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Increase of resistance and improvement of adaptation and compensatory mechanisms of the body of juvenile fish under conditions of multitrophic aquaculture

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Abstract. The relevance of the study is conditioned by the trend in the development of organic aquaculture with the production of environmentally safe products. The purpose of the study was to determine and compare the effectiveness of the introduction of feed factors of different origins in feeding and rearing rainbow trout in the early stages of ontogenesis. The study was based on theoretical (analysis, synthesis, comparison, modelling), experimental, and laboratory methods adopted in fisheries, physicochemical studies. The results show an increase in the resistance and overall viability of the body of young trout, an improvement in the morpho-functional parameters of the blood, and activation of metabolic processes in the experimental groups 1 and 2. However, higher parameters were obtained in experimental group 2 in relation to other study groups. The average body weight of fish exceeded the parameters in experimental group 1 (by 11.7%, $p < 0.01$) and experimental group 2 (by 19.5%, $p < 0.001$) of the control group. The total number of red blood cells in experimental group 1 exceeded the values in the control group by 10.6% ($p < 0.01$) and in experimental group 2 by 15.3% ($p < 0.001$). In experimental group 1, the total protein content exceeded the value by 14.8%, in experimental group 2 – by 22.2% ($p < 0.01$)

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compared to the control group. The creatinine content in the blood of fish in experimental group 1 exceeded the values (by 9.7%) and in experimental group 2 (by 17.6%, $p < 0.05$) of the control group. The biochemical composition of the muscle part of trout was higher and better in terms of nutritional characteristics in experimental group 1 and 2 compared to the control group. The proposed method of feeding by two methods (experimental groups 1 and 2) promotes activation of fish growth rates in two experimental groups. The practical significance of the study is to help improve qualitative and quantitative parameters, in particular, the biochemical composition of the muscle part in experimental groups 1 and 2 compared to control values against the background of increased growth rates

Keywords: *Oncorhynchus mykiss*; physiological and biochemical processes; alternative natural feed resources; optimisation of feeding technology

Introduction

Integrated approach to optimisation of technological elements in aquaculture involves the harmonisation of ecological and biological parameters in the body of aquatic organisms with the technological scheme of their rear-ing. O . Bokii & O. Kovalenko, (2024) emphasises the importance of taking such aspects into consideration, as this will ensure the rational use of their potential simultaneously with obtaining high-quality aquaculture products. In this context, the issue becomes of practical value and has scientific relevance. In particular, in the study by O.V. Honcharova & V.V. Bekh (2023), optimisation and "reset" of the fisheries sector in modern conditions was considered as a single integral system of functioning of multi-vector tools of the "ecological and economic mechanism". Nowadays, innovative trends contribute to a radical revision of the classic ways of doing business in the industry. One of the accents in the context of successful development of the industry is the desire of manufacturers to have high qualitative and quantitative characteristics of aquaculture products that must meet the consumer requirements. In accordance with the course of European integration, the emphasis is on maximising information from the manufacturer about the "history" of production of a particular finished product on supermarket shelves. In this context, one of the dominant issues is the feeding of aquatic organisms, achieving harmonisation of quantitative and qualitative characteristics of the industry, the quality of feed, additives, etc. In modern conditions, fish farming and aquaculture acquire the character of industrial production, based on the rearing of fish in ponds, basins, recirculating aquaculture systems (RAS), lakes, and reservoirs. As demonstrated by the authors of this study and the practical experience of specialists, in particular, O.V. Honcharova *et al.* (2021), V.V. Sakharnatsky (2024), the consolidation of several forms of industry management can contribute to improving the efficiency of growing and breeding aquatic organisms (Improving existing competencies..., 2020).

The multitrophic aquaculture model has all the prerequisites for sustainable development and gaining first positions in optimising and improving industry development strategies (Improving existing competencies..., 2020). The model system for growing aquatic organisms, which provides for the presence of natural feed cultivation sectors, will make it possible to use available resources in aquaculture more efficiently at the level of the production segment. Currently, natural components for feeding aquatic organisms are interpreted as innovative sources of various biologically active environmentally safe compounds, as noted

by V.V. Bekh *et al.* (2020), O.V. Honcharova & V.V. Bekh (2023).

Methods of intensifying the industry during the transition to an industrial form involve the use of compaction of fish stocking. However, the proportional increase in the concentration of fish, respectively, increases the life-supporting requirements of its body against the background of the influence of such factors. Under such conditions, there is a need to support the fish body, stabilise the parameters of homeostatic balance, and improve adaptive and compensatory capabilities. One of the ways may be to optimise the general economic diet, and feeding conditions. It is well known that one of the most vulnerable stages of trout ontogenesis is the transition to mixed and external nutrition. M.Yu. Yevtushenko *et al.* (2022) noted the importance of the early development period in larvae, since at this stage the immune system and digestive system with the corresponding enzyme complex, metabolic processes, etc., do not fully function. Therefore, in trout farming, as in other areas, considerable attention is paid to the issue of balanced feeding, providing protein and amino acids to the needs of the fish body at the early stages of development. It is important for the fish organism to receive biologically active substances, vitamin and mineral compounds with the feed for normal life in the future. However, the issue that is important to pay attention to when optimising and choosing natural feeds is the technological aspects of their production or processing. The study by V.P. Barkar & O.B. Tribuntsova (2022) presented information on the importance of the substrate, which is a resource for the cultivation of natural feed, since it determines and correlates with the qualitative and quantitative characteristics of products in the future. In this context, the topic becomes relevant to investigate ways to improve the overall functional status of the body of young trout under conditions of feeding and rearing in the early stages of ontogeny. Given the current vectors of development of technological solutions in aquaculture, the purpose of the study was to conduct a comprehensive comparative assessment of the influence of natural components on the functional status of the body and qualitative parameters of rainbow trout growth in the early stages of ontogenesis.

Literature Review

Despite the existing scientific developments on the subject of the study, the issue of full-fledged provision of the body of aquatic organisms with the necessary complex of nutrients with a vector of environmental and economic effi-ciency remains open and relevant. O.Bokii & O. Kovalenko, (2024) notes that in accordance with the recommendations of the European Union and current trends in optimising the industry as a whole, there is a transition from "aggressive chemicals" and hormonal stimulants of development to natural components. Undoubtedly, one of the vectors of development is to con-sider the negative impact of these factors and in the background of the anthropogenic load on the ecosystem in the global sense. In addi-tion, most researchers note not only the risk of such consequences for industrial production, but also for open natural reservoirs when using chemical fertilisers antibiotics, hormonal drugs (which, after entering the fish body, undergo a number of complex biochemical transforma-tions and, together with food, are excreted by the human body after consuming finished fish products). An example of such consequences can be many processes, in particular, eutroph-ication of water bodies, their contamination with toxic substances of anthropogenic origin, the arrival of toxic compounds with wastewa-ter, as a result of human activities. This leads to the establishment of so-called "dead zones", without living organisms with an appropriate hydro-biological regime and a decrease in the natural productivity and sustainability of other equally important environmental parameters (European Union. Commission Implementing Decision (EU) No. 2017/1442, 2017; Monitoring

and ecological assessment..., n.d.). Scientific and practical justifications of most researchers, in particular, V.V. Sakharnatsky (2024), demonstrate the possibility of replacing a significant amount of animal protein with vegetable protein in trout feeds. In addition, V.V. Bekh *et al.* (2000) determined the effectiveness of including a number of new ingredients of various origins in the fish diet, focusing on the prospect of using protein components of non-conventional origin in mixed feeds. O.V. Deren & M.O. Fedorenko (2023) note that due to the relevance of this issue for aquaculture in Ukraine and abroad, comprehensive research and practical studies are carried out to optimise feeding diets, methods of production and use of mixed feeds and feed mixtures in aquaculture. Due to the biological plasticity of the trout body, rapid growth rates compared to other representatives of salmon, and dietary and high taste properties, this fish is commercially profitable for both producers and consumers. In the European region, there is a trend towards the development of industrial production of ASI products (Algae, Single cell proteins/oils and Insects), the use of microalgae as a protein source. Some researchers investigated the possibility of optimising the main approaches in the industry by using the integrated fisheries model within the framework of the integrated approach of multitrophic aquaculture (Bruni *et al.*, 2018). There are positive results of using microalgae for biofiltration and complex feeding of young fish, using them as alternative energy sources, etc. Undoubtedly, compliance with technological parameters, in particular, for recirculating systems of the biofiltration level, as emphasised by N.E. Hrynevych *et al*. (2019), is important and should be considered in optimisation applications. The complex of components of microalgae after entering the body of fish helps to increase their nutritional qualities and bioavailability of products for the body. Based on their findings, J.W.I. Samarathunga *et al*. (2023) note the metabolic, stimulating, and antioxidant effects of such supplements. Scientific papers on these topics reflect information on the importance of transforming the cost of feed resources, such as fish meal. Currently, they remain very high in terms of production costs for manufacturers. In this regard, their availability will tend to decrease in the future. Considering the current requirements for compliance with "environmental hygiene" and the load on the ecosystem during certain activities, it is advisable to focus on the production of the above-mentioned ASI products. The studies by V.V. Bekh *et al.* (2020) note that obtaining them implies a much smaller impact on the environment, both in terms of greenhouse gas emissions and water and energy consumption. Microbial protein production has a low anthropogenic load, while restrictions on plant protein production are increasing, including limited land, water, and fertiliser reserves. In addition, according to M.L.R. Souza *et al.* (2015), the trout body uses plant protein less efficiently than animal protein. Therefore, the use of alternative feed ingredients based on available local resources to reduce costs, improve their quality, and maximise the efficient use of land, water, and energy resources will dominate. Research by E.G. Amenyogbe *et al*. (2020), I.A. Zaloilo *et al*. (2021), O. Dobryanska *et al*. (2022) also presents a positive result on the use as immunomodulators, correctors of the overall development of the body in the ontogenesis of hydrobionts among a wide selection of probiotics.

Nowadays, the ecological and economic problems of rational use, protection, and reproduction of water resources in Ukraine necessitate the further study and substantiation of a wide range of theoretical and applied aspects of the features of their ecological and economic assessment. The Biodiversity Strategy of the EU until 2030. Bringing nature back into our lives (2020) approves assessment of ecosystem services, mapping throughout the community on the need to restore freshwater ecosystems. In this regard, experts face a number of questions

in the industry, including measures to update the technological aspects of the use of feed, dietary supplements, premixes in the context of their environmental safety.

One of the areas, as noted by the authors' findings, is natural high-protein and high-energy feed components in aquaculture. Given the specific features of the action of each individual, there is a need to continue research in this area to detail the effect of biochemical components on the trout body, identify side effects, etc. Scientific and experimental work that has already been carried out shows that partially skimmed flour from *H. illucens* larvae is a valid alternative source of protein. L. Bruni *et al*. (2018) note that it can replace up to 50% of fish meal in rainbow trout feed without compromising both organo-somatic parameters and fillet yield. In particular, it was determined that the protein content in pre-pupae of *H. illucens* ranges from 399 to 431 g/kg, which allows recommending using *H. illucens* in mixed feeds. Biological features of metabolic processes of *H. illucens* provide the transformation of organic waste into a source of nutrients (proteins, lipids, and chitin) that help to reduce the burden on the ecosystem of the environment. In addition, the authors' current research reveals the potential for using *H. illucens* to produce biodiesel. V.P. Barkar & O.B. Tribuntsova (2022), comparing the efficiency of the obtained resource and rapeseed oil, note that the results allow considering *H. illucens* as sources of non-food raw materials for the production of biodiesel. High-quality biofertiliser is synthesised as a result of larval life activity of *H. illucens*, which also has a positive effect on the environmental situation. The authors substantiate that in the composition of the amino acid profile of black soldier fly *H. illucens* larvae contains one of the forms of omega-3 fatty acid – linolenic acid. But the most valuable, according to C.M. Bolton *et al*. (2021), is that black soldier fly larvae contain a large percentage of the essential amino acid for protein structures – methionine. Most animal organisms cannot synthesise it naturally, so it is important to get it exclusively with feed. There are also debatable questions among researchers about the beneficial effects of chitin for the trout body simultaneously with providing protein and other components. However, M.D. Finke (2007) notes that the discussion remains open, and the positive effect in the context of a high-protein supplement is justified if the optimal percentage of this supplement is introduced into the trout diet.

Feeding juvenile trout with nauplii *Artemia sp*. and larvae of the *Chironomidae* family as part of the starter feed ration shows positive results. The researchers note an increase in the growth rate of fish and its reproductive ability. In addition, arginine contained in the composition helps to increase the viability of fish, its sufficient amount in feed increases the body's resistance. There are studies where feeding these components contributes (by exposure to glutamine) to an increase in the synthetic processes of muscle proteins in fish. In addition, crustacean cysts are enriched with vitamins of group A, B (in particular, B_{12}), β-carotene (provitamin, antioxidant A) and carotenoids. In natural conditions, the fish body receives a large amount of a specific carotenoid (astaxanthin) with natural food. It gives a bright pink colour to the muscles and caviar of salmon, which contains commercial value. It is not synthesised in the body of fish, practically does not occur in products of land origin, so there are recommendations for including it in the diet of salmon. Researchers, including R.C. Gutierrez *et al.* (2023), note that feeding feed mixtures with crustaceans will provide energy resource requirements and pigmentation requirements.

It is physiologically justified that with the appearance of swimming movements in trout larvae, that is, when they begin to concentrate on the source, it is recommended to start feeding them with small zooplankton in the required quantities. Therefore, food should always be in trays or pools. Thus, the first feeding

of yolk sac larvae is carried out after the physiological stage of rest of the body, the duration of which depends on the water temperature, when larvae gradually begin to float up and swallow air with the filling of the swim bladder. Their yolk sac at this time dissolves by 2/3 of the original volume. Therefore, additional feeding with small branched crustaceans (daphnia, moines, etc.) is relevant at this stage of development. The relevance of additional feeding in the early stages of trout ontogenesis is conditioned by a gradual increase in the activity of digestive enzymes in early juveniles. Researchers, including M.Yu. Yevtushenko *et al.* (2022), note that in the first days after hatching, the enzyme pepsin was not detected in trout progenitors, while trypsin shows weak activity. Already with the transition to an active diet, pepsin is synthesised in their body and the activity of other proteases increases. Therefore, obtaining complete protein components is important and will provide a complete set of essential amino acids for physiological and biochemical processes. Currently, 10 amino acids are essential for the trout body (lysine, arginine, methionine, threonine, leucine, isoleucine, tryptophan, histidine, phenylalanine, valine). R.C. Gutierrez *et al.* (2023) noted a positive result from partial replacement of fish meal, which may be associated with a high level of lysine, the presence of a wide complex of biologically active substances, betaine, which positively affects carbohydrate and protein metabolism in fish. Considering the features of the course of metabolic processes that adapt and compensate in the body of aquatic organisms, the processes of effective transformation of useful substances into an energy resource may differ.

There are generally accepted recommendations regarding the physiological needs of the fish body for structural elements of nutrition, depending on age, morphometric parameters, sexual maturity, and the hydrochemical properties of water. In the process of metabolism, the leading place is given to protein synthesis. Trout, given its predatory fish characteristics, uses most of the protein as a source for energy metabolism (up to 70%). Therefore, it is important to find ways to reduce unproductive protein consumption, mixtures of proteins of various origins. There are studies that note the results of the analysis of the influence of various diet options on the development of aquatic organisms. Among such studies, M. Henry *et al.* (2015) note that the nutritional value of mixed feeds increases if their variety of raw materials expands. The incubation and decapsulation of dormant organisms to use them in the early stages for feeding fish larvae is a relevant subject. However, this method is not widely used, which is explained by the high cost of high-quality eggs and the lack of guaranteed receipt of high-quality incubation batches. It is likely to be a matter of time and greater demand for this area of production. V.V. Bekh *et al.* (2000) focus on ways to use non-conventional natural feeds (crustaceans, oligochaetes, free-living nematodes, chironomid larvae, fly larvae, etc.) with several technological solutions. In particular, both autonomous installations (bioreactors, rooms with appropriate equipment and sanitary and hygienic conditions) for rearing, and integrated into a certain sector of the technological map for the rearing of aquatic organisms. The usefulness of protein nutrition is one of the main conditions that determines the efficiency of using feed nutrients, the level of productivity, the state of health and reproductive functions of fish. Proteins are the main component of cells and tissues of the animal body, with which all vital functions are associated. Their content in feed affects the level of fish productivity and the economic efficiency of production.

Thus, the presented results of scientific and practical experience of using natural feed in trout farming in feeding demonstrate the relevance and practical value of the area. However, for more reasonable recommendations, it is advisable to rely on comprehensive research. Since the body is a multifunctional

system, when studying the effect, including the feed factor on the body of fish, O.V. Honcharova *et al*. (2021) note that it is advisable to analyse not only the rate of development, but also the correlation of blood composition by morpho-functional and biochemical parameters, supplemented by histological examination, the biochemical composition of the muscle part.

Such comprehensive studies help to analyse the effectiveness of feeding aquatic organisms in a more in-depth and multidirectional manner. In this context, the subject matter of the research acquires both practical and scientific significance and value.

