурів є ретельне дослідження їх моделей поведінки і реакцій на відповідність умовам утримання, що слугує індикатором протоколу оцінки благополуччя даної статевої групи у комерційних свинофермах. Мета досліду полягала у виявленні впливу віку, сезону року і типу вентиляції на тривалість поведінкових актів кнурів у розрізі порід задля формування їх поведінкових патернів в умовах промислової технології. В експерименті задіяно 18 кнурів великої білої породи, породи ландрас та дюрок. Кнури, відібрані для дослідів, були клінічно здоровими і розділені на дві групи по 9 голів у кожній. Контрольна група кнурів утримувалася в приміщенні з поперечною системою вентиляції, а тварини дослідної групи – в умовах геотермальної подачі повітря протягом року. У процесі візуалізації показників поведінки кнурів різних порід встановлено, що: на тривалість відпочинку вірогідно ($P < 0,001$) впливають 49,1-67,6 % – вік, 10,9-23,2 % – сезон року, 0,1-3,0 % – тип вентиляції; на тривалість руху протягом доби вірогідно ($P < 0,001$) впливають 44,7-68,0 % – вік, 9,1-28,5 % – сезон року, 0,5-3,2 % – тип вентиляції; на тривалість прийому корму і води вірогідно ($P < 0,001$) впливають 49,7-71,9 % – вік, 7,9-25,9 % – сезон року, 0,1-2,4 % – тип вентиляції. Поведінковим актом, що переважав за тривалістю і частотою ($P < 0,001$), особливо у літньо-осінній період у кнурів спостерігався відпочинок, котрий за часом з віком збільшувався від 72,3 % до 76,4 %, незалежно від породи, сезону року і типу вентиляції. Влітку і восени за поперечної системи подачі повітря під час відпочинку у тварин візуалізувалася ненормальна апатична поведінка (лежання на боках, животі, із закритими очима, без жодних реакцій на індиферентні подразники, а час, який кнури витрачали на стереотипну поведінку (биття головою, стрибків і облизування грат решітки клітки) збільшувався на 3 % ($P < 0,95$) і перебували у позі «сидячої собаки» на 2 % ($P < 0,95$). Одержані результати дозволяють в умовах промислового свинарства запровадити використання етологічних факторів з метою підвищення спермопродукції кнурів, виявлення особин з відхиленнями поведінки для розробки способів оцінки благополуччя та інтеграції їх у виробництво

Ключові слова: свині; відпочинок; рух; прийом корму і води; благополуччя; трифакторний дисперсійний аналіз

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The area of loin eye in bulls of the Ukrainian Black-and-White dairy breed and its relationship with beef characteristics

Olga Kruk*
PhD in Agricultural Sciences
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-9975-8994

Anatoliy Ugnivenko
Doctor of Agricultural Sciences, Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-6278-8399

Abstract. The relevance of the work was to determine whether the loin eye area of *m. longissimus dorsi* as a criterion for evaluating the yield of high-value cuts from beef carcasses, is associated with beef characteristics from bulls of the Ukrainian Black-and-White dairy breed. The purpose of the study was to establish correlations between the loin eye area and the slaughter characteristics by the chemical composition, sensory, physical and technological properties of beef. The correlation between the cross-sectional area of the oblong muscle and slaughter indicators, the quality of carcasses, the chemical composition, sensory, physical and technological properties of beef was studied in the bulls of Ukrainian Black-and-White dairy breed (UBWDB) aged from 18 to 24 months. A linear correlation was established between the loin eye area and the slaughter weight ($r = 0.404$; $P > 0.95$), the amount of muscle tissue ($r = 0.355$; $P > 0.95$), including the highest ($r = 0.680$; $P > 0.999$) and the first ($r = 0.501$; $P > 0.99$) grades, the content of fat tissue in the carcass ($r = 0.477$; $P > 0.99$). The loin eye area correlated inversely ($r = -0.607$; $P > 0.95$) with t he amount lost in boiling beef, the amount of second-class muscle tissue ($r = -0.377$; $P > 0.95$), the development of subcutaneous fat ($r = -0.395$; $P > 0.95$), the total ash mass ($r = -0.560$; $P > 0.95$), the juiciness of boiled meat ($r = -0.522$; $P > 0.95$), taste and aroma of broth ($r = -0.587$; $P > 0.95$). There was a tendency for an inverse correlation between the loin eye area and the total fat content of beef ($r = -0.119$), protein

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*Corresponding author

(r = -0.401), dry matter (r = -0.403), acidity (r = -0.458), muscle tissue colour (r = -0.126), conformation (r = -0.127), penetration (r = -0.477), taste (r = -0.214) and aroma (r = -0.363) of boiled meat, tenderness (r = -0.256), residue after chewing (r = -0.442), the thickness of broth (r = -0.207), and to a linear correlation – with the amount of tendons and ligaments (r = 0.331), marbling (r = 0.162), the colour of fat tissue on the carcass (r = 0.276), transparency of the broth (r = 0.180). The practical significance of the data is to obtain knowledge that allows formulating marketing strategies for predicting food quality, quantity of premium and first-grade beef, its technological properties and intended use based on the correlation between the loin eye area of *m. longissimus dorsi*

Keywords: meat productivity; conformation; marbling; carcass quality traits; sensory characteristics of meat

Introduction

To improve food quality and consumer safety, it is important that the quantitative and qualitative characteristics of meat from Ukrainian cattle meet international standards. Beef of different cuts has different nutritional quality, since it varies under the influence of many factors, and affects the cost of products. It is technologically difficult to determine their number during the life of an animal. Therefore, it is relevant to establish methods for predicting the slaughter characteristics, chemical composition, physical, technological and sensory properties of beef from animals of common Ukrainian breeds by the area of the loin eye of *m. longissimus dorsi*.

The loin eye area is the cross-section of the oblong muscle between the 12th and 13th ribs, which is determined by dividing the carcass into quarters. As noted by A. Ugnivenko *et al.* (2022), the loin eye area of *m. longissimus dorsi* in cattle depends on the breed of animals. Thus, bulls of the Korean Hanvoo breed at the age of 30 months have an average loin eye area of 87.4 cm^2 (Bhuiyan *et al*., 2017), and Ukrainian meat cattle aged 22 months – 133.5 cm^2 (Ugnivenko *et al.,* 2022). Data on the loin eye area of *m. longissimus dorsi* is used to determine the optimal growth parameters of dairy cattle during their rearing for meat, determine the age and live weight for slaughter, and predict the resulting beef and its belonging to a certain variety through a direct connection with valuable carcass cuts. A linear positive correlation between the loin eye area of *m. longissimus dorsi* and pre-slaughter live weight and carcass weight were established by M.S.A. Bhuiyan *et al.* (2017) in bulls of the Hanvoo meat breed.

According to A. Ugnivenko *et al.* (2022), in Ukrainian beef cattle, the loin eye area of *m. longissimus dorsi* has a linear significant correlation with slaughter weight (r = 0.614; P > 0.95) and slaughter yield (r = 0.653; P > 0.95). This indicates a better effect on the development of muscle tissue in the carcass. Similar results were obtained (Naserkheil *et al.,* 2021; Piment-el-Concepción *et al.,* 2024) in studies of genetic correlations of the yield of primary cuts with qualitative features of the carcass and it was found that genetic correlations with the carcass weight and the loin eye area of *m. longissimus dorsi* were moderate to very strong; while low, moderate, and negative correlations were observed between primary cut characteristics with marbling and subcutaneous fat thickness. The relevance of these studies is also confirmed by G. Bittante (2023), since beef quality chartacteristics cannot be directly measured on live animals, unlike traits related to growth, productivity, and disease resistance, the study of

correlation of the loin eye area of *m. longissimus dorsi* with qualitative characteristics of beef would allow predicting its quality. Thus, with the same weight of carcasses and the content of fat tissue in them, an increase in the cross-sectional area of the oblong muscle indicates an increase in the yield of valuable cuts and a larger weight of steaks from them, which are the most profitable to sell. These are the features that manufacturers and processors are interested in.

According to I. Randhawa *et al.* (2021), consumers make their choices based on the nutritional value and sensory characteristics of beef. Therefore, A. Ugnivenko *et al.* (2022) determined of the relationship between the qualitative characteristics of beef and the loin eye area of *m. longissimus dorsi* in animals of the Ukrainian meat breed. It was found that there is a tendency to a weak inverse correlation (r = -0.193) between the cross-sectional area of the oblong muscle and the tenderness of meat, the content of dry matter in it (r = -0.345). The depth of the loin eye most correlates with the technological properties of beef. Data on the correlation between the loin eye area of *m. longissimus dorsi* with the qualitative characteristics of beef in animals of meat breeds is not enough to interpret dairy cattle. According to J. Soulat *et al.* (2022), the management approach that allowed for the best ratio between carcass and meat quality was intermediate rearing over a long fattening period, with the diet mainly based on hay and a high amount of concentrated feed. Such conditions allowed producing carcasses with a high conformation, smooth grain of meat, more uniform colour, darker and tastier meat, and low moisture content. The purpose of the study was to establish correlation relationships between the cross-sectional area of *m. longissimus dorsi* and slaughter characteristics, chemical composition, and qualitative characteristics of meat in bulls of the Ukrainian Black-and-White dairy breed, which is used in Ukraine both for the production of milk and beef.

Materials and Methods

The study was conducted on 34 bull carcasses at the "Zhuravushka" farming enterprise (FE) in the Brovary District, Kyiv Oblast. The animals were kept in groups of 25 units from birth to the age of 4 months. They were then reared and fattened to slaughter at the age of 18-24 months at the fattening facility based on their age. The farm's feed needs were met by its own fodder base. The bulls had free access to roughage, juicy, green, concentrated feed and mineral supplements, which were fed from the self-feeders in accordance with the developed rations. The cattle were slaughtered in the slaughterhouse in Kalynivka village following the Council Regulation (EC) No. 1099/2009 (2009). The animals were stunned with an electric current before exsanguination. Carcasses were suspended vertically on hooks by the fusion between the calcaneus bone and Achilles tendon. After evisceration, the carcasses were divided into halves and cleaned of excess fat and meat.

Carcasses were weighed and visually evaluated for conformation and subcutaneous fat development in accordance with the Commission Regulation (EC) system (2009). The conformation of carcasses was classified on a scale of 5 classes: from E (very high muscle development) to P (very low muscle development). Subcutaneous fat development was evaluated on a scale of 5 classes: from 1 (lean) to 5 (very fat). Next, the carcasses were sawn in half, and the half-carcasses were cut at the level of the 12th rib. The colour of muscle and fat tissue was determined using a 7-point scale, the marbling of meat was determined on a 12-point scale, and the thickness of subcutaneous fat on the carcass was measured between the 12th and 13th ribs in accordance with the JMGA method (2000). The length and depth of the loin eye were measured between the 12th and 13th ribs with a ruler (Fig. 1) immediately after dividing the half-carcasses into quarters.

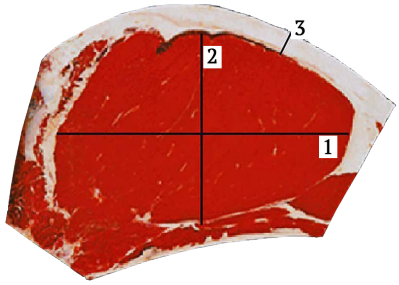

Figure 1. *Schematic division of bull carcasses into zones*
Notes: Length (1) and depth (2) of the loin eye, (3) subcutaneous fat thickness
Source: compiled by the authors

Its area was calculated in accordance with Order No. 290 "On Approval of the Instruction on Evaluation of Boars and Sows for the Quality of Offspring in Specialised Testing Stations" (2004) (equation 1):

$$S = a \times b \times 0{,}8; \quad (1)$$

where S – loin eye area, cm^2; a – loin eye length, cm; b – loin eye depth, cm; 0.8 – coefficient.

The penetration of raw meat was determined using an automatic penetrometer according to the method given in the paper (Guts & Koval, 2007). The content of bound moisture was studied by the "press method" by the amount of water that was released from the suspension of 0.3 g of crushed meat under the action of pressing and absorbed into the filter paper, forming a wet spot. The total area of the stain formed under the compressed meat and the released moisture absorbed by the filter paper was determined using a planimer. The difference between the total area of the spot and the occupied meat determined the area of the wet spot. The ability of meat to retain water was investigated by the content of bound water as a percentage of the weight of meat.