Materials and Methods

The design and implementation of the experimental study was carried out in accordance with the generally accepted requirements and standards for the organisation of experiments in fish farming in compliance with Directive 2010/63 of the European Parliament and of the Council On the Protection of Animals Used for Scientific Purposes (Directive 2010/63/EU, 2010). During the experimental part of the work, the ethology of trout was observed. All manipulations with experimental objects corresponded to the "European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes" (1986). The study was based on theoretical (analysis, synthesis, comparison, modelling), experimental, and laboratory methods adopted in fisheries, physicochemical studies. In compliance with generally accepted recommendations, the fish diet was optimised (Zheltov, 2003; Yevtushchenko & Khizhniak 2019). Object of research: rainbow trout (*Oncorhynchus mykiss* (Walbaum, 1792) in the early stages of ontogenesis. The feed factor of influence on the ontogenesis of juvenile trout was determined considering the physiological and biochemical characteristics of its body. In particular, the level of enzymatic activity in the body of prelarvae and the following age groups of fish, their needs for essential amino acids, protein and other functional actin substances was taken into account. In the technological context, the model of farm multitrophic aquaculture was used. The technological map provided for the rearing and breeding of aquatic organisms, undergrowth, cultivation sections of own production of natural feed, the sector of processing, preparatory manipulations and production of the finished feed mixture. Cultivation took place according to standard methods with ensuring, in accordance with the biological needs of the object, a hydrochemical and sanitary-hygienic regime. The second component was chosen as a feed factor flour from black soldier fly larvae *(Hermetia illucens Linnaeus*, 1758) (*Diptera: Stratiomyidae*). In entomological biotechnology, the authors report the ecological and efficient bioconversion of organic waste into feed protein. By biochemical composition, *Hermetia illucens* has an amino acid profile including with linolenic acid, a form of omega-3 fatty acid and an essential amino acid – methionine (Metlytska *et al*., 2017; Bolton *et al*., 2021). Cultivation took place at the pilot plant using several insectariums, the substrate had two groups(bran of grain crops and vegetable and fruit residues), this paper presents the results of using the residues of vegetable and fruit crops. All rearing parameters for the brood group and juveniles met the standards of cultivation parameters for *Hermetia illucens* with an emphasis on temperature and humidity (Metlytska *et al*., 2017). Control and experimental groups of 250 trout were formed (experimental group 1, in which fish were fed with larvae of *Artemia salina* and experimental group 2, in which fish received larvae of *Hermetia illucens*. The planting density was based on the generally accepted recommendations for trout rearing, consideirng body weight, 20 kg/m^3<5 g, 25 kg/m^3– 5-15 g, 30 kg/m^3 – 15-30 g; for organic cultivation – up to 35 kg/m^3. Feeding of rainbow trout larvae began at the time of its ascent to swim first in the tray, as it developed after growing and

completing the experiment - with the transition to RAS basins, with appropriate filtration levels and water treatment (Hrynevych *et al.*, 2019).

Recommended daily feeding rates, water temperature, and fish development rate were taken into consideration. Density of semi-intensive, open planting and recirculation systems was approximately 10-20 kg/m^3, (Aquaculture feed and fertiliser resources..., 2024). Natural components for additional feeding were obtained as a result of the author's own production on the model of multitrophic aquaculture. The technological scheme of cultivation provided for all sectors with appropriate equipment and conditions. Natural ingredients (*Artemia salina* and *Hermetia illucens*) in the feed mixture was 25-30% in each experimental group. The day before, the optimal ratio of natural components was experimentally established, which was used in the current study. The experience of other researchers was considered when organising research on feeding aquatic organisms with crustaceans and insects. In particular, the presence of chitin in the conditions of entry into the body can contribute to a violation of metabolic processes and the level of assimilation of nutrients in aquatic organisms. The percentage content of ingredients can have both a positive and reverse effect if it is not used efficiently and if the biological nature of the objects to be fed is not observed. After 4 weeks, all groups were gradually transferred to the ratio of natural components in the feed mixture with a proportion of 23-20% in each experimental group against the background of GED (general economic diet). After feeding in this ratio, all groups were gradually brought to GED. At the end of the experimental part after 125 days, morpho-functional analysis was performed based on the results of blood sampling from the tail vein and histological examination, biochemical analysis of the muscle part of trout. Biological samples were taken from 50 specimens in compliance with all standards and recommendations for performing experiments in fish farming (Yevtushenko & Khizhniak, 2019; Yevtushenko *et al.*, 2022; Utku *et al.,* 2023). All the necessary equipment was available in the certified laboratory of KSAU, SI KPEP, ThermoMix was used to transport biological samples. The functional status of the fish body was assessed by qualitative and quantitative parameters of biological material in the laboratory of the Department of Aquatic Bioresources and Aquaculture of KSAU on the Humalyzer 3000 analyser using Unified Human GmbH kits. Histological analysis was carried out on branded equipment guided by original methods specially developed for histological diagnostics of aquatic organism tissues using optical equipment "E. Leitz "Diaplan" Wetzlar" (Germany), halogen illuminator "Linvatec-2" (USA) with a rated power of 10-240 Watts. General morphometric studies of tissue structures were performed using a micrometer. When contrasting histological preparations, correction filters "ZHZM 2.5x", "MONOCHROM 2.5x" were used. Morpho-functional and biochemical parameters of blood (haemoglobin content, total number of erythrocytes, leukocytes, corpuscular parameters of blood; protein content, glucose concentration, creatine) were analysed using standard methods using test kits, counting method. The development schedule was compared with the rainbow trout growth schedule adjusted for temperature and rearing conditions (Aquaculture feed and fertiliser resources ..., 2024). During the entire period of the experiment, the hydrochemical regime corresponded to generally accepted standards for salmonids with appropriate age characteristics. Pools with rainbow trout larvae operated on the principle of recycling. The water temperature for the larvae in the aquarium was increased stepwise from 10 to 14°C, oxygen saturation was at 85-100%, O_2 content was 9.4-10.3 mg/l O_2 at an acidity of 7.4-7.7 pH. The level of larval development was determined by the results of control weighings, visual observation, and calculation methods.

Results and Discussion

The study of the influence of the feed factor on the overall functional state of the rainbow trout body in ontogenesis showed a positive effect on the rate of development. During feeding with natural components, the average body weight of fish in the early stages of ontogenesis in the experimental groups exceeded the actual values in the control group (Figs. 1, 2). All parameters of rainbow trout development corresponded to physiological recommendations in aquaculture and varied within these limits (FAO, 2024).

The normal course of all physiological processes of rainbow trout confirms the satisfaction of the body's nutritional needs. In all groups of the experiment, the feed contained substances and compounds necessary for the body with nutritional value for each stage of development (FAO, 2024).

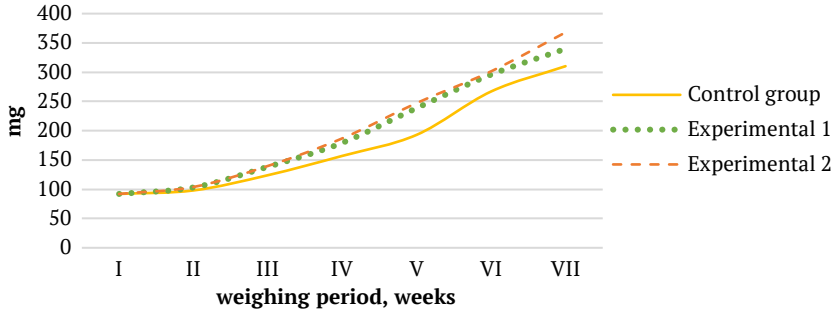

Figure 1. Analysis of the influence of feed factors of various nature on the growth rate of rainbow trout in ontogenesis (x ± SD)

Source: developed by the authors

But in the experimental groups (1 and 2), the processes of metabolism and assimilation of substances were more active than in the control group. The influence of the feeding factor contributed to the activation of metabolism in the trout body: in experimental group 1, the difference between the control was by the stages of ontogenesis: 5.2%; 11.6%; 14.2%; 23.7%; 10.8% and at the end of the feeding stage – 9.5%. The average daily weight gain was also higher than in the control group, which is biologically justified. The survival rate was 4.1% higher than that of fish that received a general diet. According to the data of weighing fish in experimental group 2, the difference in the studied indicator was higher than in the previous group of the experiment in relation to the control parameters. In experimental group 2, the difference in fish growth rate between the controls was at the stages of ontogenesis: 6.02%; 12.7%; 19.04%; 28.1%; 12.9% and at the end of the trout feeding stage – 18.6%. In the experimental groups, simultaneously with high growth rates, the average daily growth rate of fish exceeded the value of the control group.

The survival rate was 5% higher for fish that received a general diet (Fig. 2). This parameter is important, especially in the development of all biological and physiological basic functions in the fish body. As is well known, the largest loss of trout juveniles is observed when fish switch to a mixed and active diet. Probably, feed components of natural origin with the appropriate biochemical nutritional composition and biologically active substances also played the role of adaptogens. Which, after entering the trout's body, stabilised the parameters of homeostatic balance in its body and increased the resistance of young people to potential stress factors.

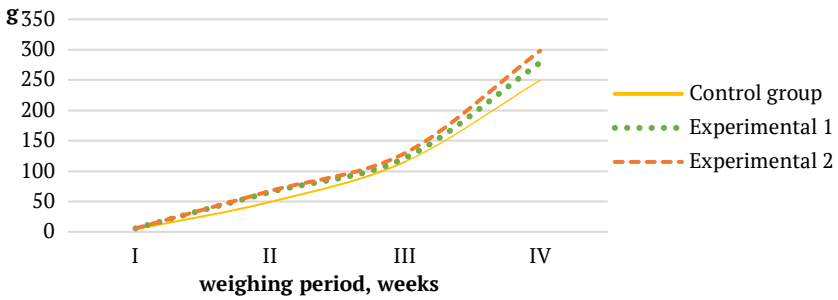

Figure 2. Analysis of the influence of feed factors of various nature on the growth rate of rainbow trout in ontogenesis (x ± SD)

Source: developed by the authors

Approximately, trout juveniles are able to consume an average of up to 1% of their weight in one feeding session (FAO, 2024). According to the results of the study, the rate of their development corresponded to the recommended values for the age groups of fish. For larvae, there was a corresponding body weight from 0.3 to 1.0 g with a size of feed crumbs of 0.3-0.7 mm and additional feeding up to 10 times a day, taking into account 5% of their body weight. Analysis of the growth rate of rainbow trout in ontogenesis showed compliance with the age group of juveniles (from 1 to 25 g), the lobule size was already 0.7-2.0 mm with the frequency of feeding 4 times a day and taking into account feeding standards (% of body weight) of 3% of body weight. Monitoring the growth of rainbow trout at the body weight stage from 25 to 1,500 g, the size of feed lobules was 2.0-4.5 mm with a feeding frequency of 2 times a day and a body weight percentage of 2% (FAO, 2024). In the future, the results of the study of the age group weighing more than 1,500 g are not presented in this paper. However, the size of pellets when feeding fish was 5 mm with a frequency of feeding 2 times a day, taking into account the body weight of 1.5%. Analysis of the feed coefficient showed the best values in experimental group 2 regarding the assimilation of feed components by the trout body and their transformation into higher indicators of body weight, average daily weight gain, and quality parameters of products.

The average body weight of rainbow trout in experimental group 1 for the entire period of using Artemia salina as additional feeding exceeded the body weight of fish in the control group by 11.7%. In experimental group 2, the growth rate was more active, which was reflected in a higher body weight at the end of feeding rainbow trout with *Hermetia illucens*. The difference between the experimental groups (1 and 2) was 7%. However, the difference between experimental group 2 and the control group was 19.5%. During the entire period of using the feed factor, when improving the functional status of the rainbow trout body, the studied indicators improved by stimulating physiological and biochemical processes, increasing feed conversion and maximising the potential in the trout body of experimental groups.

Blood is a labile functional tissue with a set of vital functions for the body. Therefore, blood parameters are the primary indicator that allows analysing the presence or absence of the influence of any factor on the state of the body. Analysis of comparison of trout blood parameters in the experimental groups with the control group showed that all indicators were observed in compliance with generally accepted regulatory parameters in trout farming.

However, within the physiological norm, there were changes in quantitative parameters in the blood of fish from experimental groups (under the influence of the feed factor) in relation to the control group.

Erythropoiesis processes were activated in the body of rainbow trout, which was additionally fed feed in the experimental groups 1 and 2. Total red blood cell count and haemoglobin content were 10.6% higher in experimental group 1 ($P < 0.01$) and 5.8% and in the experimental group 2 by 15.3% ($P < 0.001$) and 10.3% compared to the control group (Table 1). Comparison of corpuscular parameters of blood reflects the morpho-functional features of the blood of the studied object and understanding at the morphological level the course of intracellular processes.

Table 1. *Functional status of the rainbow trout body under the influence of the feed factor, (x ± SD)*

Parameters	Control group	Experimental group 1	Experimental group 2
Number of red blood cells,T/l	1,428 ± 0.067	1,579 ± 0.089**	1,646 ± 0.042***
Haemoglobin content, g/l	87.88 ± 8.534	93.018 ± 8.833	96.900 ± 6,718
MCV, mkm^3	347,254 ± 27,164	294,712 ± 36,245*	270,574 ± 19,848***
MCH, pg	61,534 ± 5,332	59,083 ± 6,607	58,931 ± 4,590
MCHC, %	17,775 ± 1,599	20,308 ± 3,431	21,872 ± 2,311**
Haemotacritis, %	49,498 ± 2,924	46,333 ± 4,131	44,500 ± 2,928
Glucose, mmol/l	3,122 ± 0.364	3,215 ± 0.484	3,652 ± 0.768
Total protein, g/l	48,433 ± 3,454	55,612 ± 8,115	59,183 ± 6,885**

Note: *0.05 ($P < 0.05$); **0.01 ($P < 0.01$); *** 0.01 ($P < 0.001$); MCV – mean corpuscular volume; MCH – mean corpuscular haemoglobin; MCHC – mean corpuscular haemoglobin concentration

Source: developed by the authors

The parameters of MCH, MCHC, and MCV in proportion to the number of red blood cells and haemoglobin concentration by actual values exceeded the data in the control group. The average concentration of the respiratory pigment haemoglobin and corpuscular indices of red blood cells may indicate a higher level of oxygen supply to tissues in fish of experimental group 1 and 2 in relation to the control. Morphofunctional indicators of fish blood showed better indicators in the body of fish that received natural components and active substances before the main diet in two experimental groups.

The transformation of physiological and biochemical processes can be explained by the activation of nutrient metabolism processes. It is possible that under the influence of natural components in the blood of rainbow trout of experimental group 1 and experimental group 2, a faster transformation of substances in the body occurred. The effect of this action was noted when analysing the blood glucose concentration of rainbow trout. The difference between control and experimental group 1 (2.98%) and experimental group 2 (16.98%) according to the control values. Such differences can identify the tendency to activate carbohydrate metabolism in the body of fish that received natural feed additives. The tendency to increase blood glucose can also be explained by the fact that the fish's body underwent dynamic metabolic processes due to the correct balance of essential amino acids in the feed and their energy supply. The obtained changes in the studied parameters indicate an accelerated transport of energy substances from the blood to tissues, more efficient assimilation of feed nutrients, and better use of glucose for the energy needs of the fish body in experimental groups.

Determination of the dependence of biochemical and morphofunctional indicators of rainbow trout juveniles on body weight showed that the coefficient of determination in experimental group 1 was in the range of 0.804-0.930 and in experimental group 2 – in the range of 0.933-0.989 (Table 2). The results obtained complement the more positive effect on the overall functional state of the rainbow trout body from experimental group 2 compared to other groups. However, a higher parameter was noted in relation to the control group and in fish from experimental group 1.

Table 2. *Coefficient of compliance with the determination of the dependence of blood parameters on body weight of Oncorhynchus mykiss*

Blood parameters	Experimental group 1		Experimental group 2	
	Logarithmic equation of connection	Coefficient of determination, R^2	Logarithmic equation of connection	Coefficient of determination, R^2
Creatinine	y = 110.3ln(x) – 564.9	$R^2 = 0.917$	y = 162.4ln(x) – 865.8	$R^2 = 0.954$
Total protein	y = 88.84ln(x) – 444.2	$R^2 = 0.804$	y = 121.8ln(x) – 635.0	$R^2 = 0.989$
Erythrocyte content	y = 1.044ln(x) – 47.519	$R^2 = 0.930$	y = 0.716ln(x) – 0.1169	$R^2 = 0.933$
Haemoglobin content	y = 179.1ln(x) – 886.9	$R^2 = 0.904$	y = 212.6ln(x) – 1,084.4	$R^2 = 0.939$

Note: x, x2 – weight; y – blood parameters
Source: developed by the authors

The body of rainbow trout from the two experimental groups most effectively and efficiently used its own mechanisms of vital activity in comparison with the control group. The total protein content in the blood of fish of experimental group 1 and experimental group 2 exceeded the values of the control group by 14.8% and 22.2% ($P < 0.01$), accordingly. With an increase in weight accumulation processes, there was an increase in the creatinine content in the blood of rainbow trout in experimental group 1 (by 9.7%) and experimental group 2 (by 17.6%, $P < 0.05$) in relation to the control group.

Physiological and biochemical processes in the trout's body were more active in groups where the fish received natural components. This positive dynamics can be explained by higher body weight gain, active protein metabolism, and higher protein content in trout muscle tissue in experimental groups 1 and 2 (Fig. 3).

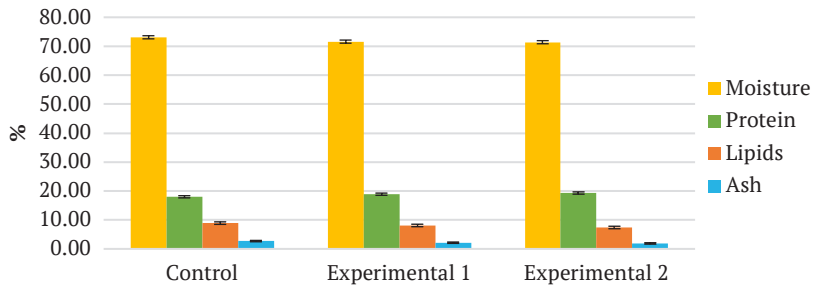

Figure 3. Analysis of the biochemical composition of the muscle part of rainbow trout under the influence of the feed factor, x ± SD

Source: developed by the authors

It was found that against the background of an improvement in the rate of trout development in the experimental groups, high-energy components did not contribute to the accumulation of lipids in the liver, internal organs, and muscle tissue (including due to the optimal percentage of lipids of 21-22%). Feeding rainbow trout according to the method of experimental group 2 helped to reduce the percentage of fat in meat in proportion to the increase in protein content.

The highest results of additional feeding were observed in experimental group 2. Comparing, it can be stated that the samples show a noticeable decrease in the proportion of the stromal component with an increase in the diameter of muscle fibres (Fig. 4). Based on the data obtained, muscle fibres in the lumbar section, on the contrary, show sufficient "fibrillar filling".

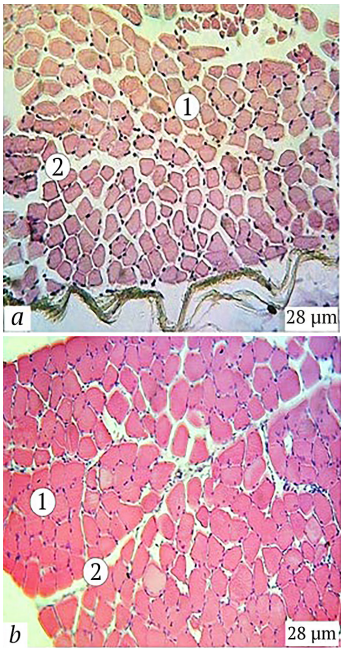

Figure 4. Structure of a fragment of the muscle bundle of the dorsal part of the rainbow trout's body

Note: a – control group; B – experimental group 2; 1 – muscle fibre; 2 – endomysium

Source: developed by the authors

It is obvious that these changes were achieved with the help of components of the feed mixture of intensification of individual parameters of homeostasis in the body of fish from experimental group 2, which contributed to the growth of muscle fibres in thickness due to the development of new fibrils, and not an increase in the proportion of sarcoplasma (watery meat). On visual inspection, all fish had the following external signs: the body surface was clean, the colour was natural, characteristic of this type of fish with a thin layer of mucus, no signs of the disease, the gills were red. The eyes were light, transparent, and undamaged. The smell was characteristic of live fish of this species, without foreign odours. A clinical review of rainbow trout in the experimental and control groups showed that the condition of internal organs, shape, and colour corresponded to the physiological norm, no pathological changes were observed. No organ obesity was detected, the structure of the liver and spleen was dense, and the kidneys were without tissue growths.

When growing trout against the background of genetic characteristics, two parameters can be distinguished that directly affect the efficiency of the industry: the quality of the aquatic environment and the general economic diet. Since an improvement in the rate of trout development under feeding conditions has already been established, it was advisable to investigate the biochemical composition of the muscle part. In order to establish the optimal level of amino acids in the feed mixture for rainbow trout, studies were conducted to determine the content of proteinogenic amino acids in the muscle tissue of fish. Data analysis showed that rainbow trout muscle tissue had the entire amino acid composition, with the deposition of amino acids such as lysine, tyrosine, phenylalanine, histidine, leucine and isoleucine, valine, and threonine in experimental samples. The resulting total amino acid content was higher in the experimental groups compared to the control group of the study.

Discussion

In trout farming, the issue of balanced fish feeding with an emphasis on early ontogenesis is given attention by scientists and practitioners. Research papers present the results of positive experience in using animal and plant protein sources, and non-conventional feeds in aquaculture. Along with this, there are no comprehensive, studies with the results of analysing the correlative relationships of growth rates and qualitative parameters of fish fillets with an emphasis on biological value. The scientific and practical experience of optimising fish feeding is reflected in the paers by S.C. Belluco *et al*. (2013), V.P. Barkar & Tribuntsova (2022), where the researchers present a positive experience of using microalgae biomass, in particular, dry spirulina and bacterial biomass. This method probably demonstrates an effective replacement for fish meal. However, the body of trout, which is biologically grounded, uses animal protein more efficiently than vegetable protein. In Ukrainian aquaculture, the researchers note the positive results of the use of non-conventional sources of protein and probiotics in optimising the conditions of feeding aquatic organisms. For example, the quality indicators of fish meal and soy concentrate when performing a comparative analysis among themselves had a relatively small difference. However, the researchers, including N. D'Souza *et al*. (2006), O. Dobryanska *et al*. (2022), emphasise the rationality, economic efficiency of production, for example, the use of soy concentrate and other feed resources can be more cost-effective for producers. The search for ways to reduce the cost of feed production remains an urgent issue, one of the implementation cases may be the inclusion of the use of animal, vegetable proteins, and protein products of microbial synthesis in the diet. The probability of a negative impact on the fish body by using components with a high content of essential amino acids and other components is not fully investigated. As is known, not always high growth rates of fish are accompanied by an improvement in the biochemical characteristics of finished products, as evidenced by the data of I.A. Zaloilo *et al*. (2021), O. Bolton *et al*. (2021), M.Yu. Yevtushenko *et al.* (2022). However, the experience of using natural feeds in feeding hydrobionts is defined as positive by most authors. In comparison with vegetable protein, animal protein is more enriched. The results of their research contain information on the concentration of protein obtained from insects (from 30 to 70% of high-quality protein). The issue of effective use of alternative protein sources has been given in the scientific and practical sphere in recent decades, however, given European integration, the rapid development of technological and digital aspects, it remains relevant and open. The confirmation are the studies by L. Velasquez *et al*. (1991), M. Espe *et al*. (2007), V.V. Bekh *et al*. (2020). According to the data, the raw protein content obtained from insect larvae is slightly inferior to fish and bone meal, but significantly exceeds the actual value of vegetable protein, for example, obtained from microalgae. There are studies in aquaculture that reflect the experience of using algae processing products, enzymatic substances, and products obtained as a result of microbial synthesis, all of which are high in protein and essential amino acids. Practical and scientific experience reflects the recommendatory nature of their use as additives. S.Y. Shiau & Y.P. Yu (1999), O.I. Metlytska *et al*. (2017) note that when feeding trout, it is important to consider its growth rate, especially juveniles, taking into account the temperature factor of the aquatic environment. Since the physiological needs of the fish body are correlated not only with gender, age, mass accumulation, but also with the feed coefficient and hydrochemical parameters. Studies show that proteins derived from insects are easily digestible, with qualities for use higher than meat and bone meal or soy flour. Experimental studies with the addition of certain species of lepidoptera, *Musca domestica*, *Hermetia illucens* larvae, and house crickets

(Gryllus assimilis) to the fish diet demonstrate an increase in average daily weight gain and activate metabolism. However, for more objective information, reasonable recommendations for the use of such components, today, the effectiveness and mechanism of their influence on the functional status of the fish body and at the same time on qualitative and quantitative parameters are not fully studied. Therefore, the research in this paper complements existing judgments and results, and provides an opportunity to analyse this topic more broadly.

In foreign studies, the authors S. Sharma *et al*. (2018) note the effectiveness of converting inedible biomass into protein for further use in fish feed. The obtained positive results of feeding fish with microbial protein based on a mixture of algae and yeast with fermentation properties indicate the activation of metabolic processes and fish growth rates. However, the researchers note that the apparent protein digestibility coefficient for yeast may be suboptimal, so further experiments are still ongoing to optimise technological aspects. The authors of the current study suggest that based on the available information in scientific and practical developments on this topic, it is advisable to supplement judgments with more comprehensive research. Emphasising the presence or absence of a correlative relationship with qualitative parameters and quantitative indicators of finished aquaculture products. Among them, attention can be paid to mass accumulation, feed conversion, preservation and biochemical composition of the muscle part according to leading indicators.

In aquaculture, the use of feed additives that are aimed at immunostimulating, antioxidant effects on the body of aquatic organisms is relevant. Among them, phytocomponents, probiotics, nanoparticles in the composition of feed mixtures, immunomodulators, etc., are noted. However, such supplements most often have a single vector: they increase the level of lysozyme activity, the immune state, but do not improve the mass accumulation in fish. N. D'Souza *et al*. (2006) note that processed animal protein is considered a valuable alternative because it is better absorbed by the body of fish (especially carnivores) than plant proteins. However, despite this, nowadays, based on the available information resources, there are certain restrictions on the use of individual processed animal proteins in the European space, justifying this by protection against transmissible spongiform encephalopathies. The results of the research also contain information about the contradictory use of such feed when feeding in unprocessed form, with an emphasis on digestion, assimilation by the body, etc. This is explained by the presence of chitin, which can potentially reduce the availability of fish feed, and therefore digestibility. There are data where the authors obtained results on the use of krill meal, which contributed to a decrease in productivity of *Oncorhynchus keta* and rainbow trout, and chitin derived from shrimp (*Pandalus borealis*), included in the diet at concentrations of 2% and 5% reduced the productivity of Atlantic salmon. According to R.C. Gutierrez *et al*. (2023), the results of such studies were generally positive. The further research on chitin in feed and its complex action when ingested is necessary. In contrast, there are data which indicate that the addition of chitin (6%) increases the growth of young rainbow trout. At the same time, there is evidence that in the experiment, Atlantic salmon received 50% of the northern krill (*Meganyctiphanes norvegica*) when feeding, and developmental stimulation was not observed. M.D. Finke (2007) and M. Henry *et al*. (2015) suggest that one of the reasons for these contrasting results may be that under certain conditions, chitin can balance the negative effects that it itself creates in the body. In this context, the research requires further experimental analyses that are more comprehensive and thorough.

Overall, the studies on the use of black soldier flies show that replacing fish meal with

black soldier larval flour in trout diets can improve productivity, growth, and environmental sustainability by reducing the use of fish meal. However, exceeding a certain level of substitution can lead to a decrease in productivity, for example, in groups that received only black soldier fly flour, there was a decrease in protein growth and digestibility due to the accumulation of chitin in the intestines of fish. Experiments on growing insects, which lead to a decrease in the growth of fish and the digestibility of proteins and lipids, contained conclusions about the negative effects of chitin. The use of black soldier fly in the trout diet is promising, but it is necessary to optimise the frequency and amount of feeding to achieve better results. Chitin digestion requires the action of chitinase, chitobiase, and lysozyme, which are present in both predatory and omnivorous fish. Chitinase, which is found in the stomach of fish, destroys chitinous exoskeletons, while chitobiase, which is present in the intestines of fish, plays a nutritional role (absorption of nutrients).

The chitin found in crustaceans is found in a matrix of proteins, minerals (mainly calcium), while the cuticle of insects consists of chitin in a matrix of proteins, lipids, and other compounds. Crustacean dietary chitin has been shown to reduce dietary digestibility and growth in rainbow trout fed 25% chitin, and in *O.niloticus×O.Aureus* hybrids fed 2%, 5%, and 10% chitin. However, unlike these two studies, there are studies that have shown high feed digestibility. In addition, low levels of dietary chitin have been reported to increase the innate immune system activity of silver seabream (<0.01%) and carp (1%) and increase carp resistance to bacterial diseases (1% chitin).. Thus, chitin may not be the main and generally not the problem discussed by the authors. Therefore, the taste, nutrient availability, digestibility, and composition of insect flour may be more suitable for feeding fish after some flour processing, such as drying, hydrolysis, silage, or degreasing. Insects contain the natural polysaccharide chitin, which is characterised by a prebiotic effect, but fish cannot digest it. Therefore, chitin is either removed or extracted for the purpose of being used as part of feed. Analysis of the effectiveness of feeding rainbow trout with Artemia salina compared to commercial feed shows that this method can significantly improve growth and stress resistance in fish larvae and juveniles. Research on the effectiveness of feeding trout with vermiculture (for example, *Eisenia fetida)* show that worms can be a promising alternative to fish meal in trout diets. The use of worms in trout diets promotes growth, improves feed conversion, and increases protein efficiency. However, high levels of fish meal replacement for worms can lead to reduced feed intake and growth, which is likely due to an imbalance of energy and protein. The addition of worms in small amounts (up to 50%) does not negatively affect the growth and feed efficiency. For example, feeding trout with *Eisenia fetida* in the proportion of 25-50% in the diet, helped to reduce the lipid content in fish. L. Velasquez *et al.* (1991) do not rule out that excessive use of worms can lead to the accumulation of toxic elements such as lead. Feeding trout with *Eisenia fetida* promotes better feed growth and conversion rates when replacing up to 50% of fish meal. Other additives are introduced to some recipes to improve feed absorption: betaine, protein concentrate, rapeseed. As pointed out by M. Espe *et al.* (2007), lysine, L-methionine and arginine (or threonine) are the three main limiting amino acids in rainbow trout feeds when less fishmeal and more vegetable protein is used. To optimise trout productivity, as with most fish, the optimal protein level in foods depends on the amount of energy in the diet and the ratio of essential and non-essential amino acids. The authors define the 55:45 ratio as optimal (FAO, 2024). The use of soy meal and corn starch is practised as additional sources of vegetable protein in foods with a low content of fish meal. In the

case of feed used at the beginning of rearing, soy protein concentrates or wheat gluten flour are sometimes used (FAO, 2024). Recommendations are justified by the positive result of the following components for trout: cotton flour (solvent extracted, peeled) (<31%), soy meal (<31%), non-fat soy meal (less than 73%), soy protein concentrate (<31%), corn gluten flour (<5%), wheat gluten flour (<21%), pea flour (<30%), rice protein concentrate, barley protein concentrate, concentrate canola (rapeseed) (<15%). Rice bran, whole wheat (less than 35%), wheat flour (<5%), and whole corn contain less than 20% protein and are very important sources of carbohydrates (FAO, 2024).

To summarise, it should be noted that the effect of feeding aquatic organisms and using them as a stimulant can be multidirectional with a complex effect. Assessment of the level of exposure depends on the biological form of use of the biostimulator, considering the biological characteristics of the body of aquatic organisms, the ratio of components of the feed mixture in GED (general economic diet) of fish, etc. Considering all aspects, it is advisable to take an individual approach with a reasonable algorithm for the process of growing fish and a comprehensive approach to optimising technological processes. Therefore, to preserve the production of aquaculture, while reducing its impact on the environment, it is advisable to optimise methods with a vector to reduce the use of antimicrobial, hormone, and synthetic preparation.

Conclusions

Optimisation of trout feeding conditions, considering current trends in the development of the industry and the requirements of potential consumers, is one of the key vectors of aquaculture development and its transition to a new level. Physiological and biochemical processes in the body of young trout form a potential, the resource of which will be used in the future. Therefore, rationality and validity when choosing the components of the diet, technological aspects when growing trout should consider the wide format of all factors and in the future predict the effect of the selected measures.

It has been scientifically and practically established that, based on the general diet, the additional use of natural components as a high-protein source for juvenile trout contributes to high quality and quantity parameters, considering the "environmental friendliness" of the process. The results obtained on the influence of the feed factor on the physiological, biochemical, zootechnical, and histological parameters of trout demonstrate an overall improvement in the functional state of the trout body in ontogenesis. A stimulating effect of metabolic processes at all levels was obtained, which was confirmed by the best indicators of blood composition (within the physiological norm). In the experimental groups, the use of methods of feeding with natural components in the feed mixture of GED contributed to the activation of the body's resource reserves in comparison with the control group. In particular, the oxygen capacity of rainbow trout blood and haemopoiesis improved, which also improved the growth rate of young fish. Most indicators of blood composition correlated with the parameters of trout development in ontogenesis, which was reflected in the qualitative parameters of finished products. Histological and biochemical studies of the muscle part in experimental groups supplemented the positive effect of the studied supplements when feeding young trout. Feeding rainbow trout with *H. illucens* reduced the percentage of fat in meat in proportion to the increase in protein content. However, higher parameters that significantly differed from the control group were found in experimental group 2. Based on the results obtained and the relevance of the research topic, the purpose of further study is to investigate the influence of natural components during feeding on the functional status of different

age groups of rainbow trout and a comparative analysis of the correlation of the rearing substrate and the qualitative parameters of the finished product itself in aquaculture.

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Conflict of Interest

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Підвищення резистентності та поліпшення адаптаційно-компенсаторних механізмів організму молоді риб за умов мультитрофічної аквакультури

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Анотація. Актуальність дослідження зумовлена тенденцією розвитку напряму органічної аквакультури з отриманням екологічно-безпечної продукції. Метою дослідження було визначення та порівняння ефективності впровадження кормового чинника різного походження при підгодівлі та підрощенні райдужної форелі на ранніх стадіях онтогенезу. Дослідження ґрунтувалось на теоретичних (аналіз, синтез, порівняння та моделювання) експериментальних, лабораторних методах, загальноприйнятих у рибогосподарських та фізико-хімічних дослідженнях. Результати демонструють підвищення резистентності та загальної життєздатності організму молоді форелі, поліпшення морфо-функціональних параметрів крові, активацію метаболічних процесів в експериментальній групі 1та 2. Втім, вищі параметри були отримані в експериментальній групі 2 по відношенню до інших груп дослідження. Середня маса тіла риби перевищувала параметри в експериментальній групі 1 (на 11,7 %, $p < 0,01$) та експериментальній групі 2 (на 19,5 %, $p < 0,001$) контрольну групу. Загальна кількість еритроцитів в експериментальній групі 1 перевищувала значення в контрольній групі на10,6 % ($p < 0,01$) та в експериментальній групі 2 на 15,3 % ($p < 0,001$). В експериментальній групі 1 вміст загального білку перевищував значення на 14,8 %, в експериментальній групі 2 – на 22,2 % ($p < 0,01$) по відношенню до контрольної групи. Вміст креатиніну в крові риб в експериментальній групі 1 перевищував значення (на 9,7 %) та в експериментальній групі 2 (на 17,6 %, $p < 0,05$) контрольну групу. Біохімічний склад м'язової частини форелі був вищим та кращим за поживними характеристиками в експериментальній групі 1 та 2 по відношенню до контрольної групи. Запропонований метод підгодівлі за двома способами (експериментальної групи 1 та 2) сприяє активації швидкості росту риб в двох експериментальних групах. Практична цінність дослідження полягає у сприянні поліпшенню якісних та кількісних параметрів, зокрема, біохімічного складу м'язової частини в експериментальних групах 1 та 2 в порівнянні з контрольними значеннями на фоні збільшення темпів зростання

Ключові слова: *Oncorhynchus mykiss*; фізіолого-біохімічні процеси; альтернативні природні кормові ресурси; оптимізація технології підгодівлі

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Autonomic nervous system tone in poultry protein metabolism

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Abstract. The problem of the world market in the lack of one of the main components of all living organisms, namely protein, is more urgent than ever. Products from poultry farms are rapidly trying to fill this gap, which is ensured by the rapid growth in the number of livestock and its growth rate. The main material that ensures the growth of a given number of animals is protein. There is a direct relationship between protein metabolism and poultry productivity. The purpose

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of the study was to establish the influence of the autonomic nervous system on the indicators of protein metabolism in poultry blood serum. The study was conducted on COBB-500 chickens. The experimental groups were established according to the Baevsky method. The LabLine-010 spectrophotometer (Austria) was used to determine the content of total protein, globulins, and albumins. For the analysis of blood serum, a test system from Granum Laboratory LTD, Kharkiv, was used According to the results of the biochemical study, it was found that the total protein content in the experimental group of normotonics with a balanced effect of the sympathetic and parasympathetic nervous systems was higher in comparison with sympathotonics by 10.5% ($p < 0.001$) and vagotonics by 21.1% ($p < 0.001$). The albumin content in normotonics was 9% higher than in sympathotonics ($p < 0.001$) and vagotonics by 18.1% ($p < 0.001$). In the experimental group of normotonics, globulin values on day 35 were 11.4% higher in relation to sympathotonics ($p < 0.001$). The experimental group of vagotonics had the lowest globulin content compared to the experimental group of normotonics, which was 19.1% less compared to them ($p < 0.001$). According to the results of the study, it should be noted that poultry belonging to the experimental group of normotonics was characterised by more active processes of protein metabolism in the body, which introduced a new variable that should be considered when studying the processes of protein synthesis and resynthesis and used as an additional factor for the use of various feed additives

Keywords: broilers; protein; whey; amino acids; autonomous regulation

Introduction

According to J. Peinado-Izaguerri *et al.* (2023), due to the active growth of the world's population, the need for a protein source is growing more and more. Among the variations of products that can provide a lack of this organic element are meat products from poultry farms, which is justified by the fact that it takes less time to raise poultry compared to a cow or pig. These complexes can accommodate a large number of livestock on a small area, which provides a large volume of production. On the world market, the percentage of meat products obtained from poultry is gradually growing.