To determine the residual weight of beef after boiling down, rectangular pieces of meat weighing 150 g were cut out of *m. longissimus dorsi*. They were weighed on a THB-600 scale with an accuracy of 0.01 g. Next, they were placed in a 5-litre pot and 2-3 litres of cold distilled water were poured. The water was brought to a boil and cooked over low heat for 90 minutes. After cooking, the pieces were removed from the water, cooled to 20°C and weighed. The amount of meat lost in boiling was determined by equation (2) (Shkurin *et al.,* 2002).

$$Sm = \frac{Cm \times 100}{Rm}, \quad (2)$$

where Sm – amount lost in boiling of meat, %; Cm – weight of boiled down meat, g; Rm – weight of raw meat sample, g.

The chemical composition of beef was studied in the laboratory of the Department of Meat, Fish and Seafood Technology of the National University of Life and Environmental Sciences of Ukraine (NUBiP) in accordance with the methods described in Table 1.

Table 1. *Methods for determining the chemical composition of m. longissimus dorsi in bulls*

Studied indicators	Source
Total fat content	DSTU ISO 1443:2005 (2008)
Total ash weight	DSTU ISO 936:2008
Moisture content	DSTU ISO 1442:2005 (2008)
Protein	G.T. Shkurin *et al.* (2002)
Acidity (pH)	DSTU ISO 2917:2001 (2003)

Source: compiled by the authors

The characteristics of aroma, juiciness, tenderness, ease of chewing boiled beef, colour, taste, and strength of broth from it were determined by the tasting commission in the amount

of 8 people in the laboratory of "Meat quality" of the Department of Milk and Meat Production Technologies of the NUBiP of Ukraine.

The data were processed statistically using Microsoft Excel 2016 in combination with XLSTAT. They were evaluated using correlation coefficients calculated using appropriate methods (Osadcha, 2021). The correlation between the loin eye area and the above-mentioned quantitative and qualitative characteristics of all the studied carcasses and separately in the meat of 21-month-old bulls was calculated to compare the results obtained. The age difference in the group between them was up to 5%. Animal studies were conducted in accordance with the "General ethical principles for conducting animal experiments", approved by the First National Congress on Bioethics (Law of Ukraine No. 3447-IV "On the Protection of Animals from Cruelty", 2006), and the provisions of the "European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes" (1986).

Results and Discussion

In bulls aged 18 to 24 months and 21 months, a linear significant correlation was found between the loin eye area of *m. longissimus dorsi* and such traits as pre-slaughter live weight and carcass weight, the amount of muscle tissue, including the highest and first grades (Table 2), which mainly constitute the nutritional value of beef.

Table 2. *Correlation coefficients between the loin eye area of m. longissimus dorsi and slaughter characteristics and morphological composition of carcasses in bulls*

Indicator	Animal age at slaughter	
	from 18 to 24 months (n = 34)	including on the 21st month (n = 13)
Live weight after fasting	0.409*	0.650*
Carcass weight	0.404*	0.633*
Carcass yield	0.069	-0.285
Amount of muscle tissue	0.355*	0.524
including the highest grade	0.680***	0.811***
including first grade	0.501**	0.822***
including second grade	-0.377*	-0.367
Amount of fat tissue	0.477**	0.566*
Amount of tendons and ligaments	0.331	0.640*
Amount of bone tissue	0.049	0.160

Notes: *)P > 0.95; **)P > 0.99; ***)P > 0.99
Source: compiled by the authors

A positive insignificant correlation was established between the loin eye area and the amount of tendons and ligaments in the carcasses of 21-month-old bulls. As for the amount of bone tissue in the carcasses of experimental animals, there is no correlation.

There is also a tendency for a linear correlation between the cross-section of *m. longissimus dorsi* and the contents of tendons and ligaments in the carcass. There is practically no correlation between the number of bones in the carcasses of slaughtered animals and the loin eye area. This can be explained by the fact that the growth of muscle tissue (including *m. longissimus dorsi* an fat in the ontogenesis of cattle proceeds relatively faster, and the skeleton – slower, then the correlation between the area of the studied muscle and the content of bones is much lower. There is a reverse correlation (P > 0.95) between the cross-sectional area of *m. longissimus dorsi* and the amount of second-class beef, which has a significant amount of fat that

is not separated from the muscles during dressing. The obtained linear significant correlation coefficients between the loin eye area and quantitative characteristics of meat productivity on 21-month-old bulls better reflect the relationship between them than in the period from 18 to 24 months. Thus, the data obtained by the authors confirm the results of the study by V. Vinay-Vadillo *et al.* (2014), who reported that the loin eye area of *m. longissimus dorsi* can be used to predict the production of a certain amount of muscle tissue in the carcass, including by its belonging to the appropriate grade.

A similar relationship between the above-mentioned indicators was established in dairy breeds (Pogorzelska-Przybyłe *et al.,* 2014) and meat breeds (Ugnivenko *et al.,* 2022). So, according to R. Pogorzelska-Przybyłe *et al.* (2014), linear close correlation coefficients (r = 0.80) exist between the loin eye area of *m. longissimus dorsi* and the amount of muscle tissue in the carcasses of Holstein cattle, including the highest grade (r = 0.69). In animals of the Ukrainian meat breed, there is only a tendency to a positive relationship (r = 0.614) between the cross-sectional area of the oblong muscle, and the slaughter weight (carcass) and its output (r = 0.653).

The established linear significant correlation between the loin eye area and the slaughter weight (carcass), the amount of muscle tissue, including the highest and first grades, can be explained by the fact that the *m. longissimus dorsi* muscle is located mainly in the thoracic and lumbar regions, which are the most valuable cuts of carcass and its muscle tissue makes up a significant share. There is a linear significant correlation between the loin eye area and the total amount of fat tissue in the carcass. A similar correlation between the loin eye area of *m. longissimus dorsi* and the fat content in the carcass was also obtained by A. Oler *et al.* (2015).

Determining the correlation coefficients between the qualitative characteristics of beef carcasses evaluated in accordance with international standards, an inverse relationship was established between the loin eye area and the development of subcutaneous fat (Table 3).

Table 3. *Correlation coefficients between the loin eye area of m. longissimus dorsi and other qualitative features of bull carcasses*

Animal age at slaughter	Indicator					
	conformation	Subcutaneous fat development	Subcutaneous fat thickness	marbling	colour of muscle tissue	colour of fat tissue on the carcass
from 18 to 24 months (n = 34)	-0.127	-0.395*	-0.030	0.162	-0.126	0.276
including on the 21st month (n = 13)	0.301	-0.495	0.271	0.149	0.341	0.810***

Notes: *)P > 0.95; ***)P > 0.999

Source: compiled by the authors

There was only a tendency for a linear correlation between the cross-sectional area of *m. longissimus dorsi* and the colour of fat tissue in bulls from 18-24 months of age and a high correlation (P > 0.999) at 21 months. This can be explained by the significant content of feed rich in carotene – green (28.3%), silage (9.6), hay (8.6), haylage (4.7), and relatively small (18.5%) – concentrated. According to A. Clinquart *et al.* (2022), in cattle that were fattened

on concentrated feed without greens, subcutaneous fat had a more yellow colour. There is a tendency for both a weak inverse correlation in bulls aged 18 to 24 months and a linear correlation (in 21-month-old animals) between the loin eye area of *m. longissimus dorsi* and the thickness of subcutaneous fat, conformation, and muscle tissue colour. From 18 to 24 months, the growth rate of the longest muscle passes regardless of the fleshiness of carcasses, the thickness of subcutaneous fat, and the colour of beef.

This indicates that *m. longissimus dorsi* develops better with the worse fatness of carcasses. A. Oler *et al.* (2015) also proved that in the presence of a significant amount of subcutaneous fat, the slaughter yield (carcasses) and some of the edible parts in muscle tissue are reduced. That is, a greater development of subcutaneous fat on the carcass (its fatness) inhibits the development of the loin eye area of *m. longissimus dorsi*, and therefore, simultaneously reduces the number of valuable edible parts in it. In addition, (Kruk *et al.,* 2023) found that the best development of fat tissue under the skin does not correlate with the sensory characteristics of boiled beef and broth from it and water retention, penetration, and marbling. According to the obtained data, there is a linear weak correlation between the loin eye area of *m. longissimus dorsi* and marbling of meat, which does not guarantee its good sensory characteristics. The marbling of beef is the main factor determining its sensory quality (Sakowski *et al.,* 2022). According to T. O'Quinn *et al.* (2024), no factor has a more beneficial effect on the taste of beef than its marbling content.

In the study, there is no correlation between a certain loin eye area and the rate of water loss (Table 4). The water-binding capacity is influenced by glycolysis metabolism. It is closely related to the juiciness of beef. The lack of correlation between the loin eye area and the water-binding ability of beef affects its further technological processing, and the yield of the product made from it, which is important in cattle breeding, since the preservation of more meat during its preparation (boiling down) is an important feature. So, the technological feature of beef – boiling down – inversely correlates with the loin eye area, which indicates an increase in waste during cooking.

Table 4. *Correlation coefficients between the loin eye area of m. longissimus dorsi and technological features of beef in bulls*

Animal age at slaughter	Indicator		
	water binding capacity	boiling down	penetration
from 18 to 24 months (n = 15)	0.096	-0.607*	-0.477
including on the 21st month (n = 13)	0.015	-0.612*	-0.446

Notes: *)P > 0.95
Source: compiled by the authors

Therefore, the cross-sectional area of *m. longissimus dorsi* can be used as an indicator of boiling down of beef from bulls of the Ukrainian Black-and-White dairy breed, since it correlates with it inversely and significantly. The correlation coefficients between the cross-sectional area of *m. longissimus dorsi* and its penetration stress were average and inverse. With an increase in the loin eye area of *m. longissimus dorsi* in beef, the content of the main elements of its chemical composition decreased (Table 5). That is, evaluating carcasses for this trait does not imply an increase in important nutrients for human health.

Table 5. *Correlation coefficients between the loin eye area of m. longissimus dorsi and the chemical composition of beef*

Animal age at slaughter	Indicator					
	Acidity (pH)	moisture content	dry matter	protein	total fat content	total ash weight
from 18 to 24 months (n = 15)	-0.458	-0.086	-0.403	-0.401	-0.119	-0.389
including on the 21st month (n = 13)	-0.420	0.518	-0.519	-0.527	-0.245	-0.534

Notes: *)P > 0.95

Source: compiled by the authors

The correlation between the loin eye area and acidity, the amount of dry matter, protein content, and total ash weight is inverse and average, and between the loin eye area and the total fat content – weak. A trend towards an inverse correlation between the loin eye area of *m. longissimus dorsi* and the acidity of beef indicates that in meat with a larger cross-section of the loin eye, the pH decreases faster to normal (<5.8) and receives microbial stability earlier. Sensory evaluation of the juiciness, tenderness, taste, and aroma of boiled meat determined its acceptability for the consumer. By analysing the sensory properties, a detailed description of how boiled beef and its broth are perceived by the human senses was provided.

However, G.A. Ferreira *et al*. (2024) conducted a study in Brazil to assess the perception of beef with different pH values. It was found that beef consumers do not devalue steaks in terms of its freshness even at pH⩾6.0. The chemical composition of beef depends on the type of breed productivity, the age of animals at slaughter (Hoa *et al.,* 2022), type of muscle and fat tissue (Vázquez-Mosquera *et al.,* 2023). The results of evaluating the sensory characteristics of boiled meat conducted by a group of tasters from 8 people are shown in Table 6. In bulls aged from 18 to 24 months, an inverse significant correlation was established between the loin eye area of *m. longissimus dorsi* and the juiciness of beef. The correlation between the cross-sectional area of the muscle and the taste, aroma, tenderness, and residue after chewing cooked meat was reverse and weak.

Table 6. *Correlation coefficients between the loin eye area of m. longissimus dorsi and sensory properties of beef*

Animal age at slaughter	Sensory characteristics of cooked meat					
	juiciness	taste	aroma	tenderness	residue after chewing	average values for 5 tasting indicators
from 18 to 24 months (n = 15)	-0.522*	-0.214	-0.363	-0.256	-0.442	-0.371
including on the 21st month (n = 13)	-0.457	-0.072	-0.176	-0.092	-0.275	-0.210

Notes: *)P > 0.95

Source: compiled by the authors

An inverse significant correlation between the sensory properties of beef and muscle tissue growth was established by I. Albechaalany *et al.* (2024). A number of factors had a negative impact on the results of the tasters' evaluation of boiled beef from the loin eye area of

m. longissimus dorsi. The main reason for the inverse relationship between the development of the loin eye area of *m. longissimus dorsi* and the sensory properties of beef is the weak inverse correlation between this trait and the total fat content in muscle tissue, and the direct correlation with the marbling of meat. According to A. Listrat *et al.* (2020), juiciness, which has a positive effect on the quality of beef consumption and which in the mouth is characterised by the amount of juice during chewing, also closely correlates with the fat content inside muscles. Increasing the area of the loin eye of *m. longissimus dorsi* partially contributes to the reduction of a valuable technological property – the tenderness of meat. Optimal distribution of total fat content inside muscle tissue can improve the tenderness of beef. V. Bulgaru *et al.* (2022) found that tenderness is significantly affected by the content of soluble proteins, fats, and collagen. Increase in the diameter of muscle fibres, due to which the loin eye area of *m. longissimus dorsi* increases, can be one of the main reasons for the deterioration of beef tenderness.

Results of the studied correlation coefficients between the loin eye area of *m. longissimus dorsi* in bulls and the signs of tasting beef broth are presented in Table 7. The linear positive correlation ($r = 0.587$; $P > 0.95$) between the loin eye area and the taste and aroma of broth was affected by feeding the bulls a significant amount of green, coarse, and juicy feed.

Table 7. *Correlation coefficients between the loin eye area of m. longissimus dorsi and sensory characteristics of beef broth in bulls*

Animal age at slaughter	Broth tasting indicators			
	taste and aroma	strength	transparency	average values
from 18 to 24 months (n = 15)	0.587*	-0.207	0.180	-0.057
including on the 21st month (n = 13)	0.594*	-0.161	0.215	0.018

Notes: *P > 0.99

Source: compiled by the authors

There is a tendency for a relatively weak inverse correlation between the loin eye area of *m. longissimus dorsi* and the strength of the broth. The inverse relationship between the loin eye area and the strength of the broth was conditioned by the fact that with a decrease in the content of dry matter, protein, total fat, and total ash in the muscles, fat diffuses less from the endomysium and pericardium cells into the boiled water, and less proteins, extractives, and mineral salts are transferred to the broth.

Thus, the qualitative trait of carcasses – the loin eye area of *m. longissimus dorsi* in bulls of the Ukrainian Black-and-White dairy breed aged 18 to 24 months – is directly correlated with the slaughter characteristics, the weight of muscle tissue, including the highest and first grades, and the weight of fat tissue in the carcass. There is a tendency to worsen the chemical composition of muscle tissue with an increase in the size of the loin eye. The bone content in animal carcasses did not correlate with the cross-sectional area of the long back muscle. Assessing correlation coefficients between the lin eye area of *m. longissimus dorsi* with the qualitative characteristics of beef carcasses evaluated in accordance with international standards, there is a tendency for both weak inverse and linear relationships with their conformation, the development of subcutaneous fat and its thickness, colour and marbling of muscle tissue. Comparison of results with data from literature sources on correlations between the loin eye area of *m. longissimus dorsi* and the animal slaughter indicators, technological and sensory properties of meat from animals of

different breeds in most cases coincide. This indicates the possibility of using this method to predict the composition of carcasses and the sensory and technological properties of beef.

Among the characteristics of carcasses, an increase in the loin eye area of *m. longissimus dorsi* indicates only an increase in quantitative characteristics of muscle tissue yield in cuts, including those of the highest and first grades. It has no correlation with the moisture retention capacity of meat, which determines the technological quality of many meat products during thermal (boiling) processing.

Since the loin eye area of *m. longissimus dorsi* has a linear correlation with the quantitative characteristics of beef, rather than sensory characteristics that depend on the chemical composition, including the content of total fat in the middle of the muscle, in many countries of the world, the loin eye area is supplemented by the severity of meat marbling when assessing the quality of cattle carcasses. Thus, beef marbling is determined in the carcass quality assessment systems of the USDA (2001), JMGA (2000) and MSA (2015). In Ukraine, the demand for low-fat and biologically complete beef is growing. Such meat in the required amount is obtained from animals of the Ukrainian Black-and-White dairy breed. The biological feature of this cattle is that the beef from it is lean. At the age of 21 months, bulls of this breed have a mid-muscle fat content of only 2.6%. The curved relationships between meat tenderness, juiciness, taste, and muscle fat scores are aligned with its content of 15 to 17% (Thompson, 2004). Such cattle respond to satisfactory feeding with a significant growth of muscle tissue and late accumulation of fat. Since the quality characteristics of carcasses compared to beef quality are more sensitive to changes in animal husbandry management, J. Soulat *et al.* (2022) suggest that the same quality of carcasses or meat can be achieved under different conditions of keeping. According to R. Leighton *et al.* (2023), relying solely on their estimates by trained individuals may provide limited insight. Therefore, the findings of these researchers indicate that it is possible to manage the quality of carcass and beef using various methods of breeding, feeding, and housing. For Ukraine, it is currently important to develop ways to simultaneously improve the quantitative and qualitative characteristics of beef from animals of common breeds in the country.

Conclusions

Development of the loin eye area of *m. longissimus dorsi* in Ukrainian Black-and-White bulls aged from 18 to 24 months does not allow predicting the content of only quantitative characteristics in beef: slaughter weight (carcass), number of cuts of the highest and first grades, the content of fat tissue and tendons and ligaments in the carcass, but not qualitative characteristics, including sensory and physical characteristics, chemical composition of meat.

There is a direct correlation between the loin eye area and the pre-slaughter live weight of animals ($r = 0.409$; $P > 0.95$), the slaughter weight ($r = 0.404$; $P > 0.95$), the amount of muscle tissue ($r = 0.355$; $P > 0.95$), including the highest ($r = 0.680$; $P > 0.999$) and the first ($r = 0.501$; $P > 0.99$) grades, the content of fat tissue in the carcass ($r = 0.477$; $P > 0.99$); the data obtained confirm the possibility of using the cross-sectional area of the transverse muscle to predict the production of beef of a certain variety. The loin eye area of *m. longissimus dorsi* correlates inversely ($r = -0.607$; $P > 0.95$) with the amount lost when boiling beef, an important technological indicator, the amount of second-class muscle tissue ($r = -0.377$; $P > 0.95$), the development of subcutaneous fat ($r = -0.395$; $P > 0.95$), which protects the carcass from the penetration of pathogenic microflora, weathering and drying, affects the juiciness and tenderness of beef, the total weight of ash ($r = -0.560$; $P > 0.95$), juiciness of boiled meat ($r = -0.522$; $P > 0.95$), taste and aroma of broth ($r = -0.587$; $P > 0.95$). There is a tendency for an inverse correlation between

the loin eye area and the total fat content in beef (r = -0.119), protein (r = -0.401), dry matter (r = -0.403), acidity (r = -0.458), colour of muscle tissue (r = -0.126), conformation (fleshiness) of carcasses (r = -0.127), penetration (r = -0.477), taste of cooked meat (r = -0.214), its aroma (r = -0.363), tenderness (r = -0.256), the residue after chewing (r = -0.442), the strength of the broth (r = -0.207), and to a linear relationship – the amount of tendons and ligaments (r = 0.331), marbling (r = 0.162), colour of fat tissue on the carcass (r = 0.276), transparency of the broth (r = 0.180). In the future, a study should be conducted to determine the management factors for raising and fattening animals of other breeds of cattle common in Ukraine, the correlation between the loin eye area of *m. longissimus dorsi* and quantitative and qualitative characteristics of beef, and to substantiate the qualitative characteristics of carcasses that would be combined with sensory, physical and technological properties evaluated with the participation of consumers.

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None.

Conflict of Interest

None.

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Площа «м'язового вічка» бугайців української чорно-рябої молочної породи та її взаємозв'язок з ознаками яловичини

Ольга Крук

Кандидат сільськогосподарських наук
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-9975-8994

Анатолій Угнівенко

Доктор сільськогосподарських наук, професор
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-6278-8399

Анотація. Актуальність роботи полягала у необхідності визначення, чи площа «м'язового вічка» *m. longissimus dorsi*, як критерій оцінювання виходу високоцінних відрубів з яловичих туш пов'язаний із ознаками яловичини від бугайців української чорно-рябої молочної породи. Метою дослідження було встановити кореляції між площею «м'язового вічка» та ознаками забою хімічним складом, сенсорними і фізико-технологічними властивостями яловичини. У бугайців української чорно-рябої молочної породи (УЧМП) віком від 18 до 24 місяців дослідили кореляцію між площею поперечного перерізу продовгуватого м'яза та ознаками забою, якості туш, хімічним складом, сенсорними, фізичними та технологічними властивостями яловичини. Установлено прямолінійну кореляцію між площею «м'язового вічка» і забійною масою (r = 0,404; P > 0,95), кількістю м'язової тканини (r = 0,355; P > 0,95), у т. ч. вищого (r = 0,680; P > 0,999) та першого (r = 0,501; P > 0,99) сортів, вмістом жирової тканини у туші (r = 0,477; P > 0,99). Площа «м'язового вічка» корелювала зворотньо (r = -0,607; P > 0,95) з уварюванням яловичини, кількістю м'язової тканини другого сорту (r = -0,377; P > 0,95), розвитком жиру-поливу (r = -0,395; P > 0,95), загальною масою золи (r = -0,560; P > 0,95), соковитістю вареного м'яса (r = -0,522; P > 0,95), смаком і ароматом бульйону (r = -0,587; P > 0,95). Проявлялася тенденція до зворотньої кореляції між площею «м'язового вічка» та загальним вмістом жиру у яловичині (r = -0,119), протеїну (r = -0,401), сухої речовини (r = -0,403), кислотністю (r = -0,458), кольором м'язової тканини (r = -0,126), конформацією (r = -0,127), пенетрацією (r = -0,477), смаком (r = -0,214) і ароматом (r = -0,363) вареного м'яса, ніжністю (r = -0,256), залишком після розжовування (r= -0,442), міцністю бульйону (r = -0,207), та до прямолінійного зв'язку – із кількістю сухожилок і зв'язок (r = 0,331), мармуровістю (r = 0,162), кольором жирової тканини на туші (r = 0,276), прозорістю бульйону (r = 0,180). Практичне значення даних полягає в отриманні знань, які дозволяють формувати маркетингові стратегії прогнозування якості продуктів харчування, кількості яловичини вищого та першого сортів, її технологічні властивості і призначення для використання за урахування кореляційних зв'язків між площею «м'язового вічка» *m. longissimus dorsi*

Ключові слова: м'ясна продуктивність; конформація; мармуровість; якісні ознаки туш; сенсорні характеристики м'яса

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Assessment of heavy metal contentin water bodies of Zhytomyr Oblast

Nataliia Mosiienko*

Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03040, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0009-1941-5007

Nataliia Rudyk-Leuska

PhD in Biological Sciences, Associate Professor
Head of the Department of Hydrobiology and Ichthyology,
National University of Life and Environmental Sciences of Ukraine
03040, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-4355-7071

Alina Makarenko

PhD in the Field of Water Resources and Aquaculture
National University of Life and Environmental Sciences of Ukraine
03040, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-2166-8566

Anatoliy Polishchuk

Doctor of Agricultural Sciences, Professor
Poltava State Agrarian University
36003, 1/3 Skovorody Str., Poltava, Ukraine
https://orcid.org/0000-0003-3572-8491

Mykhailo Leuskyi

Assistant at the Department
National University of Life and Environmental Sciences of Ukraine
03040, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-5646-8524

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*Corresponding author

Abstract. Pollution of water bodies with heavy metals can lead to the death of fish and other aquatic organisms, a decrease in biodiversity and a threat to ecosystems, emphasising the importance of preserving the natural environment; pollution of water bodies can have serious economic consequences, in particular, a decrease in profits from fishing, tourism, and other activities related to water use, which requires the development of water management strategies. The purpose of the study was to determine the general trends in the content of heavy metals in the surface waters of the Teteriv River and fattening pond No. 1 of the LLC "SHF INTERRYBHOSP". Water samples were taken at the stream of the Teteriv River (Vidsichne Reservoir) and in the fattening pond No. 1 at a depth of 0.2-0.5 m from the surface for further laboratory analysis of the content of heavy metal ions (HM). The atomic absorption method of analysis was used to study water. Laboratory studies of surface waters in the Teteriv River and pond were performed according to the following indicators: hydrogen index (pH), lead, cadmium, manganese, zinc, and iron content. The results of the study of the content of heavy metals in the Teteriv River are presented, which showed that the content of such heavy metals as: Pb, Cd, Mn, Zn and Fe, in river water, with the exception of iron, exceed the limits of maximum admissible values of water quality indicators for fishery water bodies. Background HM indicators from fattening pond No. 1 did not show an excess of the MAC (maximum admissible concentration). High concentrations of lead, cadmium, manganese, and iron are explained by powerful anthropogenic pollution, the source of which is agricultural and industrial complexes of Zhytomyr Oblast. The results can be used to establish effective monitoring of water quality in reservoirs and develop strategies to reduce pollution in aquatic ecosystems

Keywords: water environment; aquatic organisms; background indicators; pollution; rivers

Introduction

Rivers perform various ecological functions, such as water transport, ecotourism, aquaculture, and influence the restoration of ecological balance (Ali *et al*., 2022). The studies by V. Aghadadashi *et al.* (2019), L.M. Cai *et al.* (2019) and M. Hossain *et al*. (2020) found that heavy metals (HM) such as lead, cadmium, mercury, chromium, nickel, etc., can accumulate in biological systems and be toxic even at low concentrations. Heavy metals pose a serious environmental threat to living organisms and aquatic ecosystems due to their inability to decompose, bioaccumulate, environmental stability, persistence, and biotoxicity. According to Y. He *et al.* (2019), HMs affect the physical and chemical properties of sediment and water, inhibiting microbial activity after release from the source. The study by M. Lian *et al*. (2019) indicates that HMs are harmful to the ecological environment through the food chain and have acute and chronic effects on the human body. Studies conducted by M.J. Kang *et al*. (2019) and H.E. Nour *et al*. (2019) confirm that HMs that do not decompose accumulate and remain in surface sediments for a long time, causing numerous diseases and complications in the human body.