According to A. Geng *et al.* (2023), not everything is positive in the future development of this economy, there are quite a few different sharp corners of this issue. Without considering the technical support of this complex, it is necessary to focus on the processes of protein metabolism. This issue is quite important both from the economic and environmental sides. If it is possible to regulate protein metabolism with the use of less concentrated protein feeds, the development of poultry on rearing improves, and the financial costs of the farm for the purchase of mixed feeds with a high feed content are reduced, which solves the issues of the economic plan. S. Ma *et al.* (2023) and M. Kidd *et al.* (2021) note the significant role of protein metabolism in poultry rearing. According to their research, in addition to total protein, protein components, namely amino acids, also play a significant role in the development of animals. They note that a balanced diet should consider the content of essential amino acids. In addition to their specifics in the genetic coding of protein substrates, it is necessary to distinguish their secondary functions, which are reflected in immune functions, correction of metabolic processes as antioxidants, components of enzymes, hormones, structural role as the main component of muscle weight, etc. Therefore, an adjusted diet is quite an important component in raising poultry.

According to P. Selle *et al.* (2023) and K. Qiu *et al.* (2023), the active development of

poultry farming appears as an excess source of carbon in the form of carbon dioxide and methane and nitrogen in the form of nitrogen compounds. This is quite dangerous from the standpoint of ecology, because the accumulation of these compounds causes the development of global warming and the accumulation of carbon dioxide.

According to V. Stoyanovskyy *et al.* (2020) and A. Saleh *et al.* (2021), correction of protein metabolism is an important issue, and understanding aspects of factors that have a direct impact on these processes is currently relevant. The exchange of organic compounds is subject to a certain number of complex systems of the body. In the current case, the issue is considered from the standpoint of the role of the autonomic nervous system in the correction of protein metabolism. After all, this system is quite good with the participation of its own departments of the sympathetic and parasympathetic nervous systems is able to correct the constancy of the body's homeostasis quite well, being part of the neurohumoral regulation of metabolism in the body. This is a very relevant issue in the study of this area. The purpose of the study was to determine the influence of the autonomic nervous system on the indicators of protein metabolism in the blood serum of poultry.

Literature Review

Poultry farming has made a huge step in development compared to previous years. An increasing number of methods are being applied to improve the growth and development of poultry, using both genetic and metabolic factors. For the rapid growth of these animals, considering their growing technologies, high-energy feed and the necessary amount of energy for the growth of the body are required to maintain it. However, organic components, such as proteins, should not be neglected as they are essential for building a rapidly developing organism. G. Wu (2022) notes the significant role of a balanced diet for raising animals, since if these conditions are provided, the energy consumption for growth will be successfully compensated with feed, which will improve weight gain. The main goal is to achieve a zero value between the nitrogenous compounds consumed and spent, because protein plays a key role in ensuring the sustainable development of the poultry body.

Groups of researchers including P. Maharjan *et al.* (2021) and G. Brugaletta *et al.* (2023), in their discussion of the importance of high-protein feedstuffs, draw attention to the problem of nitrogen leakage into the environment and the efficiency of their assimilation. The fact is that with a large amount of protein consumed, the leakage into the environment of a large number of end products of their metabolism, such as methane, nitrogen, and carbon dioxide, increases. This is taking into account the active growth of these enterprises, which contributes to the growth of the poultry population and, as a result, the leakage of these exchange products becomes an integral factor of an environmental catastrophe. Therefore, according to the researchers, it is necessary to take this factor into consideration and adjust the diet of animals to reduce crude protein and improve the assimilation of what is consumed, which is successfully implemented by introducing components such as carbohydrates and lipids.

Against the background of the development of environmental problems, the issue of technological stress arises. The main issue of which, which is more frequent at this time, is temperature adjustment in production. This factor should always be one of the priority issues to solve. The development of this problem is influenced by many factors, the main of which are the rapid change in climatic conditions, the number of poultry and conditions of keeping, which in most cases is characterised by a significant accumulation in a small space. As noted by M. Kumar *et al.* (2021), if this issue is ignored, the poultry farm will necessarily face heat stress, which will have a significant

negative impact on the growth and development. The question of heat stress and the overall impact factor on the animal is widely studied. After all, correcting the condition of the poultry in this situation is quite difficult. Direct impact on the stress of animals in the conditions of a huge farm is practically impossible and the occurrence of this variable for this enterprise can lead to significant economic losses. To avoid these problems, it is worth considering the following points, namely the causes of this problem and what consequences they will have for the animal's body, namely, how the bird will counteract external factors of influence.

To solve this problem, attention should be paid to systems that take an active part in responding to these variables. It is known that the constancy of any living organism is characterised by its homeostasis. The systems that control this condition consist of the nervous and endocrine systems, which provide a composite complex of neurohumoral regulation. Given this, the response to stress is complex (Hyun & Sohn, 2022). But what is the primary structure of the body has a primary role in responding to this factor of influence. When analysing the work of the neurohumoral system, the autonomous nervous system plays a special role in this issue. This system, through the well-coordinated work of its own departments of the sympathetic and parasympathetic nervous systems, can provide a primary response to the stress factor. This feature is still actively used in the analysis of the constancy of homeostasis of the body and more than once confirms the significant role of the autonomic nervous system in correcting the metabolism of organic substances (Adeniyi, 2022; LeBouef *et al.*, 2023).

Poultry farming is a promising area in the production of animal products against the background of the growth of the human population. To ensure a balanced development of poultry, especially meat, a balanced diet with a significant protein content is required. But significant protein intake poses a significant environmental threat in the form of the release of nitrogen and carbon dioxide into the environment. Methods of countering this environmental catastrophe are aimed at reducing crude protein in the diet, or replacing excess protein. Therefore, the study of protein metabolism and its correction factors is an urgent issue today.

Materials and Methods

The study was conducted on COBB-500 chicken cross with 5 animals in each experimental group. When performing the experimental studies presented in the paper, all manipulations with the bird involved in the research were carried out considering the basic principles of bioethics, in accordance with the European Convention for the Protection of Vertebrate Animals Used for Research and Other Scientific Purposes (1986) and Procedure for Conducting Research and Experiments on Animals by Scientific Institutions (2012). The tone of the autonomic nervous system was determined according to the Baevsky method. An electrocardiographic study was performed with recording of the electrical potentials of the bird's heart for at least 100 cardiac intervals. The cardiograph electrodes were placed at the humerus and tibia. Blood sampling was performed at the age of 60 days from the saphenous vein of the shoulder, after a starvation diet.

To obtain the serum, the obtained samples were placed in a thermostat at a temperature of 37°C. Total protein was determined using a LabLine-010 spectrophotometer (Austria). Determination of total protein was carried out using a test system from Granum Laboratory LTD, Kharkiv. Measurement conditions: 540 (530-650) nm wavelength cuvette with an optical layer thickness of 1 cm, temperature 15-25°C. Before using the reagents, they were kept at room temperature for 30 minutes. Next, the following samples were prepared for analysis.

The samples were mixed and placed in a thermostat at 37°C for 5 min. Measurements were made on a photocolourimeter in cuvettes

with an optical layer thickness of 10 mm relative to the blank sample at a wavelength of 540 (530-650) nm.

The results obtained were calculated using the equation:

$$C_{exp} = \frac{E_{exp}}{E_{st}} \times C_{st}, \quad (1)$$

where C_{exp} – total protein concentration in the experimental sample, g/l, E_{exp} – optical density of the experimental sample, optical density units, E_{st} – optical density standard, optical density units, C_{st} – total protein content in the standard, 70.0 g/l.

Determination of albumin was carried out using a test system from Granum Laboratory LTD, Kharkiv. Measurement conditions: 630 (600-650) nm wavelength cuvette with an optical layer thickness of 1 cm, temperature 15-25°C. Before using the reagents, they were kept at room temperature for 30 minutes. Next, the samples were prepared for analysis.

The samples were mixed and placed in a thermostat at 37°C for 5 min. Next, measurements were made on a photocolorimeter in cuvettes with an optical layer thickness of 10 mm relative to the blank sample at a wavelength of 630 (600-650) nm.

The albumin concentration was calculated using the equation:

$$C_{exp} = \frac{E_{exp}}{E_{st}} \times C_{st}, \quad (2)$$

where C_{exp} – albumin concentration in the experimental sample, g/l; E_{exp} – optical density of the experimental sample, optical density units; E_{st} – optical density standard, optical density units; C_{st} – albumin concentration in the standard, 50 g/l.

Determination of globulins was carried out using a test system from Granum Laboratory LTD, Kharkiv. Measurement conditions: 640 (620-670) nm wavelength cuvette with an optical layer thickness of 1 cm, temperature 15-25°C. Before using the reagents, they were kept at room temperature for 30 minutes.

The samples were mixed and placed in a thermostat at 37°C for 5 min. Next, measurements were made on a photocolourimeter in cuvettes with an optical layer thickness of 10 mm relative to the blank sample at a wavelength of 640 (620-670) nm.

The concentration of globulins is calculated using the equation:

$$C_{exp} = \frac{E_{exp}}{E_{st}} \times C_{st}, \quad (3)$$

where C_{exp} – globulin concentration in the experimental sample, g/l; E_{exp} – optical density of the experimental sample, optical density units; E_{st} – optical density standard, optical density units; C_{st} – globulin concentration in the standard, 50 g/l.

Statistical analysis of the results obtained was calculated using Microsoft Excel software suite. The probability of the difference between the obtained indicators was calculated according to the Student's t-test. Differences between the compared indicators were considered probable at the significance level $p < 0.05$, $p < 0.01$, and $p < 0.001$.

Results and Discussion

During a biochemical analysis of the blood plasma of poultry at the age of 35 days, the following indicators were established for the experimental group of normotonics (Table 1).

Table 1. *Indicators of the protein fraction content in the blood serum of poultry of the experimental normotonic group at 35 days (n = 10)*

Indicators	NVO	SE	M	SD	A	Min	Max
Total protein	10	0.04	43.87	0.13	-0.83	43.56	44.00

Table 1. Continued

Indicators	NVO	SE	M	SD	A	Min	Max
Albumins	10	0.06	19.99	0.15	-0.85	19.85	20.04
Globulins	10	0.08	23.88	0.11	-0.82	23.72	23.95

Note: NVO – number of valid observations, SE – standard error, M – median, SD – standard deviation, A – asymmetry, Min – minimum value, Max – maximum value
Source: developed by the author

The biochemical study of poultry blood plasma found that the total protein content of normotonics on day 35 ranged from 43.56-44.00 g/l with an average value of this indicator of 43.87 ± 0.13 g/l. Total protein in the experimental group of poultry with a balanced effect of the sympathetic and parasympathetic nervous systems among five animals had discrepancies of 0.44 g/l, which indicates a small discrepancy in the initial results of a biochemical analysis of blood serum. The albumin content ranged from 19.85-20.04 g/l and had an average value of 19.99 ± 0.15 g/l. Albumins in the experimental group of poultry with a balanced effect of the sympathetic and parasympathetic nervous systems among five animals had discrepancies of 0.19 g/l, which indicates a small discrepancy in the initial results of a biochemical analysis of blood serum. The globulin content in the experimental group of normotonics ranged from 23.72-23.95 g/l with an average baseline value of 23.88 ± 0.11 g/l. Globulins in the experimental group of poultry with a balanced effect of the sympathetic and parasympathetic nervous systems among five animals had discrepancies of 0.23 g/l, which indicates a small discrepancy in the initial results of a biochemical analysis of blood serum.

The experimental group of sympathotonics according to the results of biochemical analysis of blood plasma had differences in the content of total protein and albumins with globulins, in contrast to other experimental groups (Table 2).

Table 2. *Indicators of the protein fraction content in the blood serum of poultry of the experimental sympathotonic group at 35 days (n = 10)*

Indicators	NVO	SE	M	SD	A	Min	Max
Total protein	10	0.27	39.69	0.21	-1.14	39.21	39.92
Albumins	10	0.13	18.30	0.19	-1.16	18.08	18.41
Globulins	10	0.18	21.44	0.11	-1.17	21.18	21.56

Note: NVO – number of valid observations, SE – standard error, M – median, SD – standard deviation, A – asymmetry, Min – minimum value, Max – maximum value
Source: developed by the author

It was established based on a biochemical study of blood plasma of the experimental group of sympathotonics that the total protein ranged from 39.21 to 39.92 g/l with an average value of 39.69 ± 0.21 g/l. Total protein in the experimental group of poultry with a predominance of sympathetic over parasympathetic nervous system among five animals had discrepancies

of 0.71 g/l, which indicates a slight discrepancy in the initial results of a biochemical analysis of blood serum. The albumin content in this group ranged from 18.08 to 18.41 g/l and averaged 18.30 ± 0.19 g/l. Albumins in the experimental group of birds with a predominance of the sympathetic over parasympathetic nervous system among five animals had discrepancies of 0.33 g/l, which indicates a slight discrepancy in the initial results of a biochemical analysis of blood serum. In this experimental group of sympathotonics, the plasma globulin content was in the range of 21.18-21.56 g/l with an average value of 21.44 ± 0.11 g/l. Globulins in the experimental group with a predominance of the influence of the sympathetic over parasympathetic nervous system among five animals had discrepancies of 0.38 g/l, which indicates a slight discrepancy in the initial results of a biochemical analysis of blood serum.

The experimental group of vagotonics according to the results of a biochemical study had differences in the content of total protein, albumins, and globulins in blood plasma (Table 3).

Table 3. *Indicators of the protein fraction content in the blood serum of poultry of the experimental vagotonic group at 35 days (n = 10)*

Indicators	NVO	SE	M	SD	A	Min	Max
Total protein	10	0.24	36.24	0.19	1.03	36.11	36.52
Albumins	10	0.21	16.92	0.15	1.13	16.86	17.04
Globulins	10	0.16	19.33	0.18	1.06	19.26	19.47

Note: NVO – number of valid observations, SE – standard error, M – median, SD – standard deviation, A – asymmetry, Min – minimum value, Max – maximum value

Source: developed by the author

It was determined that in the experimental group of vagotonics, total protein values ranged from 36.11 to 36.52 g/l, which overall averaged 36.24 ± 0.19 g/l. Globulins in the experimental group with a predominance of the sympathetic over parasympathetic nervous system among five animals had discrepancies of 0.41 g/l, which indicates a slight discrepancy in the initial results of a biochemical analysis of blood serum. The albumin content according to the results of biochemical analysis ranged from 16.86 to 17.04 g/l and had an average value of 16.92 ± 0.15 g/l. Globulins in the experimental group with a predominance of the sympathetic over parasympathetic nervous system among five animals had discrepancies of 0.41 g/l, which indicates a slight discrepancy in the initial results of a biochemical analysis of blood serum. In the experimental group of vagotonics, the obtained globulin values ranged from 19.26 to 19.47 g/l and had an average value of 19.33 ± 0.18 g/l. Globulins in the experimental group of birds with a predominance of parasympathetic over sympathetic nervous system among five animals had discrepancies of 0.21 g/l, which indicates a slight discrepancy in the initial results of a biochemical analysis of blood serum.

When analysing the total protein content, differences in indicators were found among experimental groups of poultry with different tones of autonomic nervous regulation. Thus, in the experimental group with balanced influence of the sympathetic and parasympathetic nervous systems, the total protein values on day 35 (43.87 ± 0.13) were 10.5% higher in relation to animals with a predominance of the influence of the sympathetic over the parasympathetic nervous system (39.69 ± 0.21) ($p < 0.001$). The experimental group with a predominance

of parasympathetic over sympathetic nervous system had the lowest total protein content (36.24 ± 0.19) compared to the experimental group of normotonics, which was 17.4% less compared to them ($p < 0.001$). As a conclusion, a bird with a balanced influence of the sympathetic and parasympathetic nervous systems had the highest total protein content, which may indicate a better exchange of protein compounds compared to other groups (Fig. 1).

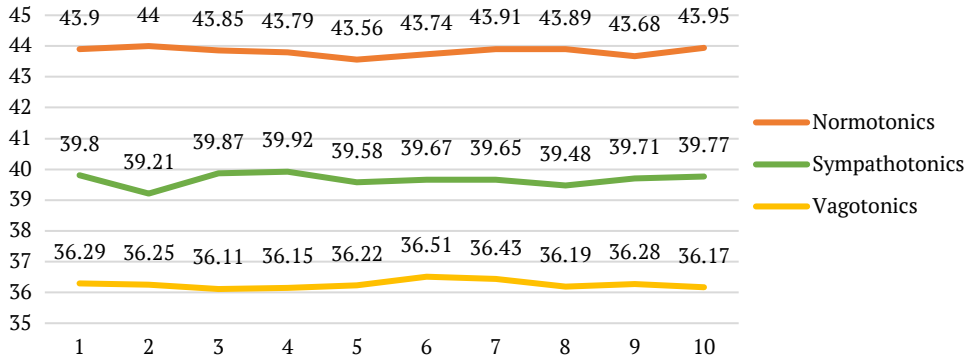

Figure 1. Total protein content in blood plasma of experimental poultry groups
Note: the colours show different tones of the autonomic nervous system, respectively
Source: developed by the author

According to statistical analysis of the results of biochemical analysis of the content of albumins in the blood plasma of poultry, a high content was determined in the experimental group, with a balanced sympatho-vagal balance. Thus, the experimental group with balanced influence of the sympathetic and parasympathetic nervous systems had a higher albumin content (19.99 ± 0.15) by 9% compared to the experimental group with a preference for the influence of the sympathetic over the parasympathetic nervous system (18.30 ± 0.19) ($p < 0.001$), a bird that had a preference for the influence of the sympathetic nervous system. It was established that the experimental group of vagotonic animals with the predominance of the influence of the parasympathetic nervous system had the lowest albumin content (16.92 ± 0.15) in blood plasma, which is 15.4% less than in the experimental group of normotonic animals ($p < 0.001$). The experimental group with a balanced sympatho-vagal balance had the highest albumin content, which indicates intensive protein metabolism processes, especially in poultry during the active growth period (Fig. 2).

When analysing the total protein content, differences in indicators were found among experimental groups of poultry with different tones of autonomic nervous regulation. Thus, in the experimental group with balanced influence of the sympathetic and parasympathetic nervous systems, globulin values on day 35 (23.88 ± 0.11) were 11.4% higher in relation to animals with a predominance of the influence of the sympathetic over the parasympathetic nervous system (21.44 ± 0.11) ($p < 0.001$). The experimental group with a predominance of parasympathetic over sympathetic nervous system had the lowest globulin content (19.33 ± 0.18) compared to the experimental group of normotonics, which was 19.1% less compared to them ($p < 0.001$). Poultry with a balanced influence of the sympathetic and parasympathetic nervous systems had the highest globulin content, which may indicate a better metabolism of protein compounds compared to other experimental groups (Fig. 3).

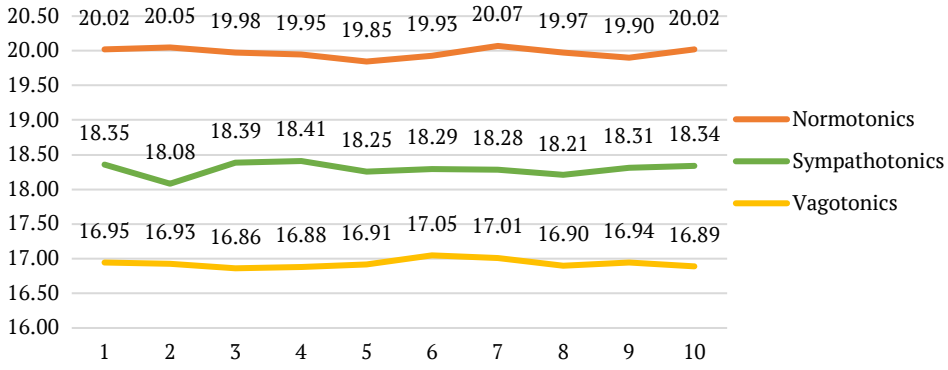

Figure 2. Albumin content in blood plasma of experimental poultry groups
Note: the colours show different tones of the autonomic nervous system, respectively
Source: developed by the author

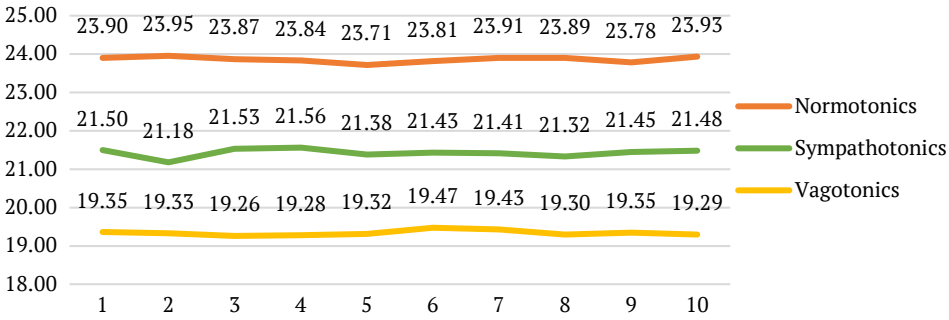

Figure 3. Albumin content in blood plasma of experimental poultry groups
Note: the colours show different tones of the autonomic nervous system, respectively
Source: developed by the author

The content of protein fractions in blood growth plays an important role in understanding the issues of metabolic processes in the bird's body. When the body is actively developing during this period, it is quite important to balance the concentration of nutrients in the diet of broiler chickens. According to S. Harlap *et al.* (2021), protein is one of the most important components among blood parameters. The most common method for assessing the protein spectrum in poultry is to assess the biochemical parameters of total protein, albumins, and globulins. They provide the researcher with an idea of the anabolic or catabolic processes in the body, which further helps to predict the poultry's productivity. The results obtained confirm that considering the tone of the autonomic nervous system, it is possible to record differences in the protein fractions.

Based on the results of the study by S. Liu *et al.* (2021) and T. Nikravesh-Masouleh *et al.* (2021), blood protein levels are very important for obtaining better live weight gain, especially in the initial stages of poultry fattening. The high content of protein fractions in the blood becomes a good reflection of the metabolic processes of metabolism and growth of the body. But there are a number of specific challenges in consuming and conquering protein. It is noted that the excessive protein

content in the bird's body causes a decrease in feed intake and a deterioration in live weight gain. This is because protein intake should be balanced with high-energy compounds. Since for the development and growth of muscle mass of fattening animals, a sufficient amount of carbohydrates and lipids is required. Without considering this variable, there will be an imbalance in the body, without a sufficient amount of energy, protein synthesis and the formation of protein structures are impossible, and it is also worth remembering about the deamination reactions, which are also highly dependent on energy-rich compounds.

The issue of correcting protein metabolism is actively developing. The most popular area is the use of feed additives with a lower level of crude protein. According to T. Woyengo *et al.* (2023), the use of these feeds will have a positive impact on animal health indicators. This is evidenced by the results of growing broilers with a low content of crude protein, the lack was compensated by the introduction of crystalline amino acids into the feeding diet, which equalised the lack of proteins and did not negatively affect the weight gain, which was 200-220 g/kg. Notably, due to the reduced content of crude protein, the economic costs of purchasing feed have decreased. N. Dankevych *et al.* (2020) argue that it is necessary to consider the features of protein metabolism and the rapid growth of the poultry body on fattening, the use of a diet with a lower percentage of crude protein will help prevent nitrogen imbalance, which is reflected in their work and supported by research.

It is also worth noting the importance of switching the poultry diet to a diet with a lower crude protein content according to Z. Goluch *et al.* (2023) and A. Dal Bosco *et al.* (2021), as this solution not only improves the growing technology but also solves the environmental issue. According to the conclusions of P. Maharjan *et al.* (2021), excessive protein nutrition of animals in poultry farms may become an environmental disaster in the future. Since, as a result of raising poultry under such conditions, it contributes to the accumulation of a significant amount of gases that negatively affect the ecological state of the planet.

According to M. Yakubu Abare *et al.* (2023), poultry farming suffers quite a lot from changing climatic conditions. The primary problem that has a negative impact on protein metabolism is heat stress. This indicator is quite actively studied; this is argued by the fact that the bird is located in a much smaller space of existence with a significant accumulation of livestock. The appearance of minor changes in the climatic state of isolated poultry can lead to significant economic losses. Diagnostics of the health status of broilers in this case plays a key role. To counteract the influence of the stress factor, C. Brown *et al.* (2023) used corticosterone hormone preparations to study changes in metabolic processes in the body under artificially simulated production stressors. G. Brugaletta *et al.* (2023) used arginine supplements to counteract cyclic heat stress, which had minor changes in metabolism when exposed to a stress factor. When evaluating these results, it is worth noting that the use of hormonal drugs or protein supplements in the form of amino acids is ineffective compared to the results of this study, and it is also worth noting that diagnosing poultry stress is a time-consuming process. To improve the initial results based on the data obtained in this study, it is worth noting the need to consider the tone of the autonomic nervous system, which will improve the effectiveness of scientific research.

Summing up, poultry farming is gaining more and more momentum over time to ensure the protein nutrition of humanity. More and more methods are being developed to help stabilise and improve the growth and development of poultry, taking into consideration the metabolic processes in their body. The problem is growing not only in providing livestock products, but also in gradually increasing the consequences of such successful production,

which is characterised by an environmental catastrophe. After analysing the work of other researchers, it should be noted that the correction of protein metabolism is taken into account by external feed input, there is also consideration of internal metabolic issues, which primarily concerns balancing the energy integrity of the body. Few questions relate specifically to the analysis of factors controlling protein synthesis and resynthesis. Therefore, it is worth noting that the omission of the body's systems that correct homeostasis in general can worsen the initial results. This is based on the results of a study that analysed the effect of the autonomic nervous system on protein metabolism. According to the results of biochemical analysis, depending on the activity of the sympathetic or parasympathetic nervous system, the results of protein content differ in experimental groups of animals. Thus, it is possible to assert the dependence of protein metabolism processes on the tone of the autonomic nervous system. This leads to the conclusion that it is worth considering this variable as an additional factor in the analysis of protein metabolism, as protein content is quite well correlated with poultry performance.

Conclusions

The influence of the tone of the autonomic nervous system on the indicators of protein metabolism in the blood serum of poultry was established. Differences in protein metabolism indicators in the animal body depending on the tone of the autonomic nervous system were determined: normotonics, vagotonics, and sympathotonics. In particular, differences were found in the blood serum of poultry regarding the content of total protein, globulins, albumins with different tones of the autonomic nervous system

It was found that the total protein content in poultry with a balanced effect of the sympathetic and parasympathetic nervous systems was 10.5% higher in relation to the experimental group of poultry with a preference for the influence of the sympathetic nervous system ($p < 0.001$). The experimental group of poultry that had a 17.4% lower total protein content compared to the experimental group that had a balanced sympatho-vagal balance ($p < 0.001$). It was found that the albumin content in the experimental group of animals with balanced influence of the sympathetic and parasympathetic nervous systems was higher by 9% compared to the experimental group of animals with an advantage of the influence of the sympathetic nervous system ($p < 0.001$). The experimental group of poultry with a predominance of vagotonia had a 15.4% lower content compared to the experimental groups of animals with a predominance of normotonia ($p < 0.001$). It was found that the total protein content in poultry with a balanced effect of the sympathetic and parasympathetic nervous systems was 10.5% higher in relation to the experimental group of poultry with a preference for the influence of the sympathetic nervous system ($p < 0.001$). The experimental group of poultry that had a 17.4% lower total protein content compared to the experimental group that had a balanced sympatho-vagal balance ($p < 0.001$).

Depending on the individual characteristics of the tone of the autonomic nervous system, differences in protein metabolism were determined in experimental groups of poultry that have the predominance of sympathotonia, vagotonia, and normotonia.

The prospect of further research is the use of biologically active additives of nanopreparations to improve protein metabolism and poultry productivity, considering individual characteristics, which are represented by the tone of the autonomic nervous system.

Acknowledgements

None.

Conflict of Interest

None.

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Роль тонусу автономної нервової системи у білковому обміні птиці

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Анотація. Проблема світового ринку у нестачі одного із головних компонентів всіх живих організмів а саме білку є як ніколи актуальною. Продукція від птахофабрик стрімкими темпами намагається заповнити дану ношу, що забезпечується швидким зростанням кількості поголів'я та темпом його росту. Основним будівельним матеріалом, що забезпечує ріст даної кількості тварин займає саме протеїн. Оскільки є пряма залежність білкового обміну і продуктивності птиці. Мета дослідження полягає у встановленні впливу автономної нервової системи на показники білкового обміну сироватки крові птиці. Дослідження проводили на курях кросу Кобб-500. Формування дослідних груп виконувалося за методикою Баєвського. Для визначення вмісту загального білку, глобулінів та альбумінів застосовували спектрофотометр LabLine-010 (Австрія). Для аналізу сироватки крові використовували тест системи від ТОВ «Лабораторія Гранум» м. Харків. За результатами біохімічного дослідження було встановлено, що вміст загального білку у дослідної групи нормотоніків із збалансованим впливом симпатичної і парасимпатичної нервової системи був більший в порівнянні з симпатотоніками на 10,5 % ($P < 0,001$) та ваготоніками на 21,1 % ($P < 0,001$). Вміст альбумінів у нормотоніків більший відносно симпатотоніків на 9 % ($P < 0,001$) та ваготоніків на 18,1 % ($P < 0,001$). У дослідної групи нормотоніків показники глобулінів на 35 день були на 11,4 % більше по відношенню до симпатотоніків) ($P < 0,001$). Дослідна група ваготоніки

мала найменший вміст глобулінів відносно дослідної групи нормотоніків, що було на 19,1 % менше порівнюючи з ними ($P < 0,001$). За результатами дослідження варто відмітити, що птиця яка відноситься до дослідної групи нормотоніків характеризується більш активними процесами обміну білків у організмі, що вносить нову змінну котру варто враховувати при вивченні процесів синтезу і ресинтезу протеїнів та використовувати як додатковий фактор за використання різних кормових добавок

Ключові слова: бройлери; білок; сироватка; амінокислоти; автономна регуляція

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Study of technological aspects of *Procambarus clarkii* cultivation in terms of ensuring their welfare

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Abstract. A crucial element in improving aquaculture performance, including the crayfish farming sector, is enhancing and developing cultivation technologies for new species, whose potential can rapidly supply the market with commercial products. This study aimed to analyse the impact of dietary modifications on the growth performance of *Procambarus clarkii* when fed a vitamin-amino acid complex, "Chicktonic", at rates of 1.0 mL/kg (Group 2) and 2.0 mL/kg (Group 3). The study employed theoretical (analysis, systematisation, comparison), experimental (laboratory), and standard aquaculture research methods. Results indicated that crayfish fed diets supplemented with "Chicktonic" exhibited higher growth rates throughout the experimental period. For instance, Groups 2 and 3 demonstrated a 3.9 and 4.3-fold increase in weight, reaching 13.70 ± 1.10 g and 16.24 ± 1.30 g, respectively. In the control Group 1, which received feed without the vitamin supplement, the lowest weight gain was recorded, increasing by a factor of 3.7, reaching 13.93 ± 1.89 g by the end of the study period. No significant differences in body length were observed among all groups; however, in experimental Group 3 (2.0 mL/kg), this indicator was 8.34±0.22 cm, compared to 7.83 ± 0.42 cm in Group 1 and 7.83 ± 0.18 cm in Group 2. It was found that the introduction of the vitamin-amino acid supplement into the crayfish diet accelerated the sexual maturation of females

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in experimental Groups 2 and 3, where the first specimens with eggs were recorded. The effect of vitamin intake was also noted in the visual assessment of the colour of the crayfish's external chitinous covering. Group 3 (2.0 mL/kg) exhibited a bright red hue, whereas the control group had a pale red, sometimes pale orange, carapace colour. The results obtained may be used to optimise the artificial cultivation of *Procambarus clarkii* and suggest the use of vitamin supplements to improve their welfare and well-being

Keywords: aquaculture; cultivation; weight; length; survival; red swamp crayfish; feeding

Introduction

Given the global challenges and the current state of the crayfish farming industry, there is a pressing need to identify crustacean species with high economic potential that can fill the market gap with high-quality products. To fully explore the possibilities of cultivating new species, efforts should be directed towards optimising or improving methods for their industrial farming. Among the species with high cultivation potential, the red swamp crayfish, *Procambarus clarkii* (Girard, 1852), also known as the Louisiana crawfish or red swamp crayfish, is particularly interesting. According to the criteria of Article 4(3) of *Regulation* (EU) No. 1143/2014 of the European Parliament (2019), *Procambarus clarkii* is a species widely distributed in Europe and cannot be eradicated by economically feasible means. According to the DAISIE invasive species checklist (Roy *et al.,* 2020), this species is registered as having significant invasive potential at the biogeographic level. In a study of this species outside its native range, A. Ballinger (2022) describes the invasive situation of this species on all continents, highlighting the problem of rapid introduction and spread of this species in natural water bodies throughout Europe and other countries. According to A. Nota *et al.* (2024), such a high level of introduction is attributed to the species' high adaptive capacity to various artificial and natural environments, a result of its evolutionary development. This leads to significant imbalances in local ecosystems, driven by consumer pressure on the trophic structure and the dominance of *Procambarus clarkii*. The authors' assumptions were confirmed by a study conducted near the Mediterranean Sea, where individuals of the species were found in close proximity to the coastline at depths of about 1.5 m, with the nearest freshwater sources located 0.5-1.7 km away (note: the salinity of the Mediterranean Sea varies from 36.0 to 39.5‰). The influence of salinity as a limiting factor for the survival and distribution of the species was previously studied by A.J.M. Dörr *et al.* (2020), who found that this parameter has a temporary adverse effect, especially on females, causing a moderate disruption to the redox process, thus not limiting the adaptive abilities of the species.

Overall, the biological characteristics of *Pr. clarkii* provide this species with a significant competitive advantage in terms of cultivation technology and economics. For this reason, when inventorying alien species used for aquaculture and related activities, D. Savini *et al.* (2010) included it in the list of the 27 most popular alien species introduced in Europe. An analysis of crayfish products on the Ukrainian fish market has shown the presence of frozen red swamp crayfish imported from Spain for over 8 years. Statistical data on import volumes and demand for this product are either absent or inaccessible, but the duration of supply indicates an existing economic benefit. Products grown by Ukrainian producers could provide a worthy competitor to imports and replace frozen products with fresh ones. Moreover, the controlled cultivation of *Procambarus clarkii*, particularly

in industrial settings, would reduce pressure on wild crayfish populations in Ukraine, allowing time for their recovery and stabilisation (given a combination of optimal factors), while at the same time guaranteeing a stable supply of crayfish products to the fish market.