Natural activities (e.g. geological weathering, precipitation, wave erosion, wind and bioturbation) and anthropogenic activities (e.g. rapid industrialisation, urbanisation, and agricultural runoff) play a key role in the spread of HMs in aquatic ecosystems such as rivers. In addition, human activity, which can cause industrial emissions, household waste generation, and extensive use of chemical fertilisers and pesticides, contributes to the accumulation and deposition of HMs in the surface sediments of aquatic ecosystems – this was confirmed by P.K. Lee *et al*. (2019), J. Rinklebe *et al*. (2019). Water quality is negatively affected

by HMs entering the water column, and surface sediments that change environmental parameters such as pH, temperature, salinity, etc.

The use of water resources is usually accompanied by a deterioration in their quality due to anthropogenic stress. This is manifested not only in changes in the physical and chemical composition of waters, but also in the quantitative and qualitative characteristics of aquatic organisms inhabiting reservoirs and watercourses. Rivers experience different anthropogenic loads depending on economic activity in the regions. This can include exhausting water abstraction for the needs of the population and households, discharge of wastewater from enterprises and housing and communal services, use of rivers as navigable arteries, construction of hydraulic engineering structures, etc. (Mosiienko, 2022a).

Considering the described events, the relevance of assessing the content of heavy metals in the surface waters of the Teteriv River is confirmed. The discharge of untreated wastewater containing heavy metals into the Teteriv River channel results in the saturation of water environment and aquatic life with toxic substances. The harmful effects of toxic HMs cover not only water, but also aquatic organisms and people who constantly use water and fish for food. Therefore, practical studies were conducted in the context of assessing the content of heavy metals in water and their impact on aquaculture.

Materials and Methods

The study was conducted in 2023, the water temperature of the Teteriv River at the time of sampling was +18°C, and the hydrogen index (pH) – 7.70 units. The water temperature from the pond was +16°C, the hydrogen index (pH) – 7.38 units. The object of the study was the surface waters of the Teteriv River and the surface waters of the fattening pond No. 1.

Water sampling was carried out according to the generally accepted method (Arsan *et al*., 2006). Samples were collected at the stream of the Teteriv River (Vidsichne Reservoir), 2.5 km downstream of Zhytomyr, and in the fattening pond No. 1. Random elements (the surface layer of water with random pollutants) were excluded during the selection process. Samples were taken below the surface layers (0.2-0.5 m) using a wide-mouth beaker with a rod. The volume of the water sample was 2 litres. The main sample was taken in plastic bottles. The main condition for taking water samples was clean dishes. The dishes were thoroughly washed in advance with a chromium mixture (0.3 n solution of potassium bichromate in concentrated sulphuric acid) and rinsed with tap water, after which they were washed at least three times with distilled water and dried in a drying cabinet. The same applied to plugs. Before taking the sample, the dishes were rinsed several times with water that was taken for analysis. Each water sample was labelled with the place, time, depth, sampling horizon, temperature, and the name of the person who took the sample.

The research was conducted in the Measurement Laboratory of the Educational and Scientific Centre for Ecology and Environmental Protection, located at the Polissia National University. Laboratory studies of surface waters in the Teteriv River were performed according to the following indicators: hydrogen index (pH), lead, cadmium, manganese, zinc, and iron content. A portable DLS-02 pH meter was used to determine the hydrogen index (ph). Before measuring, the electrode was first washed with distilled water, and then with test water, and only then immersed in the sample. Before immersion of the electrode, a sample of water was mixed so that its composition on the surface of the electrode corresponded to the general composition. In addition, a WSD-12 thermometer was immersed in the sample together with the electrodes to measure the temperature.

Samples were analysed for heavy metal content in accordance with the methods (Pupyshev, 2014) using atomic absorption

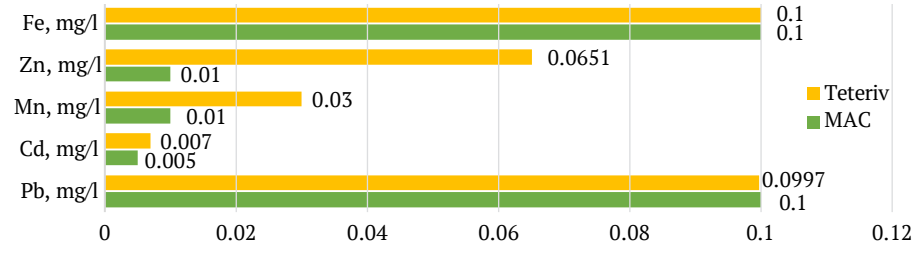
spectrophotometry (AAS) on the C-115M1 instrument. The atomic absorption method was used for water analysis, as this method has a high sensitivity of element determination, allows conducting an analysis with a high salt content, can be used in the emission mode, is highly reliable, has an automatic gas system, a light optical system, displays information on a digital indicator in units of optical density or concentration, and has electrothermal atomisation at a speed of 3-4 minutes. Statistical data analysis and chart generation were performed in the Statistica and Microsoft Excel software suites.

Results and Discussion

The Teteriv River, a right-bank tributary of the Dnipro, stretches for 365 km and has a water intake area of 15,100 km². Its water regime mainly depends on meltwater, which leads to high spring floods and low summer-autumn low water, which are often disturbed by short-term rain floods. Geographically, the Teteriv basin is located on the territory of the Ukrainian Shield and its slope, which extends into the Dnipro-Donetsk depression. This led to a higher hypsometric position of the river in comparison with other areas of the Ukrainian Polissia, and to the appearance of narrow and deeply embedded river valleys and a small number of swamps (only 4.5% of the total area of the river basin). The soil cover of the basin includes northern chernozems in the upper reaches and podzolic soils in the middle and lower reaches (Kuzminchuk & Shcherback, 2004).

Many studies have been conducted on anthropogenic contamination of river waters with both biogenic elements and surfactants (synthetic surfactants), pesticides, etc. Most of these studies were directly related to basins of big (for example, Dnipro, Dnister) (Strokal & Kovpak, 2021; Skyba *et al.*, 2023), small (Bosak *et al.*, 2020; Nahaieva *et al.*, 2020), and medium-sized rivers in various regions (Loboda & Kuza, 2023; Ukhan & Osadcha, 2023). However, the topic of analysing water pollution in the Zhytomyr Oblast remained rather neglected.

The analysis of the surface waters of the Teteriv River revealed that the background values of HMs were either at the MAC level or above the admissible values (Fig. 1). Lead and its compounds are essential components of surface waters and significantly affect their quality and functioning (Makarenko *et al.*, 2021). Many of these compounds are known for their mutagenic and carcinogenic properties. Lead enters rivers through wastewater from metallurgical and chemical enterprises, and as a result of coal burning, which was confirmed by M. Clarholm & U. Skyllberg, (2013), A.M. Iordache *et al.* (2022); K. Mashkova *et al.* (2022).



	Pb, mg/l	Cd, mg/l	Mn, mg/l	Zn, mg/l	Fe, mg/l
Teteriv	0.0997	0.007	0.03	0.0651	0.1
MAC	0.1	0.005	0.01	0.01	0.1

Figure 1. Comparison of HM concentrations in the water of the Teteriv River (Vidsichne Reservoir) with the MAC

Source: developed by the author

Based on the results of research, it can be noted that the background indicator of lead in the surface waters of the Teteriv River, which affects the activity of certain enzymes and intercellular communication in aquatic organisms, corresponded to the MAC and amounted to 0.0997 mg/l.

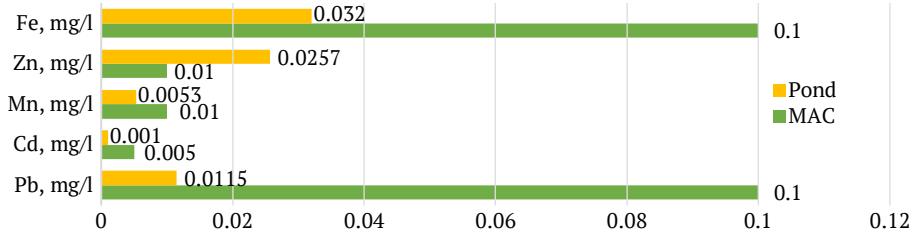
Cadmium in nature is mainly found in zinc and lead ores. It often enters water bodies as part of industrial wastewater from lead-zinc plants, chemical industry enterprises, ore processing facilities and metallurgical plants. The cadmium content did not significantly exceed the maximum admissible concentration of 0.007 mg/l, but this poses risks for structural and functional changes in the gills, intestines, liver and kidneys, stagnation and swelling of blood vessels in fish.

Manganese is one of the biologically active metals involved in the reactions of water photolysis and photosynthesis. The most common sources of manganese in a water body are iron and manganese ores, wastewater from metallurgical plants, water discharged from chemical plants, and mine water. In addition, one of the sources of manganese intake is organic residues that remain after the death of aquatic organisms and higher aquatic plants (Makarenko *et al.*, 2021; Mashkova *et al.*, 2022). Excess of manganese – 0.03 mg/l according to the results of laboratory tests, can affect the haematopoietic organs, which negatively affects the haemolytic parameters of fish blood.

Zinc, in terms of concentration in surface fresh waters, ranks second after manganese. The main source of zinc intake in water bodies are the processes of rock destruction. Since zinc is a biogenic metal, it is actively absorbed by aquatic plants and participates in photosynthesis. Zinc is a vital metal, but it can be toxic to fish, causing structural damage that affects growth, development, behaviour, and survival, as noted by O. Prokopchuk & V. Hrubinko (2016) and A. Makarenko *et al.* (2021). The content of zinc exceeded the maximum admissible concentration and amounted to 0.0651 mg/l, its intake in the Teteriv River could have occurred as a result of untreated wastewater from a pulp and paper mill and a cardboard factory. The accumulation of zinc, unlike other metals, is associated with its geochemical mobility.

Iron is one of the most common elements, but its concentration in natural waters is extremely low due to its limited migration capacity. It plays an important role in the vital activity of aquatic organisms and is largely absorbed by them. Iron deficiency can cause a number of diseases or even lead to death. Iron mainly comes from agricultural complexes located near the river, namely through drains (Rabcheniuk, 2016). The background iron index corresponded to the MAC of 0.1 mg/l, but was at the limit, which makes water of little use for the life of aquatic organisms. The results of the study confirm the assumption about the unsatisfactory state of water in the Teteriv River, and as a result, its harmful effect on aquatic organisms.

According to the results of laboratory studies, the background indicators of lead, cadmium, manganese, zinc, and iron in the water from fattening pond No. 1 did not exceed the maximum admissible concentration (MAC), in contrast to the background HM indicators in the Teteriv River. The maximum admissible concentration of heavy metals in fattening pond No. 1 indicates compliance with the technological requirements of ponds (Fig. 2).The analysis of the obtained concentrations of heavy metals in the reservoir shows that the content of some of them in the Teteriv River exceeded the MAC, which caused a violation of the ecological balance. After analysing the literature sources, it can be concluded that insufficient attention has been paid to studies of the content of heavy metals in the reservoirs of the Zhytomyr Oblast. There are fragmentary data from similar studies.