However, an analysis of available information sources reveals a significant lack of new data or recommendations concerning the cultivation technology for *Procambarus clarkii*. The vast majority of methods for producing commercial products are based on so-called ecological aquaculture, involving cultivation in earthen ponds. Some farms employ elements of intensive technology, building on the results of individual studies. For instance, in their study, M. Zhao *et al.* (2024) investigated the impact of different types of shelters for crayfish, establishing that under their experimental conditions, PVC pipes demonstrated the highest protective efficacy; researchers reached this conclusion based on improved growth indicators of the crayfish. The growth and development of the red swamp crayfish were studied by J. Wang *et al.* (2023) based on the assessment of an ecological growth and development index; based on a set of biological characteristics, the researchers established a trend towards an improvement in the index with the appearance of a greater amount of nutrients in the crayfish diet. In turn, the crayfish diet was investigated by A. Kaliszewicz *et al.* (2022), studied the possibility of using fatty acids to improve the survival and growth of *Procambarus clarkii*, establishing improved survival rates when palmitic acid was introduced into the diet. X. Chen *et al.* (2024) conducted a large-scale study investigating the influence of different feeding and maintenance conditions on the correlation between carapace colour and astaxanthin content. Thus, groups of crayfish whose diet contained a higher content of β-carotene and were kept at a higher water temperature (30.0°C) had a higher level of astaxanthin, which formed a saturated bright red colouration of the crayfish carapace.

Considering the above information, the search for methods to improve the growth and survival rates of crayfish in the context of developing an artificial cultivation technology for *Procambarus clarkii* is of great relevance. In this regard, the use of vitamin-amino acid supplements is of particular interest, with positive experiences in their application reported for other promising aquaculture species, as described in the research of B. Kovalenko *et al.* (2021), I. Kononenko *et al.* (2023), and I. Kononenko & B. Kovalenko (2023). This issue also becomes relevant in the context that the use of various technological techniques in feed production at different levels can lead to the destruction or alteration of the activity of certain unstable components. Measures aimed at increasing the digestibility of carbohydrates or reducing the negative effects of non-starch polysaccharides can, in some cases, cause the destruction of 35-40%, and sometimes even 50-70% of vitamins and other nutrients.

This study aimed to analyse the impact of feeding *Procambarus clarkii* on the effectiveness of changing their biological and fishery parameters when the vitamin-amino acid complex “Chicktonic” was introduced into the feed.

Materials and Methods

To assess the impact of the vitamin-amino acid complex “Chicktonic” on the growth and welfare of *Procambarus clarkii*, individuals aged 2.5-3.0 months were used. The study involved three groups of subjects: Group 1 – control, which received feed without vitamin supplementation, and two experimental groups: Group 2 received feed with the preparation at a rate of 1.0 mL/kg, and Group 3 – 2.0 mL/kg of feed. The initial number of individuals in each group was 10. Groups were formed by random selection. In total, 30 red swamp crayfish were used in the experiment. The crayfish were kept in 100-litre aquariums.

Water conditioning was carried out using an external JBL CristalProfi e902 greenline

filter, creating a closed water circulation system designed for a volume of 90-300 litres. Water heating was provided by an Atman AT-100W heater. Water temperature and dissolved oxygen content were measured daily using a portable AZ-86021 oximeter.

Compound feeds for trout fish were used for feeding individuals of all groups: Alltech Coppens Advance 1.0 mm (protein content 54.0%, vitamins: vitamin A – 12,000 IU/kg, vitamin D3 – 738 IU/kg) and Alltech Coppens Supreme – 22 3.0 mm (protein content 43.8%, vitamins: vitamin A – 9,138 IU/kg, vitamin D3 – 1,198 IU/kg). The feeds were supplemented with a combined vitamin-amino acid complex, "Chicktonic", which contained (per 1 mL): vitamin A – 2,500 IU, vitamin D3 – 500 IU, alpha-tocopherol – 3.75 mg, vitamin B1 – 3.5 mg, vitamin B2 – 4.0 mg, vitamin B6 – 2.0 mg, vitamin B12 – 0.01 mg, sodium pantothenate – 15.0 mg; vitamin K3 – 0.250 mg, choline chloride – 0.4 mg, biotin – 0.002 mg, inositol – 0.0025 mg, D, L-methionine – 5 mg, L-lysine – 2.5 mg, histidine – 0.9 mg, arginine – 0.49 mg, aspartic acid – 1.45 mg, threonine – 0.5 mg, serine – 0.68 mg, glutamic acid – 1.16 mg, proline – 0.51 mg, glycine – 0.575 mg, alanine – 0.975 mg, cystine – 0.15 mg, valine – 1.1 mg, leucine – 1.5 mg, isoleucine – 0.125 mg, tyrosine – 0.34 mg, phenylalanine – 0.81 mg, tryptophan – 0.075 mg, and a filler.

The required vitamin dosage was measured using a single-channel LLG micropipette with a measurement volume of 100-1,000 µL. The compound feed was treated with the vitamin-amino acid preparation "Chicktonic" using a spray-drying method. This involved spraying and subsequent drying of a vitamin emulsion, which was prepared using distilled water at room temperature at a rate of 100 mL of water per 1.0 kg of feed. The compound feed was spread out in a single layer on a tray. During the spraying process, the feed was continuously mixed to ensure maximum uniformity of the mixture distribution across the feed surface.

To minimise the loss of activity, the compound feed was treated in small batches: 0.1-0.5 kg, adjusted according to the growth of the individuals and changes in their diet. Treated feed was used within 4-5 weeks to prevent significant vitamin losses during prolonged storage. The treated feed was stored in individual zip-lock bags placed in containers, which were kept in a cupboard away from direct sunlight. The daily feeding rate for *Procambarus clarkii* was determined based on their total biomass and varied from 2.0 to 5.0% of their total biomass at different stages of individual development. The experimental groups were fed twice daily: the determined feed ration was divided into two portions in a 30:70 ratio – the first portion was introduced in the morning, and the second in the evening. The feed was placed in two feeding stations located on opposite sides of the aquarium.

Intermediate measurements of crayfish length and mass, as two primary fish-biological parameters, were conducted every 10 days. The daily feed ration was adjusted based on the data obtained. The study duration was 2 months. Measurements of mass and body length were performed following general fish-biological recommendations using a vernier calliper, measuring tape, and a TVE-0.21 laboratory balance with a minimum increment of 0.02 g. The conditions for keeping, feeding, and caring for the crayfish complied with the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (1986) and adhered to the bioethical standards of good animal welfare as outlined in the Regulation "On the Protection of Animals Used for Scientific or Educational Purposes at the National University of Life and Environmental Sciences of Ukraine" (2023).

Results and Discussion

Daily monitoring of the water's hydrochemical parameters during the cultivation of *Procambarus clarkii* over the study period showed

that, with the experimental temperature set at 25.0°C in all aquariums, the actual temperature readings fluctuated from 25.9°C at the beginning of the study (October) to 24.8°C at the end (December), but remained within the optimal range for the species. The dissolved oxygen content varied within the optimal range for this species: from 6.1 mgO2/L to 7.1 mgO2/L; pH – 7.9-8.3. Thus, from the standpoint of hydrochemical parameters, the aquatic environment was within the optimal range.

The results of measurements of biological and fishery parameters, specifically the weight and length of *Procambarus clarkii*, during the study period, are presented in Table 1.

Table 1. *Biological and fishery parameters of Procambarus clarkii over the study period*

Date	Mean mass, g (M±m)			Mean length, cm (M±m)		
	Group 1 (control) *max/min**	**Group 2 (1.0 mL/kg)** *max/min**	**Group 3 (2.0 mL/kg)** *max/min**	**Group 1 (control)** *max/min**	**Group 2 (1.0 mL/kg)** *max/min**	**Group 3 (2.0 mL/kg)** *max/min**
	μ**	μ**	μ**	μ**	μ**	μ**
06.10.23	*2.60/4.90*	*2.00/4.70*	*2.90/4.30*	*4.50/6.50*	*4.50/6.00*	*5.00/5.50*
	3.74 ± 0.24	3.50 ± 0.28	3.78 ± 0.15	5.40 ± 0.19	5.25 ± 0.16	5.30 ± 0.09
16.10.23	*3.70/6.00*	*3.10/6.00*	*4.3/6.1*	*6.00/6.50*	*5.00/6.20*	*5.50/7.00*
	4.55 ± 0.28	4.80 ± 0.29	4.79 ± 0.18	5.56 ± 0.16	5.57 ± 0.13	6.30 ± 0.15
25.10.23	*4.50/8.80*	*3.80/10.70*	*6.2/9.3*	*5.50/7.00*	*3.20/7.70*	*6.2/7.5*
	6.17 ± 0.59	6.79 ± 0.75	7.44 ± 0.43	6.46 ± 0.20	6.21 ± 0.52	6.84 ± 0.17
08.11.23	*6.40/13.60*	*8.10/13.60*	*8.2/12.8*	*6.00/7.50*	*6.50/8.00*	*6.30/7.50*
	9.21 ± 1.00	9.73 ± 0.90	10.53 ± 0.71	6.79 ± 0.23	7.22 ± 0.23	7.21 ± 0.20
15.11.23	*8.10/14.20*	*8.20/14.90*	*8.8/14.1*	*6.50/8.10*	*6.50/8.50*	*6.80/7.80*
	11.37 ± 1.12	10.52 ± 1.06	11.97 ± 0.76	7.25 ± 0.31	7.25 ± 0.31	7.43 ± 0.16
22.11.23	*9.60/15.70*	*10.50/15.50*	*10.00/16.20*	*6.50/8.00*	*7.00/8.20*	*7.50/8.50*
	12.82 ± 1.22	11.73 ± 0.84	13.71 ± 0.82	7.25 ± 0.27	7.33 ± 0.21	7.96 ± 0.15
06.12.23	*9.50/21.50*	*16.10/17.00*	*12.7/21.60*	*7.00/9.50*	*7.50/8.500*	*7.70/9.00*
	13.93 ± 1.89	13.70 ± 1.10	16.24 ± 1.30	7.83 ± 0.42	7.83 ± 0.18	8.34 ± 0.22

Note: * – minimum and maximum values of the measured parameter; ** – mean value of the measured parameter

Source: authors' development

It was established that through random selection, three experimental groups of *Procambarus clarkii* were formed with relatively homogeneous initial mass and body length. At the beginning of the study, the mean body mass of the control Group 1 was 3.74 ± 0.24 g with a minimum and maximum value in this group of 2.60 and 4.90, respectively. Individuals in the experimental Group 2 were characterised by a mean body mass of 3.50 ± 0.28 g with a minimum mass of 2.00 g and a maximum of 4.70 g. In the experimental Group 3, the studied mean body mass was 3.78 ± 0.15 g with a minimum and maximum value of 2.90 and 4.30 g, respectively.

The most intense increase in body mass in all three groups was observed during the first month of cultivation – it was during this period that each group experienced a "mass jump" (Fig. 1). At the same time, the mass gain in the control group increased by an average of 1.35 times at each measurement stage. Thus, during the first month of cultivation, the average mass of individuals in the control group was 9.21 ± 1.00 g, increasing the mass gain by an average of 5.47 g. The average mass of crayfish

in experimental Group 2 (1.0 mL/kg) increased by 1.39 times, and the average gain of 1 individual was 6.23 g. The mass of individuals in experimental Group 3, which received the vitamin at a dose of 2.0 mL/kg, increased by 1.45 times during the first month of cultivation, reaching 10.53 ± 0.71 g, which is 6.75 g more compared to the initial mass.

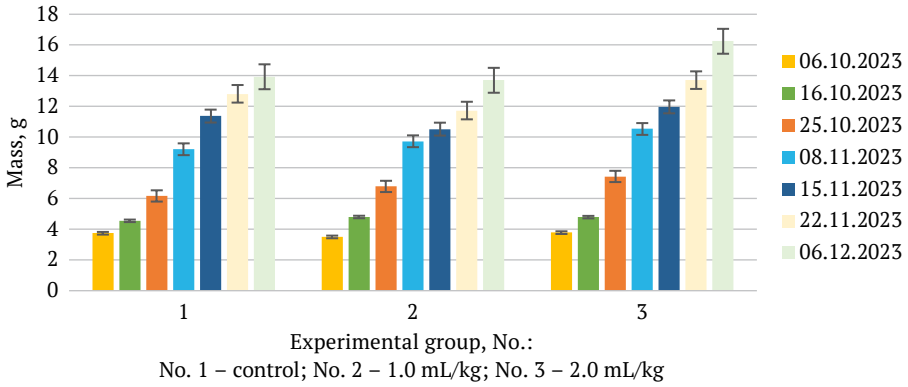

Figure 1. Weight gain of crayfish over the study period
Source: authors' development

Further analysis of mass during the second month of cultivation did not reveal any significant differences in the growth rate among the three experimental groups. On average, the mass gain of individuals in the control Group 1 increased by 1.15 times (by 4.72 g), compared to the first month of cultivation. For individuals in experimental Groups 2 (1.0 mL/kg) and 3 (2.0 mL/kg), this figure increased by 1.14 and 1.16 times, respectively (by 3.97 and 5.71 g). Overall, during the second month of cultivation, there was a trend towards a similar growth rate for individuals in all groups. However, it is essential to emphasise that the use of the vitamin supplement in Groups 2 and 3 during the first month of feeding effectively "kick-started" their growth, providing a solid foundation for weight gain that was maintained throughout the remainder of the study period.

Overall, the final mass of crayfish in the control Group 1 increased 5.36 times compared to the initial mass, reaching 13.93 ± 1.89 g, with an average mass gain of 10.20 g. In experimental Group 2, the initial mass of individuals increased 6.85 times, reaching an average of 13.70 ± 1.10 g with a gain of 10.20 g. The highest average mass was obtained in experimental Group 3 – 16.24 ± 1.30 g, where the initial mass increased by 12.46 g, which is 5.60 times greater compared to the initial mass.

Regarding the linear growth of crayfish in all groups, analysis of the obtained data did not show a significant difference in the growth rate intensity, not only in the first month of cultivation but also throughout the entire study period. Linear growth occurred with a relatively constant intensity throughout the entire study period (Fig. 2). On average, the body length of crayfish in the control Group 1 increased by 2.43 cm compared to the initial length (5.40 ± 0.19 cm), reaching 7.83 ± 0.42 cm. In crayfish of experimental Group 2 (1.0 mL/kg), no significant differences in linear growth rates were found compared to the control group. Thus, on average, the body length of individuals in Group 2 increased by 2.58 cm, reaching 7.83 ± 0.18 cm at the end of the study period. The highest results of linear growth were established in individuals of experimental Group 3 (2.0 mL/kg),

which reached 8.34 ± 0.22 cm after two months of the study, increasing body length by 3.04 cm compared to the initial length (5.30 ± 0.09 cm).

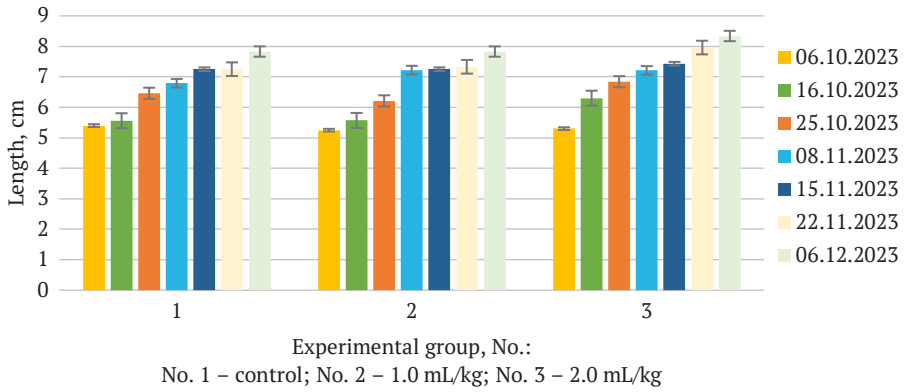

Figure 2. Linear growth of crayfish over the study period

Source: author's development

This study does not assess the welfare and well-being of *Procambarus clarkii* in terms of survival, as all recorded deaths in each experimental group were caused by cannibalism and are indicative of a behavioural rather than a physical issue. This aspect will be examined in a subsequent study investigating the use of different shelter designs and configurations. The following table (Table 2) provides an overview of the changes in the number of *Procambarus clarkii* individuals in the experimental groups throughout the study period.

Table 2. *Changes in the number of individuals in experimental groups over the study period*

Age, months	Number of specimens, n		
	Group 1 (control)	Group 2 (1.0 mL/kg)	Group 3 (2.0 mL/kg)
2.5-3.0	10	10	10
3.0-3.5	10	10	9
3.5-4.0	7	8	7
4.0-4.5	7	6	7
4.5-5.0	6	6	7
5.0-5.5	6	6	7
5.5-6.0	6	6	7
% survival	**60**	**60**	**70**

Source: authors' development

The first recorded mortality occurred in experimental Group 3 on the ninth day of the study, coinciding with the first instance of moulting in this group, which triggered a behavioural response – cannibalism. Overall, survival rates for the control Group 1 and experimental Group 2 were 60%. In experimental Group 3, survival was 70%, which is 10% higher than the control and experimental Group 2. While not significant, this result could also be linked to the use of feed with a higher vitamin and amino acid complex content (2.0 mL/kg of feed).

The enrichment of feed with the vitamin-amino acid complex "Chicktonic" during

feeding also had an effect on the colour of the chitinous exoskeleton of *Procambarus clarkii* in the experimental groups. Visual assessment of colour intensity showed that experimental Group 3, which consumed feed supplemented with 2.0 mL/kg of the vitamin, had a bright red colouration of the carapace (Fig. 3), while crayfish in the control Group 1, which received feed without the vitamin, had a pale red, and in some cases even pale orange, the colouration of the carapace (Fig. 4). The colour difference was clearly noticeable and did not require the use of any additional measurement methods.

Figure 3. Individuals from Group 3
Source: authors' material

Figure 4. Individuals from the control group
Source: authors' material

Analysis of the use of "Chicktonic" in the feeding of the red swamp crayfish showed that the first females with eggs were recorded in experimental Groups 2 and 3, i.e., those that consumed compound feed supplemented with the vitamin-amino acid complex "Chicktonic" at doses of 1.0 and 2.0 mL/kg, respectively. This indicates one advantage of introducing this preparation into the diet. By the end of the second month of the study, when the females were 5.0-5.5 months old, fully developed ovaries capable of participating in the reproductive process had formed.