	Pb, mg/l	Cd, mg/l	Mn, mg/l	Zn, mg/l	Fe, mg/l
Pond	0.0115	0.001	0.0053	0.0257	0.032
MAC	0.1	0.005	0.01	0.01	0.1

Figure 2. Comparison of HM concentrations in water from the fattening pond No. 1 with MAC
Source: developed by the authors

The research was conducted during the period from 2006 to 2011 on the territory of the Polissia part of the Zhytomyr Oblast. The object of the study was the water of 13 small rivers. In the rivers of Zhytomyr Polissia, which mainly flow within the Ukrainian Shield, the water during the summer-autumn low-water period contained small concentrations of heavy metals, such as copper (Cu), cadmium (Cd), lead (Pb), zinc (Zn), Cobalt (Co), and nickel (Ni). However, there is an exception for manganese (Mn) and iron (Fe), whose concentrations exceed the maximum admissible values by 1.2-6.8 times and 1.5-12.3 times, respectively. This is conditioned by natural factors, such as the conversion of primary minerals to secondary ones, which leads to the release of iron and manganese compounds. In addition, iron and manganese can be washed out of iron-manganese nodules, which are often contained in the iluvial horizon of sod-podzolic soils in the study area, which was established by T.M. Myslyva & I.S. Kot (2011). The highest content of manganese, namely 0.63-0.68 mg/dm^3, was observed in the Zlobych and Irshytsya rivers. As for iron, the highest values, namely 2.12-3.71 mg/dm^3, were recorded in the Zheriv and Zlobych rivers.

In Korostyshiv District, the main water polluters of the Teteriv River are the Korostyshiv Municipal Utility Company "Vodokanal", which discharged 353.9 thousand m^3 of wastewater into water bodies in excess of the MAC, and the Korostyshiv Distillery. General and specific indicators were selected to assess the water quality of the Teteriv River. The research was conducted during 2010-2013. It was found that the manganese content significantly exceeded the norm. The highest value of this indicator was recorded in 2013, which was 0.068 mg/dm^3. The lowest rates were recorded in 2012, which amounted to 0.022 mg/dm^3. The study by N.S. Bordiug & L.M. Kostrytsia (2014) found that the iron content in the water of the Teteriv River in the Korostyshiv District exceeded the established MAC, which is a consequence of anthropogenic impact. In 2010, the highest concentration of it was detected, which was 0.47 mg/dm^3. It was found that in 2012, its content sharply decreased to the lowest value for the entire study period – 0.3 mg/dm^3.

When conducting studies of the Teteriv River within the Radomyshl District of Zhytomyr Oblast from 2006 to 2015, a sharp increase in the concentration of manganese was detected, in particular in 2014 and 2015, when its content in water was 7.3 and 8.8, compared to this, in 2008 the lowest value was observed, only 1.4 in MAC units. As for iron, the maximum content in general was recorded in 2008, when the indicator was 4.9 in MAC units. Instead, the lowest values were recorded in 2007 and 2015, when iron concentrations were 3.1 and 3.6 in MAC

units, respectively, as established by G.M. Marteniuk (2013). According to the data obtained, the concentration of manganese and iron in the rivers of Polissia exceeds the maximum admissible concentration by 2-12 times and 2-10 times, respectively.

In 2021, the Teteriv River, which is a source of water supply for Zhytomyr Oblast, experienced an eco-disaster due to extremely low precipitation, which led to a critical drop in the water level. Residents have about 1-1.5 months of water supply left. Over the past two years, the Teteriv River has been suffering from a large amount of untreated sewage entering it. Zhytomyr Oblast has a significant industrial and agricultural complex, which are often sources of pollution of water bodies, in particular the Teteriv River. According to the ecological certificate, there are 11 enterprises in the Zhytomyr Oblast that are the most polluting and have a negative impact on the region's water resources (Mosiienko, 2022). Zhytomyr Thermal Insulation Plant, Zhytomyr Cardboard Factory, PJSC Beer-Non-Alcoholic Plant "Radomyshl", PJSC "Bio Med Sklo", LLC "Cersanit Invest", PJSC "Ushitsky Construction Materials Plant", PJSC "Pershotravensk Electrotechnical Porcelain Plant" and other facilities are environmentally hazardous and can cause pollution of water basins in this region.

In 2021, the amount of conditionally clean non-treated return water discharged increased by 3.2% compared to 2020. The municipal enterprise of Zhytomyr in 2021 and in 2022 more than once discharged untreated wastewater from a sewage pumping station containing excess MAC of heavy metals in surface, return, and wastewater. As a result of the discharge in 2021, almost 120,000 m^3 of untreated wastewater entered the river basins of the Zhytomyr Oblast, which led to massive fish death, with more than 15,000 fish specimens dying. The water contained 4 times the normal amount of lead, 3 times the normal amount of phosphate, and 5 times the normal amount of nickel and nitrate, which led to a massive fish death. Among the aquatic inhabitants of the Teteriv River, which suffered the most destructive effects of heavy metals, were the silver carp *(Hypophthalmichthys molitrix)*, common carp *(Cyprinus carpio)*, northern pike *(Esox lucius)*, European perch *(Perca fluviatilis)*, etc. These fish species are most sensitive to increased toxicity in the aquatic environment. In August 2022, an oxygen deficiency was recorded in the Vidsichne Reservoir, and an excess of the concentration of manganese by 2.7 times and iron by 12.3 times, compared to the admissible values. Pollution of aquatic ecosystems poses a serious threat to the ichthyofauna, and can also lead to an excess of pollutants in fish products, which poses a risk to human health (Mosiienko, 2022b). Fish play a key role in aquatic ecosystems, occupying the upper trophic level. It is an important chain in maintaining the ecological balance of aquatic environments. However, through bioaccumulation and biomagnification processes, fish can accumulate pollutants, including heavy metals, from the water or from the living organisms it consumes. This creates a serious risk to the health of the person who consumes such fish. Therefore, it is important to control the level of pollution of water bodies and take measures to preserve their environmental integrity.

Conclusions

According to the results of the study, the background level of lead in the surface waters of the Teteriv River met the MAC and was 0.0997 mg/l. The cadmium content did not significantly exceed the MAC of 0.007 mg/l. The results of laboratory tests revealed an excess of manganese of 0.03 mg/l. The zinc content exceeded the MAC and amounted to 0.0651 mg/l. The background iron level met the MAC of 0.1 mg/l, but was at the limit. Studies confirm the assumption of an unsatisfactory state of water in the Teteriv River. This can lead to a decrease in the number and diversity of aquatic life, including fish, invertebrates, and algae; disrupt the natural

balance of the ecosystem and cause a decrease in biodiversity.

The results of laboratory tests show that the background values of lead, cadmium, manganese, zinc, and iron in the test water from the fattening pond No. 1 did not exceed the maximum admissible concentration (MAC). Low levels of heavy metals in the water indicate that water from fattening pond No. 1 is safe for human consumption and use. It can be assumed that as a result of the armed aggression against Ukraine, agriculture has suffered heavy losses and reduced its capacity, but still remains one of the key economic sectors of Ukraine. The anthropogenic impact on the Teteriv River channel was established. The activities of enterprises and agriculture lead to an increase in the accumulation of heavy metals in water, so it is recommended to establish measures to reduce the anthropogenic load on the ecosystem of the Teteriv River.

The study highlights the need for measures to prevent further pollution of the region's river systems. In particular, these measures include: establishing systematic control over the use of water by enterprises and organisations, and monitoring the discharges of industrial and agricultural waste; increasing attention to issues related to the prevention of pollution and salinisation of surface and underground waters; conducting experimental studies of the content of heavy metals. These measures focus on preserving and protecting the region's water resources and ensuring an environmentally friendly environment for aquatic life.

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Conflict of Interest

None.

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Оцінка вмісту важких металів у водоймах Житомирської області

Наталія Мосієнко
Здобувач PhD
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0009-1941-5007

Наталія Рудик-Леуська
Кандидат біологічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-4355-7071

Аліна Макаренко
Кандидат наук у галузі водних ресурсів та аквакультури
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-2166-8566

Анатолій Поліщук
Доктор сільськогосподарських наук, професор
Полтавський державний аграрний університет
36003 вул. Сковороди, 1/3, м. Полтава, Україна
https://orcid.org/0000-0003-3572-8491

Михайло Леуський
Асистент кафедри
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-5646-8524

Анотація. Забруднення водойм важкими металами може призвести до загибелі риби та інших водних організмів, зменшення біорізноманіття та загрози екосистемам, що підкреслює важливість збереження природного середовища; забруднення водних об'єктів може мати серйозні економічні наслідки, зокрема зниження прибутку від рибальства, туризму та інших діяльностей, пов'язаних з використанням води, що вимагає розробки стратегій управління водними ресурсами. Мета роботи полягала у визначенні загальних тенденцій вмісту важких металів у поверхневих водах р. Тетерів та нагульному ставу №1 ТОВ «СГФ «Інтеррибгосп». Відбір проб води проводився на струмені потоку р. Тетерів (водосховище Відсічне) та в нагульному ставу №1 на глибині 0,2–0,5 м від поверхні для подальшого лабораторного аналізу щодо вмісту іонів важких металів (ВМ). Для дослідження води застосовано атомно-абсорбційний метод аналізу. Лабораторні дослідження поверхневих вод р. Тетерів та ставу проводили за такими показниками: водневий показник (pH), вміст свинцю, кадмію, марганцю, цинку та заліза. Представлені результати дослідження вмісту важких металів у р. Тетерів, які показали, що вміст таких важких металів як: Pb, Cd, Mn, Zn та Fe, у річковій воді, за винятком заліза, перевищують межі гранично допустимих значень показників якості

води для рибогосподарських водойм. Фонові показники ВМ з нагульного ставу №1 області не показали перевищення ГДК (гранично допустима концентрація). Високі концентрації свинцю, кадмію, марганцю та заліза пояснюються потужним антропогенними забрудненнями, джерелом яких є аграрні та промислові комплекси Житомирщини. Результати можуть бути використані для встановлення ефективного моніторингу якості води у водоймах та розробки стратегій зменшення забруднення водних екосистем

Ключові слова: водне середовище; гідробіонти; фонові показники; забруднення; річки

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Efficiency of using spicy and aromatic plant ingredients in the technology of semi-smoked sausages

Oksana Shtonda
PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroyiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-7085-6133

Valentyna Israelian
PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroyiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-7242-3227

Tetiana Antoniuk*
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroyiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-5045-5546

Nataliia Slobodyanyuk
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroyiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-7724-2919

Liudmyla Tyshchenko
PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroyiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-3609-0920

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**Corresponding author*

Abstract. The relevance of the study lies in the need to improve the technology of semi-smoked sausages using spicy and aromatic plant ingredients, which would allow producing sausages with an extended shelf life and will help to expand the range. In order to avoid premature spoilage of sausage products or increase their consumption time, it is advisable to use a variety of food additives and antioxidants during production, with a positive effect on lipid hydrolysis and inhibition of oxidative changes in lipids. The purpose of the study was to investigate the chemical composition and freshness changes of semi-smoked sausages made using spicy and aromatic plants – thyme and caraway seeds – during storage. The following research methods were used in the study: organoleptic evaluation was carried out by appearance, cut appearance, consistency, aroma and taste; physicochemical – moisture content – by drying samples in a drying cabinet to a constant mass at a temperature of 103 ± 2°C; fat content – by Soxhlet extraction; protein content – by Kjeldahl method; determination of table salt content – by titration of a chlorine ion in a water extract from the product with silver nitrate. When determining organoleptic parameters, it was found that the samples have rather high organoleptic properties characteristic of semi-smoked sausage according to the manufacturing technology using thyme and caraway seeds. The chemical composition study found that the moisture content of the semi-smoked sausages was 54.1-59.3%, and the protein content was 19.6-20.4%, which meets the requirements of the standard for high-grade semi-smoked sausages. In the course of research, the influence of spices on the course of product spoilage and the preservation of quality indicators in the developed sausage samples was investigated. During storage, the amount of peroxides in the sausage samples was constantly increasing, which indicates the course of oxidative processes that lead to the generation of peroxides. The practical significance of the study was to improve the organoleptic properties and expand the range of semi-smoked sausages through the use of spices

Keywords: ingredients; oxidative changes; essential oils; spices; sausages; juniper; organoleptic parameters

Introduction

The meat industry meets the population's need for biologically healthy food, especially sausages, which are of great importance for human nutrition and the production of which is the most common area of meat processing for food. In a market economy, it is particularly important to improve the traditional technology of semi-smoked sausages to obtain competitive food products.

For centuries, aromatic herbs and spices have been added to various products to improve their taste and organoleptic properties. Plant spice and aromatic raw materials contain a significant amount of antioxidants, vitamins, essential oils that can inhibit the growth and development of unwanted microflora, including pathogenic ones. Meat systems are quite unstable and are subject to rapid microbiological influence. Issues related to spoilage of meat products during storage are relevant and require new scientific research and technological solutions. Every year in the world, up to 30% of food products are lost as a result of spoilage of manufactured products: due to microbiological spoilage and oxidative processes (Zhuk & Shevchenko, 2020).

Improvement of technical processes, management methods and storage conditions of products allows achieving stable quality of sausage products during storage. Free high-molecular saturated and unsaturated fatty acids and other hydrolysis products obtained by lipid

hydrolysis during storage of sausage products have no taste or smell, so they do not significantly affect the sensory evaluation of meat products. However, the accumulation of free fatty acids in foods causes spoilage due to oxidation.

The fat content of semi-smoked sausages is quite significant, due to the large amount of fat used in the recipe, and side lard is usually used. In this regard, oxidation processes and changes in organoleptic characteristics occur in semi-smoked sausages during production and storage. R. Domínguez *et al*. (2019) noted that the oxidation processes of lipids, proteins, pigments, and vitamins are frequent and interrelated, which negatively affects the quality of meat, including changes in colour and texture, the development of rancidity, loss of nutrients, and the appearance of toxic compounds.

Oxidative changes in sausage products primarily occur in the fat fraction. This is conditioned by increased contact with muscle tissue and the emulsification effect. L. Bal-Prylypko *et al*. (2021) noted that salting ingredients and myoglobin derivatives (iron-containing haem pigments found in meat) can contribute to oxidation, which can be active even at 0°C. In addition, the introduction of various additives into the minced meat system and increasing the temperature of the meat system also acts as a catalyst for lipid oxidation. Antioxidants are used to protect sausage products from oxidative damage, which are a component of spices and aromatic plants. The action of antioxidants is aimed at blocking active radicals in oxidative chain reactions.

P. Munekata *et al*. (2020) claim that different types of antioxidants, both synthetic and natural, can affect the chemical processes during fat oxidation. However, the global consumer community has a negative attitude towards synthetic antioxidants because of their potential harmfulness, which can lead to food poisoning and allergic reactions caused by chemical properties. The main focus is on natural antioxidants and how to get them. Theoretical and practical aspects of the use of spice and aromatic plants are considered in numerous papers by Ukrainian and foreign researchers.

N. Kondratiuk *et al*. (2022) investigated that the use of plant extracts from rosemary, thyme, and ginger helps maintain oxidative stability, stabilise colour parameters, and improve the technological and sensory characteristics of pickled semi-finished products. S. Hrelia & C. Angeloni (2020) confirmed that natural antioxidants undergo an intense metabolism that alters their redox potentials. In turn, K. Tzima *et al*. (2020) proved that polyphenols from black pepper, oregano, and sage can slow down the oxidative reaction, affect colour change, and alter the sensory properties of meat products.

V. Pasichnyi *et al*. (2022) found that chokeberry extracts have antioxidant activity that was comparable to blackcurrant extract in the production of semi-smoked sausages. The study showed that the addition of chokeberry extract in an amount of 0.2 to 0.5% by weight of minced meat significantly slows down the hydrolytic lipid oxidation of finished products, effectively reducing fat peroxidation. I. Simonova *et al*. (2023) investigated that extracts of chokeberry and blackcurrant berries can be a natural source of antioxidant substances, since the leaves and berries of these plants are rich in polyphenols, namely phenolic acids and flavonoids, which have strong antioxidant properties. N. Bozhko *et al*. (2020) confirmed that the addition of rosemary and cranberry extracts suppresses lipid oxidation during storage of meat products with a combined raw composition. The common disadvantages of the described extracts include a high price, different effectiveness on the course of oxidative processes at different stages of development, and insufficient antibacterial effect.

However, in the current situation, this issue requires further investigation. O. Shtonda & V. Israeli (2021) noted that many spices and aromatic plants, their extracts and essential oils, and sodium nitrite, which is included in

the composition of sausages, can act as antioxidants and slow down fat oxidation. As of 2024, the properties of various types of essential oils and their individual fractions have been studied. There are approximately 32 known types of spices that contain substances that slow down oxidation. G. Simakhina & N. Naumenko (2021; 2022) determined that the most effective are rosemary, sage, cloves, which increase resistance to fat oxidation by 15-17 times, and spices such as cardamom, anise, coriander, dill, ginger, marjoram, fennel increase resistance by 2-3 times.

Therefore, the main purpose of the study was to determine the quality indicators of sausage products and the effect of spice and aromatic plants on the lipid oxidation resistance of semi-smoked sausages during storage.

Literature Review

Currently, there are more than 200 names of spices that are used as natural flavorings and flavorings, of which just over 40 are the most popular. N. Holembovska *et al*. (2021) noted that depending on which parts of the plant are used as food additives or flavorings, spices and herbs are most often divided into seeds, fruits, flowers, leaves, roots, herbs, and bulbs. Natural spices are mostly used in dried form. Spicy plants are used both dried and fresh. Despite certain disadvantages, the use of natural spices remains quite important.

The analysis of studies shows that there is a tendency to use natural raw materials in various branches of the food industry. V. Velychko (2023) investigated the use of extracts of elderberry, blackthorn, and mountain ash in the food industry to identify their inhibitory effect on the development of free radicals. Plants have been found to contain high levels of natural antioxidants – anthocyanins and polyphenols. Multicomponent mixtures of spices are an integral part of recipes for sausage products. This ensures the production of products of stable quality and expands the range of sausage products.

I.J. Karoui *et al*. (2023) found that the use of plant raw materials (tomato pomace) is rich in valuable phytochemicals, in particular lycopene, which is an antioxidant that improves the appearance and sanitary and hygienic indicators of meat products (chicken patties). They contain substances that slow down and stop the processes of microbiological and oxidative spoilage of products, due to their harmful effects on pathogenic microflora, and slow down the growth of peroxide and acid numbers. When choosing a spice and aromatic component, special attention should be paid to the cut appearance of sausage, since some spice and aromatic plants are rich in tannins (polyatomic phenols), which have a strong antioxidant effect. Excessive use of such spices leads to product defects, i.e., black spots observed on the product cut.

In addition to spice extracts, their essential oils are widely used. F. Demarco *et al*. (2022) confirmed that rosemary and sage essential oils inhibit oxidative spoilage of food more intensively than synthetic antioxidants. S. Shityakov *et al*. (2019) found that black pepper does not affect the course of microbiological processes in spice-oil mixtures. Black pepper fruits contain essential oil up to 2.5%, the main part of it is pinene, limonene, and phellandrene, also contains choline and acetylcholine, 5-9% piperine. The active substances contained in black pepper stimulate the activity of the thyroid gland and increase oxygen consumption by tissues. Oxidative spoilage of lipids is another major cause of food quality degradation. This can lead to a loss of nutritional value and negatively affect a person's health.

R.A. Marc *et al*. (2022) studied plant spice and aromatic extracts from the stems, flowers, and leaves of rosemary, lavender, thyme and investigated their antioxidant activity. Analysing the findings, it can be concluded that plant extracts have the best antioxidant effect compared to raw materials (rosemary stems and leaves). To investigate the qualitative characteristics of the developed products, parts of

spicy plants are usually used in concentrations of 0.02%, 0.05%, 0.1%, and 0.2 %.

The antioxidant properties of juniper fruits were studied by American researchers Y.Y. Khatamovich *et al*. (2023). Juniper is an evergreen coniferous shrub of the cypress family, or a tree with a branched trunk. Juniper is distributed throughout the European Union, especially in mountainous areas, the United States, and Northern Asia. New juniper fruits contain a variety of vitamins, macro- and microelements. Special attention should be paid to vitamins: C (256) mg, PP (0.3 mg), vitamin E (TE) (0.3 mg), vitamin B_6 (pyridoxine) (0.1 mg), β-carotene (0.04 mg), vitamin B_2 (riboflavin) (0.02 mg), vitamin B_1 (thiamine) (0.01 mg), vitamin A (PE) (7 mcg), vitamin B_9 (folic acid) (5 mcg). It is noteworthy that juniper pods have a higher content of vitamin C than similar fruits of related species.

I. Basarab *et al*. (2021) investigated the effect of mixtures of thyme and juniper spices, their essential oils and alcohol extracts on the course of microbiological processes in pork breast. According to microbiological studies, the standard content of mesophilic-aerobic and facultative-anaerobic microorganisms was exceeded (more than 1.0×10^5 g/CCU) in breast samples with dry black pepper, and in samples with thyme and juniper in the ratios of 0.9:0.7:0.2 and 0.9:0.6:0.3. Excess of the QMAFAnM index was also recorded in experiments using essential oils of these spices. The most intense antibacterial properties in relation to the development of microorganisms were observed in the sample using dry crushed spices of thyme and juniper in the ratio of 0.9:0.8:0.1. The use of spice and aromatic thyme and juniper plants allows increasing the shelf life of finished products.

Juniper berries have a light forest aroma and a slightly spicy, bitter-sweet taste. For this reason, they are often used as spices in the cuisines of different countries of the world. Juniper is widely distributed in the alpine region. It is believed that the best varieties of juniper fruits can be found on the Hungarian market. Juniper berries are often sold in dried form. They are usually added to sauces and meat dishes. Due to its rich taste and aroma, juniper berries are best used in small quantities. Juniper fruits are known to be an excellent seasoning for most types of game, especially venison (combined with marjoram and black pepper), wild pigeon and wild boar meat. This spice adds a pleasant spicy taste to the famous English bull tail soup and various stews of fat beef, and can even turn ordinary lamb into wild roe deer meat. Thus, the use of spice and aromatic plants has become widespread in the technology of sausage products and various meat dishes. When used as a spice, they can give foods a taste with spicy notes. Essential oils contained in plants ensure that the proper quality of the product is preserved during storage.

Materials and Methods

The “Drohobytska” semi-smoked sausage of the highest grade was produced according to DSTU 4435:2005 (2007). The main raw material used was 100% lean pork. Variable formulations were determined to investigate the effectiveness of using parts of spice and aromatic plants in the technology of semi-smoked sausages (Table 1) The product was manufactured using the following technology: 5% of the raw materials were frozen, without being kept in salt, and ground on a laboratory cutter. Salt and sodium nitrite were added to the cutter bowl in the form of a 2.5% solution (the content of auxiliary raw materials varied in quantity according to Table 1). The remaining 95% of the meat was added in the form of pieces no larger than 2 cm and continued to be cut at low speeds for 20-30 seconds. Minced sausages were stuffed into artificial protein shells. Sausage loaves were deposited at a temperature of 2-4°C in a household refrigerator for 24 hours. The heat treatment was carried out by smoking and drying, the boiling operation was excluded: after

sedimentation, the control and 4 experimental sausage samples were fried in a drying oven at t = 80-95°C for 35-45 min; smoking was carried out in a smoking chamber at an initial temperature of 40°C, then every 30 min the temperature was increased by 10°C until the temperature in the centre of the product reached 71 ± 1°C. After smoking, the sausages were cooled to a temperature in the product thickness of no more than 4-6°C. Semi-smoked products were stored at a temperature of 2-4°C and relative humidity of ω = 76 ± 2% for 20 days.