When assessing the behavioural responses of *Procambarus clarkii* during measurements of aquaculture biological indicators and aquarium maintenance (such as water changes and cleaning shelters), it is believed that the studied subjects were temporarily in conditions of suboptimal welfare. This was indicated by their experiencing minimal negative impacts from all manipulations, as their basic needs for optimal management were met (including the absence of physical stress, prompt execution of tasks, careful handling, and the provision of comfortable conditions). Active behaviour in the subjects was observed for a while after their return to the rearing environment; however, the crayfish quickly returned to their usual state and responded positively to feeding.

Analysis of the results from the first month of rearing *Pr. clarkii* showed that the ratio of vitamins and amino acids in the diet of the study subjects in all three groups had little impact on their biological and fishery parameters during the early stages of rearing. This finding is corroborated by research conducted by J. Wang *et al.* (2023), where the research group assessed the morphological and biological characteristics of *Procambarus clarkii* by comparing the results of feeding with diets containing protein and fat levels ranging from 6.0-25.0% in the experimental groups to 8.0-32.0% in the control groups. For the first 20 days, the studied parameters were at a reference level in all groups, and a significant difference was recorded between 40 and 80 days of the experiment. In the current experiment, a positive effect of introducing vitamins into the crayfish feed was first recorded

20 days after the start of the experiment, when, after relatively stable indicators in all groups, a significant increase in average body weight of 1.9 g was observed in Group 3 (2.0 mL/kg) compared to the previous measurement. In contrast, Group 1 (control) showed an increase of 0.8 g and Group 2 (1.0 mL/kg) an increase of 0.7 g. However, starting from the 30th day of rearing, a stable increase in weight gain was recorded, with this trend continuing until the end of the experiment, also in experimental Group 2. Thus, the groups that received the additional vitamin-amino acid complex had more distinct results compared to the control group. A similar effect of the "Chicktonic" preparation was established by B. Kovalenko *et al.* (2021) when studying the effect of this preparation on the fish farming parameters of the African sharptooth catfish. In that study, the weight gain of fish that received an additional vitamin-amino acid preparation was activated on days 20-30 of rearing in older individuals, and after day 30 of rearing in juveniles (Muzzarelli, 2013; Lyko, 2017).

It can be assumed that the high growth rates of the crayfish after the first month of rearing, especially in the experimental groups that consumed compound feed supplemented with vitamins, are associated with the well-known fact of the optimal impact of vitamin consumption in the early stages of development when complex morpho-physiological transformations occur in the organism, as detailed by M. Yevtushenko (2015). The created feeding conditions ensured the optimal course of metabolic processes, in particular, plastic and energy metabolism, due to the sufficient amount of nutrients, including vitamins, and the optimal redistribution of feed energy. A similar result was described in the study of B. Kovalenko *et al.* (2021) when feeding young African sharptooth catfish with "Chicktonic" revealed faster absorption and conversion of nutrients into linear weight gain. Additionally, likely, the decrease in weight gain intensity in the experimental groups during the second month of the study was caused by reaching sexual maturity in *Procambarus clarkii*, which is associated with rapid growth and development of gametes and a preferential allocation of energy from plastic or energy metabolism towards reproductive metabolism (Amine *et al.*, 2008; Yevtushenko, 2015). However, a decrease in the mass of individuals in the experimental groups with the onset of sexual maturity and the development of reproductive products was not recorded, suggesting that the additional intake of nutrients allows the body to compensate for energy expenditures on different levels of metabolism and maintain high results (Niu *et al.*, 2014; Wade *et al.*, 2017).

Furthermore, the results obtained in this study coincide with the data on the use of the vitamin-amino acid preparation "Chicktonic" in the feeding of African sharptooth catfish and tilapia, as described in the scientific studies of B. Kovalenko *et al.* (2021), I. Kononenko *et al.* (2023) and I. Kononenko & B. Kovalenko (2023). For example, the results of the research by I. Kononenko *et al.* (2023) also show the effectiveness of introducing the vitamin-amino acid complex "Chicktonic" into the diet of tilapia, the effectiveness of which was especially evident when creating unfavourable environmental conditions. In addition to the overall increase in fish body weight, this contributed to maintaining high survival rates in groups that consumed feed with the vitamin at a level of 90.0% compared to 60.0% in the control group.

In the study by I. Kononenko & B. Kovalenko (2023), when feeding Arican sharptooth catfish with feed containing the "Chicktonic" preparation at doses of 1.0 and 2.0 mg/kg (Groups 2 and 3, respectively), no significant difference in biological and fishery parameters was found between the experimental and control groups. However, a positive effect of the preparation on survival was established in the experimental groups, which increased by an average of 2.0-4.0%. Additionally, similar results improving survival rates to 67% ± 13

were obtained in the study by Kaliszewicz *et al*. (2022). However, when dietary supplements with fatty acids, particularly palmitic acid, were introduced into the diet of young *Procambarus clarkii*. The results obtained in the current study indicate a positive effect of vitamins in the diet of the red swamp crayfish on its survival, which was at the level of 70.0% in Group 3, which is 10.0% higher than in the control and experimental Group 2.

Analysis of the crayfish's exoskeleton colouration showed that the groups consistently fed with vitamin-supplemented feed had a bright, saturated carapace colour compared to the pink, sometimes even pale pink, colouration of the individuals in the control group. The obtained results may indicate a higher level of carotenoids, especially astaxanthin, the gene which was identified by X. Chen *et al*. (2024), which has a direct impact on the formation of the intensity and saturation of the *Procambarus clarkii* carapace colour. The saturated colour of *Procambarus clarkii* can be a great tool to influence the consumer, making the product competitive in the fish market (Wickins & O'C Lee, 2002; Luo *et al*., 2019).

The earlier sexual maturation observed in females from the experimental groups, compared to the control, could also be a result of the additional consumption of vitamins and the intake of beneficial substances. According to M. Yevtushenko (2015), the attainment of sexual maturity in fish is also linked to the accumulation of certain biologically active substances in the organism: vitamins, enzymes, amino acids, and fatty acids. Thus, the feeding conditions created for the experimental groups of *Procambarus clarkii*, whose diet contained an additional vitamin-amino acid complex, enhanced their organism's ability to convert additional nutrients from feed and optimally distribute the obtained resource to ensure the biological needs of growth and development, as well as physiological and behavioural activity in this system, which provides well-being under artificial cultivation conditions. Thus, based on the conducted research, the undeniable advantage of introducing the vitamin-amino acid preparation "Chicktonic" into the diet of *Procambarus clarkii* has been established.

Conclusions

The results of this study have demonstrated the positive impact of incorporating the vitamin-amino acid complex "Chicktonic" into the diet of *Procambarus clarkii*, influencing every aspect of the research. When comparing the results of crayfish rearing, it is evident that experimental Groups 2 and 3, which consumed feed supplemented with this preparation at different doses, showed a clear advantage in terms of linear weight gain, sexual maturation, and exoskeleton colouration. Notably, crayfish in experimental Group 3 outperformed not only the control group but also experimental Group 1, which consumed feed with half the vitamin dose compared to Group 3 – 1.0 mL/kg. Analysis of linear growth indicators did not reveal any significant difference in body length among all three groups. All recorded cases of crayfish mortality in each group were exclusively linked to cannibalism and had no relation to feeding conditions, vitamin dose, or adverse welfare. Assessment of exoskeleton colouration revealed a significant difference in carapace colour between crayfish that consumed feed with the vitamin and crayfish from the control group.

Based on the conducted research, it can be concluded that the welfare of the crayfish in the experimental groups during their artificial cultivation was evident, as the results indicate that optimal conditions for the functioning of all biological systems were established. This contributed to the good growth and appearance of the crayfish, reflecting their welfare and well-being.

The results obtained have significant potential for further research in terms of studying the specific manifestations of the effects of higher concentrations of the vitamin-

amino acid complex under various conditions of artificial cultivation, as well as optimising and intensifying the cultivation technology of *Procambarus clarkii* while adhering to the principles of animal welfare.

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None.

Conflict of Interest

None.

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Вивчення технологічних аспектів вирощування раків *Procambarus clarkii* у розрізі забезпечення їх благополуччя

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Анотація. Важливим елементом підвищення показників аквакультури, в тому числі сектору раківництва, є удосконалення та розробка технологій вирощування нових видів, потенційні можливості яких у короткі терміни здатні забезпечити ринок товарною продукцією. Мета роботи полягала в аналізі впливу особливостей годівлі Procambarus clarkii на їх рибницько-біологічні показники при введені у корми вітамінно-амінокислотного комплексу «Чиктонік» у кількості 1,0 мл/кг корму (група № 2) та 2,0 мл/кг (група № 3). В ході експерименту використано теоретичні (аналіз, систематизація, порівняння), експериментальні (лабораторні) та загальноприйняті у рибництві методи досліджень. Встановлено, що групи раків, що споживали корми з препаратом «Чиктонік», характеризувалися вищими показниками лінійно-вагового приросту протягом всього досліджуваного періоду. Так, у групах № 2 та № 3 маса збільшилася у 3,9 та 4,3 рази, досягнувши 13,70 ± 1,10 г та 16,24 ± 1,30 г відповідно. У контрольній групі №1, яка отримувала корм без добавки вітаміну, зафіксоване найнижчі показники збільшення маси – у 3,7 рази, що в кінці досліджуваного періоду становило 13,93 ± 1,89 г. Значних відмінностей у довжині тіла серед всіх груп досліду не зафіксовано, однак у дослідній групі № 3 (2,0 мл/кг) даний показник становив 8,34 ± 0,22 см, порівняно з 7,83 ± 0,42 см у групі № 1 та 7,83 ± 0,18 см у групі № 2. Виявлено, що введення вітамінно-амінокислотного препарату у раціон раків стимулювало швидше статеве дозрівання самиць у дослідних групах № 2 та № 3, де першими зафіксовані екземпляри із ікрою. Вплив споживання вітаміну виявлено також при візуальній оцінці кольору зовнішнього хітинового покриву раків – група № 3 (2,0 мл/кг) характеризувалася забарвленням яскраво-червоного кольору, водночас контрольна група мала блідо-червоний, подекуди блідо-оранжевий колір панциря. Отримані результати можуть бути використані для оптимізації штучного вирощування Procambarus clarkii та запровадити використання вітамінних комплексів для підвищення показників їх благополуччя та добробуту

Ключові слова: аквакультура; культивування; маса; довжина; виживаність; червоний каліфорнійський рак; годівля

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Quality characteristics of beef depending on its marbling

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Abstract. Marbling of muscles is a valuable feature of individual cuts of cattle carcasses, but in Ukrainian breeds it remains unexplored how the content of intramuscular fat correlates with the chemical composition, carcass characteristics, and meat processability indicators important for industrial processing and production of meat products. The purpose of the study was to establish the dependence of slaughter characteristics, chemical composition, physical and technological, and sensory properties of beef on its marbling. The marbling of muscle tissue, the content of total fat and ash mass, moisture, protein, acidity (pH), and penetration were evaluated in 34 carcasses of 18-24-month-old bulls of the "Zhuravushka" farming enterprise (FE), Brovary District, Kyiv Oblast. The aroma, juiciness, tenderness and chewiness of the boiled meat were determined by 8 tasters, focusing on colour, taste and strength of the broth. The data obtained indicate that when the marbling class improved, the content of muscle tissue in the carcass was increased by 3.0 ($p > 0.99$) points, and bones by 2.0 points ($p > 0.95$). There was a tendency to increase the second grade pulp by 1.4 points, fat tissue by 1.5 points, tendons and ligaments by 0.1 points, and to improve the conformation (meatiness) of carcasses by 6.1%, the colour of muscle (by 1.9%) and fat tissue (by 2.1%). By increasing the marbling of beef, there is a tendency to reduce the muscle tissue of the highest (by 0.9 points) and first grades (by 0.2 points), water binding capacity (by 0.7 points), boiling (by 1.1), dry matter (by 2.1 points), protein (by 1.8 points) total fat content (by 0.6 points),

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penetration (by 19.8%), meat tenderness (by 3.1%), its residue after chewing (by 6.7%), taste (by 6.9%), acidity (by 2.1%). The practical significance of the study lies in the possibility of using the data obtained to sort the carcasses of Ukrainian Black-and-White dairy bulls according to their intended purpose, considering the relationship between marbling of beef and slaughter indicators, chemical and physical, technological properties, sensory characteristics of cooked meat and broth from it

Keywords: bovine cattle; meat; conformation; carcasses; sensory characteristics

Introduction

The amount of marbling inclusions in beef is identified with the fat in the middle of the *m. longissimus dorsi*. The quality of beef carcasses according to marbling scales is determined in Australia (MSA, 2015), South Korea (MFAFF, 2007), USA (USDA, 2001), Japan (JMGA, 2000), which are mainly based on visual classification systems. In Europe, carcasses are not graded according to the EUROP (2008) system, and marbling is not determined. In addition to visual classification methods, according to E. Cardenas *et al. (*2024), marbling can be determined by automatic methods, by processing digital images, the accuracy of which is quite high and reaches a degree of correspondence with a visual score of more than 88%. T. Erena *et al.* (2024) note that meat with a high level of marbling is characterised by improved sensory properties, and T. Sakowski *et al*. (2022) suggest that no factor has a more beneficial effect on beef flavour than the fat content between muscle bundles, since marbling correlates with indicators such as taste and juiciness. But marbling did not become an indicator. It varies depending on age, sex, breed, and other characteristics. Research conducted by T. Erena *et al. (*2024) on beef obtained from animals of three different breeds, showed that the muscles localised in different parts of the body differ in the level of marbling and this difference also has certain breed features, which is advisable to consider during meat quality control. There are statistical differences in meat quality between dairy and meat breeds, but they are not detected by marbling assessment (Winebold *et al*., 2024). In breeds with a high marbling potential, when fattening livestock on concentrated feed for a long period of time, marbling improves, inedible fat is deposited (visceral and subcutaneous), the number of its scraps increases, but the quality of carcasses decreases and feed costs for products increase, which negatively affects the economy of beef production, as noted by J. Albechaalany *et al.* (2024). The quality factors of meat perceived by consumers are its sensory characteristics (tenderness and taste), nutritional properties (caloric content), appearance (colour, marbling, visible amount of fat).

Beef enters the Ukrainian markets from dairy animals, with the majority of the beef coming from Ukrainian Black-and-White dairy breeds. Features of quantitative and qualitative characteristics of meat from them with different marbling have not been studied. It is the main factor that determines the sensory quality of beef (Sakowski *et al*., 2022), has a positive effect on consumers' perception of its taste and tenderness (Beck *et al*., 2022). Dairy cattle have a slight marbling of meat, and the relationship between it and fat content in the middle of the muscles and under the skin is unclear (Martín *et al.,* 2022). There was also no correlation between beef marbling and fat content under the skin (Kruk *et al.,* 2023), indicators of the values of the "loin eye" and tenderness, juiciness, taste of boiled meat (Kruk *et al.,* 2024).

According to V.F. Ozdemir *et al.* (2024), a better understanding of the relationship between these traits will help solve the problem of beef quality in dairy cattle. Therefore, it is important to provide a practical substantiation of the need to include the quality indicator of marbling of muscle tissue in the regulatory documents on the classification of beef carcasses and to determine whether marbling affects other meat traits to increase its sustainable production from dairy animals. The marbling class should also be determined to prevent shortening of muscle fibres, which leads to the rigidity of boiled beef, since fat in bulls significantly affects the texture of meat.

The purpose of the study was to evaluate the features of the chemical composition, sensory, physical, and technological properties of beef of 18-24-month-old bulls of the Ukrainian Black-and-White dairy breed at different classes of muscle tissue marbling, according to which it would be possible to provide adequate meat and fat yield and sensory characteristics for consumers.

Materials and Methods

The study was carried out on 34 carcasses of 18-24-month-old Ukrainian Black-and-White dairy bulls at the "Zhuravushka" farming enterprise (FE), Brovary district, Kyiv Oblast. During the research, all bioethical requirements for animals were met in accordance with the Law of Ukraine No. 249 (2012) and the European Convention for the Protection of Vertebrate Animals Used for Research and Other Scientific Purposes (1986). The animals were kept from birth to 4 months of age in a group. Then they were raised and fattened on the site before slaughter. The animals' feed needs were met by the farm's fodder base. From self-feeders, bulls were fed coarse, juicy, green, concentrated feed, and minerals. Cattle were slaughtered in the slaughterhouse at the Kalynivka village. The conformation of carcasses and their subcutaneous fat were visually evaluated after weighing them in accordance with the Commission Regulation system (EC, 2008). The conformation of carcasses was classified on a scale of 5 classes: from E (very high muscle development) to P (very low muscle development). For statistical analysis, they were converted to points from 1 (corresponds to P) to 5 (corresponds to E). Subcutaneous fat development was evaluated on a scale of 5 classes: from 1 (lean) to 5 (very fat). Then the carcasses were sawn in half, and the half-carcasses were divided at the level of the 12th rib. The colour of muscle and fat tissue was determined using scales from 1 to 7 according to the method (JMGA, 2000). Between the 12th and 13th ribs, the thickness of subcutaneous fat was measured with a ruler. The marbling of meat was determined according to the JMGA (2000) method on a 12-point scale (Fig. 1). According to the class, the carcasses were divided into two groups. The first group included carcasses (n = 18) with a marbling score of 1 to 6 points. The second group (n = 16) – from 7 to 12 points.

The penetration of raw meat was determined according to the method by V. Guts & O. Koval (2007) using a PMDP-type automatic penetrometer. The content of bound moisture was determined using 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 that appeared under the compressed meat and the released moisture that the paper absorbed was examined with a planimeter. The area of the wet spot was determined by the difference between the total area of the spot and the occupied meat. The water-retaining capacity of meat was determined by the ratio of the content of bound water to the weight of the meat suspension.