Table 1. *Recipe for a spice and aromatic mixture for making semi-smoked sausages, kg per 100 kg of basic raw materials*

Spices and materials	Control	Experimental samples			
		No. 1	No. 2	No. 3	No. 4
Table salt	2.5	2.5	2.5	2.5	2.5
Sodium nitrite	0.005	0.005	0.005	0.005	0.005
Granulated sugar	0.09	0.09	0.09	0.09	0.09
Ground black pepper	0.06	–	–	–	0.12
Ground allspice	0.05	–	–	–	–
Fresh garlic	0.1	–	–	–	–
Ground caraway seeds	0.05	0.1	–	–	–
Caraway essential oil	–	–	0.0075	–	–
Juniper berries	–	–	–	0.1	–

Source: recipe of the spice and aromatic composition according to DSTU 4435:2005 (2007), samples developed by the authors

To fulfil the tasks set, studies were carried out according to the relevant standard methods: the following were examined by sensory evaluation: appearance, cut appearance, aroma, taste, colour according to DSTU 4435:2005 (2007) "Smoked sausages". Evaluation of indicators was carried out in the following order: appearance, colour on cut, consistency, aroma, and taste. Before tasting, the twine was removed from the sausage, the ends of the shell were cut off and dried with a towel. The colour, texture, and distribution of ingredients were evaluated after cutting the sausage loaves by diameter. The shell was removed from half of it, determining the appearance and taste, noting the condition of the crust, minced meat outside, and in the middle of the loaf. Samples of sausage products were cut into thin slices, ensuring hygiene rules. The length of the slice was 8 cm and corresponded to the full sample of the sample, that is, its commercial type and grade. Sausage products were cut at an acute angle to obtain wider slices. The position of the sausage loaf (or its vertical half) varied depending on the cutting angle, which was from 45 to 60°. The thickness of the slices was 2-3 mm.

Special knives with 250 mm long blades were used for cutting prototypes of sausage products. Moisture content – by drying the suspension to a constant mass and calculating the weight fraction of dry substances according to DSTU ISO 1442:2005 (2005). The protein content was determined by the Kjeldahl method according to ISO 1871:2009 (2009). This method is an arbitration, the essence of which is that proteins and other organic food components are broken down in concentrated sulphuric acid in the presence of a catalyst; the ammonia formed during the mineralisation of the components is distilled and absorbed by the acid; the next step included the titration of the excess acid with alkalis. The proportion of fat in the samples was determined by DSTU 8380:2015 (2017). The essence of the method was to wash out fats using a solvent from a paper sleeve, into which the dried suspension of the product was previously

added. Petroleum ether was used as a solvent. After extraction, the difference in the mass of the sleeve before and after extraction was determined. The results of the conducted studies were processed by statistical analysis methods.

Results

Product quality is determined by their characteristics, i.e., quality indicators, including sensory evaluation. Sensory analysis methods provide a fast, objective, and reliable overall impression of product quality. Organoleptic analysis allows quickly and purposefully influencing all stages of food production. The results of sensory evaluation in most cases were final and decisive in determining the quality of raw materials and products. Organoleptic evaluation of product quality indicators can be differentiated (according to individual quality indicators) or complex, considering the values of all indicators of the product under study. The results of the tasting evaluation showed that the tested samples had fairly high sensory indicators, as shown in Table 2.

Table 2. *Organoleptic evaluation of sausage products, in points*

Sample name	Appearance	Cut appearance	Smell	Taste	Consistency	Overall score, points
Control	4.5 ± 0.2	4.5 ± 0.2	5.0 ± 0.2	5.0 ± 0.1	5.0 ± 0.2	4.83 ± 0.2
No. 1	4.5 ± 0.2	4.5 ± 0.2	5.0 ± 0.1	4.5 ± 0.1	5.0 ± 0.1	4.68 ± 0.2
No. 2	4.5 ± 0.2	4.5 ± 0.2	5.0 ± 0.1	4.8 ± 0.2	5.0 ± 0.1	4.75 ± 0.2
No. 3	4.5 ± 0.2	4.5 ± 0.2	5.0 ± 0.2	5.0 ± 0.2	5.0 ± 0.2	4.78 ± 0.2
No. 4	4.5 ± 0.2	4.5 ± 0.2	5.0 ± 0.2	4.8 ± 0.2	5.0 ± 0.2	4.77 ± 0.2

Source: developed by the authors

When evaluating the appearance of all samples of sausage products, the surface of the loaves was clean, dry, without stains, lumps, damage to the shell and minced meat. Evaluating the cut appearance of semi-smoked sausages, it was found that the minced meat is evenly mixed, pink in colour, and pieces of pork are visible. The taste of the products was pleasant, moderately salty, in sample No. 4 slightly sharp, with the smell of garlic in the control sample; samples No. 1 and No. 2 had strongly pronounced aroma of caraway seeds; sample No. 3 was characterised by a pronounced aroma of spices and smoke. All samples had no extraneous aroma and taste. The consistency in all the samples produced was quite elastic.

The appearance of the product was most influenced by the following factors: the correct order of introduction of minced meat components and the execution of the technological process in compliance with all parameters – temperature, humidity, duration of processing, air speed. At the same time, salt-soluble proteins swell, colour stabilises, and taste is developed. The surface of the sausage loaves was visually clean and dry, without damaged shells and minced meat.

Such an indicator as the consistency of sausage characterises not only the ease of cutting the product, but also the fact that the minced meat does not stick to the knife blade, and the degree to which the product is finished. The results of the study showed that the consistency of all the sausage samples under study was elastic and dense. When examining the sausages on the cut – the appearance of minced meat was light pink, uniformly mixed with the inclusion of small pieces of pork. Taste and aroma determined the attractiveness of the product to consumers. The aroma and taste of the products was pleasant, characteristic of sausages of this type, with a pronounced aroma of spices and smoke. The taste was moderately salty and spicy, inherent in semi-smoked sausage products.

According to the data presented in Table 2, it can be seen that "Drohobytska" sausage (control) received the highest score in terms of organoleptic evaluation indicators with a total score of 4.83, and sample No. 3 with juniper berries. The lowest rating was given to sample No. 1, which contains only caraway seeds spice. To identify differences in the quality of the developed products, the sensory evaluation was supplemented with the creation of a profilogram, which allows visually presenting the overall comparative sensory evaluation of samples (Fig. 1).

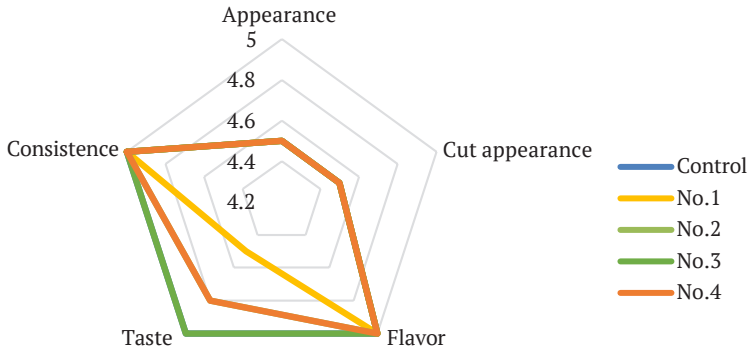

Figure 1. Organoleptic parameters of experimental sausages

Source: developed by the authors

The obtained data summarise that in terms of sensory indicators, sausage products containing various spice and aromatic plants are as close as possible to sausages that are made according to standard recipes. One of the most important stages of product development is the study of its chemical composition. The results of studies showed that the moisture content in the samples of semi-smoked sausages ranged from 54.1 to 59.3%, which did not exceed the standards (Table 3). According to this indicator, they meet the requirements of the state standard for the "Drohobytska" semi-smoked sausages.

Table 3. *Chemical composition of semi-smoked sausages*

Indicator	Standard (according to DSTU 4435:2005, 2007), %	Control	Experimental samples			
			No. 1	No. 2	No. 3	No. 4
Content: moisture	not more than 60	54.9±0.23	54.1±0.12	54.2±0.15	56.5±0.22	59.3±0.18
protein	not less than 13	20.1±0.21	19.7±0.17	20.4±0.16	19.6±0.17	20.0±0.20
fat	not more than 45	22.8±0.28	22.1±0.13	23.8±0.28	24.1±0.15	22.8±0.21
table salt	not more than 4.5	4.3±0.05	4.2±0.06	4.1±0.05	4.2±0.06	4.3±±0.05

Source: developed by the authors

When making sausages, with the exception of spice and aromatic components, no changes were made in the recipe, so the differences between the control and experimental samples fluctuated within the margin of error. In sausage products, the protein content corresponded to the standard values and ranged from 19.6 to 20.4%, fat – from 22.8 to 24.1% and salt – from 4.1 to 4.3%. When making sausage products, one of the most important factors that must be considered is the possibility of maintaining the quality characteristics of the product throughout the entire shelf life. It is well known that the rate of fat oxidation depends on their

interaction with air oxygen. The resistance of fats to oxidation is mainly determined by their fatty acid composition. In sausage products, this is directly related to technological changes in meat raw materials.

The shelf life of semi-smoked sausages is determined by indicators that do not change during storage – these are sensory and physicochemical indicators. Microbiological indicators change and characterise the oxidative transformation of products. Therefore, the further study was to determine the changes in the criteria of fat oxidation and microbiological parameters in the developed semi-smoked sausages during storage. Ready-made sausages were stored at a temperature of 0...6°C and relative humidity of 75 ± 3% for 15 days. Determination of the acid and peroxide numbers of experimental sausage products was carried out after production and during storage, using "Semi-smoked sausage" sausage as control. Hydrolytic and oxidative changes in lipids that occur during long-term storage are usually not caused by microorganisms. However, lipolytic bacteria, mould fungi, and other microorganisms contain enzyme systems that cause hydrolysis and oxidative conversion of lipids. These microbial lipases actively catalyse lipid hydrolysis. Unsaturated fatty acids and short-chain saturated fatty acids are the most sensitive to oxidative conversion. High-molecular fatty acids are more resistant to such changes.

During storage of the product in fats, hydrolysis took place, the depth of which is determined by the content of free fatty acids and is characterised by the value of the acid number. Hydrolysed fats are well absorbed by the human body, but fatty acids formed in large quantities during deep hydrolysis contribute to the development of oxidation processes. As a result of the conducted studies, a link was revealed between the meat raw materials used and the influence of spice and aromatic components on the process of spoilage of the product, and the preservation of the quality indicators of the sausages under study. Long-term storage of semi-smoked sausages can lead to fat hydrolysis processes, which leads to the accumulation of free fatty acids.

It is known that increasing the temperature increases the strength of hydrolytic enzymes, which leads to the accumulation of free fatty acids in fat. The investigation of changes in the acid number was carried out immediately after sausage production and during storage at a temperature of 0 to 6°C on the 5th, 10th, and 15th days (Table 4).

Table 4. *Investigation of the dynamics of the acid number in naturally smoked sausages during the shelf life, mg KOH, M ± m*

Sample	Storage period, days			
	0	5	10	15
Control	1.9 ± 0.03	3.0 ± 0.01	4.3 ± 0.02	4.7 ± 0.01
No. 1	1.9 ± 0.01	2.9 ± 0.02	4.2 ± 0.01	4.7 ± 0.01
No. 2	1.9 ± 0.04	3.2 ± 0.01	4.5 ± 0.02	4.6 ± 0.01
No. 3	2.0 ± 0.02	2.7 ± 0.02	3.9 ± 0.01	4.5 ± 0.01
No. 4	1.9 ± 0.01	3.2 ± 0.01	4.7 ± 0.03	5.5 ± 0.01

Source: developed by the authors

The results of a study of the dynamics of the acid number showed that in the first half of the shelf life, the amount of free fatty acids increases sharply. By the end of the storage period, their accumulation continued and doubled. However, the course varied in intensity depending on the product recipe. Thus, the least significant increase in the acid number was observed in sample No. 3 with the addition of juniper berries. At the end of the shelf life,

this figure was 4.5 mg KOH. When using caraway seeds and caraway essential oil in semi-smoked sausages, it was found that the acid number was lower than in the control sample, but higher than in sausages with juniper and black pepper (Fig. 2).

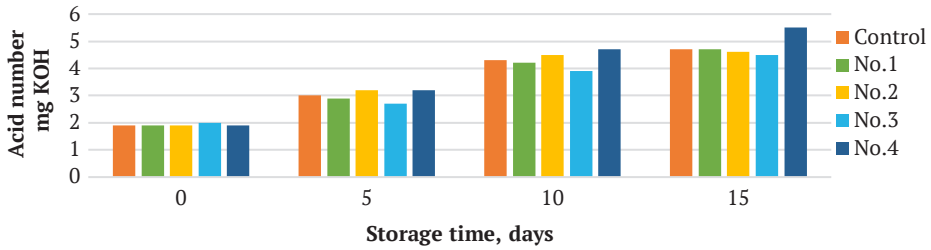

Figure 2. Dynamics of changes in the acid number in semi-smoked sausages during storage
Source: developed by the authors

During storage, the peroxide number of semi-smoked sausages is steadily increasing. This indicates that there is an oxidation process that leads to the generation of peroxide. However, under the same storage conditions, the strength of increasing the peroxide number is different. At a storage temperature of 0...6 °C after 5 days in the control sample, the peroxide number was 0.04% J_2, for 10 days – 0.08% J_2, and at the end of 15 days – 0.1% J_2 (Table 5, Fig. 3).

Table 5. *Dynamics of changes in the peroxide number in semi-smoked sausages during storage, % J_2, M ± m*

Samples	Shelf life, days			
	0	5	10	15
Control	0.01 ± 0.03	0.04 ± 0.03	0.08 ± 0.01	0.1 ± 0.02
No. 1	0.01 ± 0.02	0.03 ± 0.2	0.06 ± 0.01	0.09 ± 0.01
No. 2	0.01 ± 0.01	0.02 ± 0.0	0.05 ± 0.04	0.09 ± 0.02
No. 3	0.01 ± 0.01	0.02 ± 0.02	0.04 ± 0.03	0.08 ± 0.01
No. 4	0.01 ± 0.04	0.05 ± 0.01	0.08 ± 0.2	0.12 ± 0.02

Source: developed by the authors

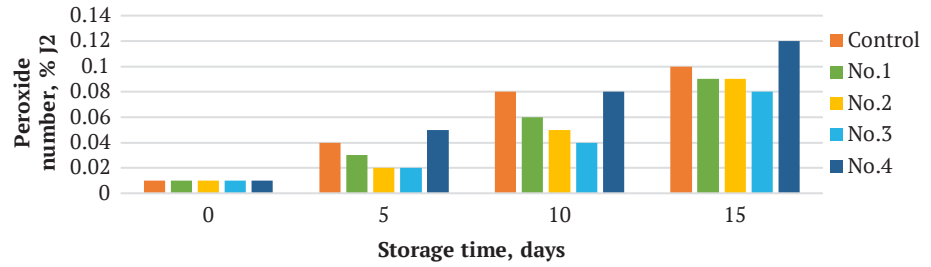

Figure 3. Results of changes in the peroxide number in semi-smoked sausages during storage
Source: developed by the authors

The indicator of the peroxide number of fat is less in the samples for the use of juniper berries – after 5 days of storage, it was 0.02 % J_2, after 10 – 0.04% J_2, and after 15 – 0.08% J_2. In semi-smoked sausages with the use of caraway seeds and essential oil, this indicator was higher than in sausages with juniper berries, but lower compared to the control sample (Fig. 3).

An increase in the peroxide number of sausage products leads to the appearance of an unpleasant smell and taste. Signs of spoilage occur when the level of peroxide in the product reaches 0.2% J_2. Although the regulation does not set a maximum permissible peroxide number for fat in sausage products, it is important for assessing the safety of this type of product.

Discussion

The use of plant extracts to preserve meat opens up broad prospects for extending its shelf life. Research conducted by G. Manessis *et al*. (2020) indicates the potential of biologically active compounds found in plant raw materials to reduce the oxidative processes that occur in meat during storage. This is especially important because fat oxidation can lead to discolouration of the meat, loss of taste, and an increased risk of spoilage. When choosing a suitable supplement for a meat product, it is necessary to consider the amount of active ingredients in the extract, the composition of the product itself, the fat content, and the ratio of saturated and unsaturated fatty acids. This helps ensure the optimal effectiveness of the antioxidant preparation. The results of studies on the acid number obtained by L. Tamkutė *et al*. (2021), confirm that triglyceride breakdown products accumulate gradually during meat storage, reaching their maximum value by the end of the shelf life. This indicates the need to use effective antioxidants to prevent the rapid breakdown of lipids and ensure the longest possible shelf life of meat without loss of quality. According to V. Pasichnyi *et al*. (2022), the addition of aronia and black currant extracts to minced semi-smoked sausages reduces microbiological contamination and has a bacteriostatic effect. The addition of aronia extract in the amount of 0.2-0.5% by weight of meat significantly slows down the hydrolytic oxidation of lipids in heat-treated products, effectively suppresses fat peroxidation. The use of black currant extract also has an antioxidant effect, but is weaker. Stabilisation of lipid peroxidation in semi-smoked sausages gives the effect of inhibiting the development of secondary oxidation products, which is confirmed by the results of studies. Due to the inhibition of hydrolysis of triacylglycerols, the concentration of free fatty acids was reduced. This was conditioned by the high oxidative capacity of flavonoids in the berry extract, which was confirmed by studies.

The study by N. Bozhko *et al*. (2019) proved that the addition of rosemary and cranberry extracts inhibits lipid oxidation during storage of meat-containing bread with a combined raw composition. The common disadvantages of the extracts used include a high price, different efficiency in passing through different stages of the oxidation process, insufficient antimicrobial action, etc. Analysis of the kinetics of the acid number of experimental samples showed that the addition of spice and aromatic plants inhibits peroxidation. Oxidation was observed after the first 5 days of storage. This is because the components of berries prevent the binding of active oxygen to fatty acid radicals and free radical oxidation is suppressed. This happens in the case of using juniper berries in a prototype.

Compounds that demonstrate the antioxidant activity of juniper berries are responsible for slowing down oxidative processes in experimental sample No. 3. And the potential of using this spice and aromatic raw material and products made from it (essential oil) in the production of semi-smoked sausages to improve their quality, which is consistent with the findings of B. Šojić *et al*. (2017). The use of natural antioxidants to reduce the consumption of synthetic supplements and produce cleaner meat prod-

ucts can be considered as one of the promising alternatives. M. Glisic *et al.* (2023) summarised data on the obtained natural antioxidants from agro-industrial by-products and their inclusion in various meat product formulations. This allows slowing down the oxidation of lipids and proteins, which is one of the main reasons for the deterioration of the quality of meat and meat products during technological processing and storage. The use of natural antioxidants has several benefits. Firstly, they are more natural and safe to consume, as they are obtained from natural sources such as fruits, vegetables, or vegetable oils. This is especially important for consumers who avoid synthetic additives in their food. Secondly, the use of natural antioxidants helps to reduce environmental impacts and promotes the use of agro-industrial by-products, such as waste from fruit and vegetable processing. This can help reduce waste in the food industry and support sustainable development. The findings of this study indicate the effectiveness of using natural antioxidants in various types of meat products, such as sausages, ham, etc. Their addition helps maintain the quality and duration of storage of meat products, and increases their resistance to oxidation, which can be especially important in the case of long-term storage or transportation.

H. Alkhattat e*t al.* (2022) found the antioxidant and antimicrobial effects of thyme against various microorganisms. These studies were conducted to investigate the effect of thyme water-alcohol extract on the quality of ground beef. The results of antimicrobial analysis of water and alcohol extracts of thyme in various concentrations showed that the water extract had a significant inhibitory effect on the growth of a wide range of bacteria compared to the alcohol extract. Thus, water-based thyme extracts can be effective and promising as preservatives for meat and its products, especially in high concentrations, to inhibit bacterial growth. The study by R. Tshabalala e*t al.* (2021 focused on three aspects: isolation and molecular identification of bacteria from meat; determination of the antimicrobial activity of spices against pathogens; evaluation of the organoleptic properties of meat with spices. Spice extracts were tested by disk diffusion to determine their inhibitory ability. The results show that clove and black cumin extracts have shown excellent antibacterial effects against most pathogenic bacteria. Cloves showed the highest inhibition zone of 18 mm against E. coli. Clove extract was the largest inhibitor, followed by black cumin, while thyme and cinnamon extracts showed weak antibacterial effects against the strains studied.

Due to the rather spicy taste and aroma, these spices are used in small quantities in minced meat systems and sausage products. As of 2024, quite a few studies have been conducted on the effects of the antioxidant and antimicrobial effects of berries and juniper berry extract. Currently, the antioxidant potential of extracts, essential oils, and oleoresins in meat products has been studied and confirmed. Using natural sources as antioxidants is an alternative to synthetic antioxidants. Their antioxidant capacity is associated with a high content of phenols. Thus, the inclusion of active components of spice and aromatic plants in the composition of sausage recipes will slow down oxidative processes and extend the shelf life of products.

Conclusions

One of the most promising areas of search for new antioxidants is the study of various biologically active substances in natural raw materials. Thus, the range of plants rich in antioxidants is rapidly expanding, both to protect food products from non-enzymatic oxidation, and to provide them with the development and production of functional food products containing antioxidant components.

Based on comprehensive studies, a comparative evaluation of the quality of sausages made using a variety of spicy and aromatic ingredients according to the traditional recipe of the “Drohobytska” high-grade sausage was

carried out. The sensory performance of sausage products using various spice and aromatic components is high and as close as possible to products made using standard technology. The protein content in sausage products corresponded to the standard values, ranging from 19.6 to 20.4%, fat – from 22.8 to 23.8%, and salt – from 4.1 to 4.3 %. It was found that the use of juniper berries in the technology of semi-smoked sausages reduces the accumulation of products of peroxidation of free fatty acids. When studying changes in acid and peroxide numbers during storage at temperatures from 0 to 6°C, an increase in indicators was observed in all samples on day 5, but in the control sample and in sample No. 3 made with juniper berries, this indicator was slightly lower.

Prospects for further research consist in a comprehensive analysis of juniper berries in comparison with other spices, their impact on changes in physicochemical and microbiological parameters. Preventing lipid oxidation in meat products with antioxidants found in plant-based raw materials not only improves the quality of food, but is also important for the health of people who consume the food. Although the human body is equipped with various defence mechanisms, including antioxidant enzymes and antioxidant compounds, maintaining an oxidant/antioxidant balance in favour of antioxidants by consuming more antioxidants through food and avoiding oxidative processes in food or pro-oxidants are the best methods to reduce oxidative stress in the human body. In the aggregate of the obtained research results, it can be concluded that sausage products with the use of various spice and aromatic plants have high quality indicators at the level of a traditional product. This makes it rational to introduce this technology in industry.

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Conflict of Interest

None.

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Ефективність використання пряно-ароматичних рослинних інгредієнтів у технології напівкопчених ковбас

Оксана Штонда

Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-7085-6133

Валентина Ісраелян

Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-7242-3227

Тетяна Антонюк

Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-5045-5546

Наталія Слободянюк

Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-7724-2919

Людмила Тищенко

Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-3609-0920

Анотація. Актуальність роботи полягає в необхідності удосконалення технології напівкопчених ковбас із використанням пряно-ароматичних рослинних інгредієнтів, що дозволить отримати ковбаси з подовженим терміном придатності та сприятиме розширенню асортименту. Щоб уникнути передчасного псування ковбасних виробів або збільшити їх терміни споживання доцільно використовувати під час виробництва різноманітні харчові добавки і антиоксиданти, з позитивним впливом на гідроліз ліпідів і гальмуванням окислювальних змін у ліпідах. Метою роботи було дослідження хімічного складу та зміни свіжості напівкопчених ковбас, виготовлених з використанням пряно–ароматичних рослин: чебрецю та кмину під час зберігання. У роботі використовували такі методи дослідження: органолептичну оцінку проводили за зовнішнім виглядом, виглядом на розрізі, консистенцією, ароматом та смаком; фізико-хімічні – вміст вологи – методом висушування зразків в сушильній шафі до постійної маси при температурі 103 ± 2°C; вміст жиру – методом Сокслета; вміст білка – методом К'єльдаля, визначення вмісту кухонної

солі – методом титруванням іону хлору у водяній витяжці із продукту азотнокислотним сріблом. При визначенні органолептичних показників було встановлено, що зразки мають досить високі органолептичні властивості характерні для напівкопченої ковбаси за технологією виготовлення з використанням чебрецю та кмину. В результаті дослідження хімічного складу було визначено, що вміст вологи в напівкопчених ковбас складає 54,1-59,3 %, вміст білку – 19,6-20,4 %, що відповідає вимогам стандарту для напівкопчених ковбас вищого сорту. В ході досліджень було вивчено вплив прянощів на перебіг псування продукту та збереження показників якості в розроблених зразках ковбас. Під час зберігання кількість пероксидів у зразках ковбасних виробів постійно зростала, що свідчить про протікання окислювальних процесів, які призводять до утворення пероксидів. Практичне значення проведених досліджень полягає в покращенні органолептичних властивостей та розширені асортименту напівкопчених ковбас за рахунок використання прянощів

Ключові слова: інгредієнти; окисні зміни; ефірні масла; прянощі; ковбасні вироби; ялівець; органолептичні показники

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03041, вул. Героїв Оборони, 15, м. Київ, Україна
E-mail: info@animalscience.com.ua
https://animalscience.com.ua/uk

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