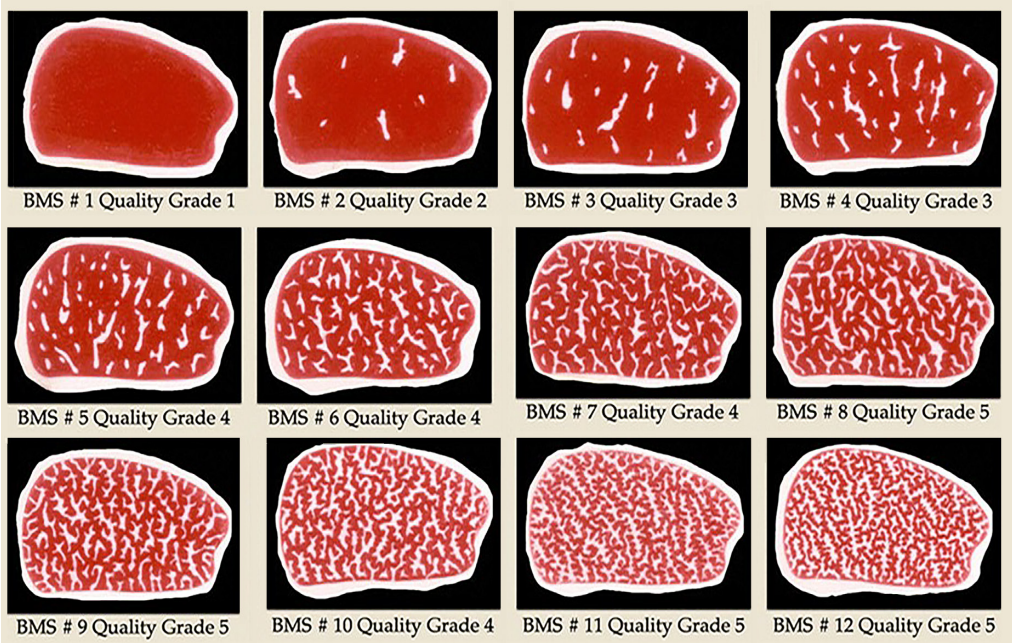

Figure 1. Marbling assessment scale for *m. longissimus dorsi*
Source: JMGA (2000)

To determine the weight of beef that remained after boiling, pieces of meat in the shape of a rectangle weighing 150 g were cut out of *m. longissimus dorsi*. They were weighed on a TNV-600 scale with an accuracy of 0.01 g and placed in a 5-litre pot and filled with 2-3 litres of cold distilled water. It was brought to a boil and the meat was cooked for 90 minutes over low heat. After cooking, the pieces were removed from the water, cooled to 20°C and weighed. Beef boiling was determined by the equation (1) provided by G. Shkurin *et al.* (2002).

$$Sm = \frac{Cm \times 100}{Rm}, \quad (1)$$

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

In the laboratory of the Department of Meat, Fish and Seafood Technology of the National University of Life and Environmental Sciences of Ukraine (NULES), the chemical composition of beef was studied in accordance with: DSTU ISO 1443:2005 (2008) – total fat content; DSTU ISO 936:2008 (2008) – total ash weight; DSTU ISO 1442:2005 (2008) – moisture content; DSTU ISO 2917:2001 (2003) – acidity (pH). The protein content was determined according to G. Shkurin *et al.* (2002).

The aroma, juiciness, tenderness, ease of chewing boiled beef and the colour, taste, strength of broth from it were evaluated 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 NULES of Ukraine according to the recommendations provided by G. Shkurin *et al.* (2002). The data obtained was processed using Microsoft Excel 2016.

Results and Discussion

With an increase in the marbling class in the range from 1-6 to 7-12 points, the content of muscle tissue in the carcass increased by 3.0 points ($p > 0.99$) and in bones by 2.0 points

(p > 0.95), there was also a tendency to improve the slaughter yield (carcasses) by 0.2 points, tendons and ligaments – by 0.1 points, fat tissue – by 1.5, and muscle of the second-grade – by 1.4 points (Table 1). The improvement in the amount of muscle tissue, including second-grade muscle tissue with an increase in its marbling, can be explained by the fact that during fatty tissue fattening, it also includes the fat tissue between the muscles. Increasing the marbling class contributes to the tendency to a slight decrease in the content of muscle tissue of the highest by 0.9 points and the first grade by 2.2 points.

Table 1. *Slaughter indicators and morphological composition of bull carcasses with different marbling classes of m. longissimus dorsi, M ± m*

Indicator	Marbling class, points	
	from 1 to 6 (n = 18)	from 7 to 12 (n = 16)
Live weight after period of fasting, kg	425 ± 13.8	407 ± 7.2
Slaughter yield (carcasses), %	45.6 ± 0.31	45.8 ± 0.12
Muscle tissue, %	68.0 ± 0.68	71.0 ± 0.56**
including the highest grade, %	23.2 ± 0.88	22.3 ± 0.88
-//- first grade, %	46.7 ± 0.64	46.5 ± 0.62
-//- second grade, %	29.9 ± 1.33	31.3 ± 1.26
Fat tissue, %	2.2 ± 0.25	3.7 ± 0.53
Tendons and ligaments, %	1.5 ± 0.18	1.6 ± 0.07
Bones, %	21.7 ± 0.61	23.7 ± 0.39*

Notes: *)p>0.95; **)p>0.99

Source: developed by the authors

Deterioration of the morphological composition of carcasses at higher levels of marbling was also proved by S. Liu *et al.* (2024). In their opinion, because of this, production workers should not breed dairy cattle with a high interspersed fat between the muscles either by genetic selection methods or by adjusting diets. To solve this problem, it is necessary to understand the distribution of fat between the main fat depots: intramuscular, subcutaneous, and visceral. In most genotypes of cattle and sheep, the rate of fat accumulation intramuscularly is lower than subcutaneous and visceral, so genetic selection for a high level of marbling or using the increased energy value of the diet to deposit fat inside the muscles will result in an increase in overall fatness and feed costs.

According to the obtained data, with an increase in the marbling class, there is a tendency to a slight (by 6.1%) increase in the assessment of the conformation (fleshiness) of carcasses (Table 2). With an increase in the marbling class in points from 7 to 12, there is a tendency to worsen by 4.0% an important sign of the quality of carcasses – the development of their fat cover, compared to the marbling class from 1 to 6 points.

Table 2. *Qualitative indicators of bull carcasses depending on the marbling of muscle tissue, M ± m*

Marbling class, points	Indicators					
	conformation, points	covering of carcasses with subcutaneous fat, points	thickness of subcutaneous fat	colour of muscle tissue, points	colour of adipose tissue on the carcass, points	loin eye area, cm^2
from 1 to 6 (n = 18)	3.3 ± 0.24	2.6 ± 0.15	0.8 ± 0.10	5.2 ± 0.18	4.7 ± 0.20	79.5 ± 4.78

Table 2. Continued

Marbling class, points	Indicators					
	conformation, points	covering of carcasses with subcutaneous fat, points	thickness of subcutaneous fat	colour of muscle tissue, points	colour of adipose tissue on the carcass, points	loin eye area, cm^2
from 7 to 12 (n = 16)	3.5 ± 0.29	2.5 ± 0.19	0.8 ± 0.08	5.3 ± 0.15	4.8 ± 0.10	85.8 ± 5.65

Source: compiled by the authors

The previous study by O. Kruk *et al.* (2023), found that higher conformation indicators are observed, in particular, for better coverage of carcasses with adipose tissue. G. Brito *et al.* (2024) note that the consumer value of beef is influenced by the weight of individual cut varieties, the degree of fat content and pH, while live weight of the animal and carcass weight are important for predicting the weight of these cuts, and for determining meat yield, the importance of quantitative characteristics of subcutaneous fat thickness is important for determining the optimal slaughter age. M.S. Ju *et al.* (2024) found that subcutaneous fat on carcasses is also a negative criterion for beef quality. By protecting the carcass from evaporation, which increases the stiffness of the meat, it helps to reduce its slaughter yield. Therefore, for high productivity and quality of meat, namely, getting a brighter colour and more tender taste of beef, as recommended by G.A. Zurbriggen *et al.* (2024), so that the thickness of subcutaneous fat in bulls is 8.0 mm.

It was found that with an increase in the marbling class, there is a tendency to increase by 7.9% the area of the "loin eye" of *m. longissimus dorsi*, which is directly and significantly correlated with the carcass weight and the amount of muscle tissue, including the highest and first grades. Therefore, these authors suggest using the values of the "loin eye" to predict the amount of beef obtained and its belonging to a particular variety. With an increase in the marbling class of muscle tissue, there is a tendency to increase the rating of the beef freshness indicator – its colour – by 1.9%. With an increase in the marbling of beef, there is a tendency to improve the colour of adipose tissue by 2.1%. Thus, no significant differences were found in the qualitative characteristics of carcasses of 18-24-month-old Ukrainian Black-and-White dairy bulls with different marbling classes (Kruk *et al.*, 2024).

The results of the penetration stress determined by us show that for the marbling class of beef from 1 to 6 points in its sample, the needle of the PMDP penetrometer penetrates 19.8% deeper in 180 seconds than for a larger (from 7 to 12 points) value of its classification (Table 3). This indicates that it is more tender and juicy when marbling is worse. This can be explained by the fact that the highest class of marbling does not protect the carcass in the refrigerator from drying out and moisture loss, which is associated with a decrease in the destruction and deformation of muscle fibres.

Table 3. *Technological features of beef in different classes of its marbling, M ± m*

Marbling class, points	Indicators		
	water binding capacity, %	boiling down, %	penetration, mm
from 1 to 6 (n = 8)	63.5 ± 3.49	36.8 ± 2.53	20.6 ± 2.21
from 7 to 12 (n = 7)	52.8 ± 4.83	37.9 ± 1.92	17.2 ± 2.27

Source: compiled by the authors

With the best marbling of beef, water is retained in the meat by 10.7 points worse, which is associated with its worse suitability for storage. Because of this, its output after cooking worsens by 1.1 points. Meat losses during water runoff negatively affected the weight and output of muscle tissue of the highest and first grades – especially valuable cuts because they are located mainly in the thoracic and lumbar regions, which are the most valuable and make up a significant share of the carcass. Due to the greater loss of water from beef during heating, the proteins become tougher and less flexible, and the collagen fibrils contract. The tendency to reduce the percentage of boiling beef in the worst marbling class means an improvement in its culinary and technological properties, since this reduces the amount of waste during cooking, which reflects the economic value of meat. With an increase in the marbling of beef, there is a tendency to reduce its total fat content by 0.6 points (Table 4).

Table 4. *Chemical composition of beef at different levels of marbling, M ± m*

Marbling class, points	Indicators					
	acidity (pH)	moisture content, %	dry matter, %	protein, %	total fat content, %	total ash weight, %
from 1 to 6 (n = 8)	5.91 ± 0.189	69.7 ± 1.30	30.3 ± 1.30	21.6 ± 0.70	6.9 ± 0.97	1.9 ± 0.34
from 7 to 12 (n = 7)	5.79 ± 0.061	71.8 ± 2.35	28.2 ± 2.35	19.8 ± 1.15	6.3 ± 1.00	2.2 ± 0.51

Source: compiled by the authors

The established trend of reducing the content of intramuscular fat in beef with an improvement in its marbling was not confirmed in studies by T. Erena *et al.* (2024). That is, it seems that the marbling of beef does not affect the same qualitative feature – the amount of total fat content in meat. Marble colour is fat that is deposited between the fibres of muscle tissue, and is located between the primary and secondary muscle bundles and in their middle intramuscular. Therefore, the assessment of visual marbling is subjective and does not coincide with the fat content determined by chemical analysis, since it is possible to study fat deposits that are not noticeable by eye examination.

According to the marbling class of beef, the value of its acidity (pH) classified according to the following requirements: normal pH ⩽ 5.8; atypical >5.8pH < 6; typical pH ⩾ 6. According to the marbling of beef of the class in the range from 7 to 12 points, there is a tendency to reduce its acidity by 2.1%, that is, its normalisation (pH = 5.79). At a lower value, atypical acidity occurred (pH = 5.91). In muscle tissue, with better marbling, the pH decreases faster, which leads to a more intense passage of glycolysis and the synthesis of lactic acid. Because of this, beef remains more stable to the development of microorganisms. Normalisation of the acidity (pH) of meat by increasing its marbling, according to I. Patinho *et al.* (2024), can serve as a sign for further prediction of the sensory properties of the finished product. According to these researchers, beef at a lower pH should have an enhanced flavour in cooked beef and beef broth compared to the atypical pH that occurs at a lower marbling level.

An assessment of the consumer preferences of boiled meat indicates that with a lower class of marbling of muscle tissue, there was a tendency to increase the protein content by 1.8 points in *m. longissimus dorsi*. If there is a tendency for carcasses to have less fat, which indicates that the animals are well-fed, the findings show that they have better marbling. According to B. Santiago *et al.* (2023), who studied the effect of castration on the qualitative characteristics of carcasses in bulls and found that in

the worst body conditions, the content of proteins increases ($p \leqslant 0.05$), which are especially associated with catabolic processes (glycolysis), muscle structure and contraction, and in the best – with energy metabolism. In animals with a higher class of marbling of muscle tissue, there is a tendency to form meat with better (by 15.8%) indicators of the total weight of ash.

Thus, the assessment of beef from bulls of the Ukrainian black-and-white dairy breed aged from 18 to 24 months by marbling does not allow predicting the chemical composition depending on its value after slaughter. Elements of the chemical composition of meat vary depending on the breed of animals, their slaughter age, gender, type of muscle and adipose tissue, and methods of processing meat into products. H. Yu *et al.* (2024) investigated the influence of the breed on the market value of beef to provide new approaches to improving its quality and features of marbling and chemical composition of meat in animals of local cattle breeds. V.B. Hoa *et al.* (2023) highlighted the influence of cattle age on the chemical composition of carcasses and meat, fatty acid profiles, and genes associated with lipid metabolism. L.W. Coleman *et al.* (2023) found that meat quality varied depending on the sex of the animals, with bulls having higher acidity (pH), redder meat, and yellower fat than heifers. J.M. Vázquez-Mosquera *et al.* (2023) evaluating beef obtained from animal fattening systems with a high olein content and its effect on the subsequent composition of fatty acids that affect consumer health and found that entrecote samples show a healthier lipid fraction. E. Yarali (2023), investigating sensory analysis as one of the most common methods for evaluating food products to date, found that the way beef is processed into a finished product affects its chemical composition.

With an increase in the marbling of beef, there was a tendency to worsen by 3.2% the main component of its sensory assessment – tenderness (Table 5), which, as noted by V. Bulgaru *et al*. (2022), significantly depends on the content of soluble proteins, fats, and collagen in it.

Table 5. *Sensory properties of boiled beef at different levels of marbling, M ± m*

Marbling class, points	Sensory characteristics of boiled meat, points					
	juiciness	taste	aroma	tenderness	residue after chewing	average values for 5 tasting indicators
from 1 to 6 (n = 6)	3.4 ± 0.22	2.9 ± 0.21	3.1 ± 0.15	3.2 ± 0.30	3.2 ± 0.31	3.2 ± 0.24
from 7 to 12 (n = 7)	3.4 ± 0.15	3.1 ± ±0.09	3.1 ± 0.09	3.1 ± 0.22	3.0 ± 0.09	3.1 ± 0.14

Source: compiled by the authors

With an increase in the marbling of beef, there were no changes in its assessment by an important characteristic – juiciness, which has a positive effect on the quality of meat. Perception of tenderness and juiciness of meat reduces the content of intramuscular fat, which lubricates the fibres between the muscles worse, and does not protect beef from drying out during cooking. Juiciness in the mouth characterises the amount of juice obtained during chewing. With the highest marbling, there is a tendency to increase by 6.9% the value of such a sensory property of beef as taste. The development of taste during cooking is affected not only by the level of lipids in the middle of the muscles, but also by their composition (Albechaalany *et al.,* 2024), which are also a source of aromatic compounds important for meat quality. The aroma and taste of beef arise from the reaction of non-volatile fatty acids during heat treatment, and the type and concentration of volatile substances that are released (Ponnampalam *et al.,* 2024). Thus, an increase in the marbling of beef leads to a decrease in the total

fat content in muscles, and to a deterioration in the signs of cooked meat evaluated by tasters – tenderness and residue after chewing, and does not improve its aroma and juiciness. Consumers draw conclusions about the quality of beef only during its consumption based on the taste, tenderness and juiciness they actually perceive, confirming or refuting their pre-formed expectations based on the marbling of the meat.

Improving marbling of *m. longissimus dorsi* leads not only to a decrease in the fat content in the middle of the muscles (Table 3), but also to a slight (3.2%) deterioration in the average value of the evaluated signs of cooked meat (aroma, juiciness, tenderness, taste, residue after chewing). Bulls of the Ukrainian Black-and-White dairy breed aged 18 to 24 months with the best marbling have a mid-muscle fat content of only 6.3%, which does not affect sensory characteristics. The ambiguous relationships between sensory ratings and mid-muscle fat content may have a positive effect on the tenderness, juiciness, and taste of meat at higher parameters, which need to be substantiated for dairy animals.

Evaluating the sensory characteristics of boiled meat broth, it was found that at higher levels of marbling, there is a tendency to increase such signs of its tasting as taste and aroma (by 18.2%), and transparency (by 13.0%) (Table 6).

Table 6. *Sensory characteristics of beef broth at different marbling levels, M ± m*

Marbling class, points	Broth tasting indicators, points			
	taste and aroma	strength	transparency	average values
from 1 to 6 (n = 6)	2.2 ± 0.57	2.4 ± 0.27	2.3 ± 0.20	2.3 ± 0.19
from 7 to 12 (n = 7)	2.6 ± 0.11	2.4 ± 0.09	2.6 ± 0.20	2.6 ± 0.15

Source: compiled by the authors

With an increase in the marbling of beef, there are no changes in the strength of the broth, there is a tendency to increase its average values of tasting signs. Thus, the data obtained indicate that with an increase in the marbling class of the Ukrainian Black-and-White dairy breed from 18 to 24 months of age, only the percentage of muscle tissue ($p > 0.99$) in carcasses and the content of bones ($p > 0.95$) significantly improve, there is a tendency to increase the area of the "loin eye" and the content of muscle tissue of the second class, the conformation of carcasses. From the best class of qualitative signs of beef – marbling in animals, the yield of muscle tissue of the highest and first grades does not significantly decrease, the chemical composition of muscle tissue worsens, and the pH of muscle tissue is normalised due to glycolysis. In addition, better marbling of muscle tissue does not significantly affect the sensory characteristics of boiled beef broth.

Beef producers and its processors are interested in the quality, the carcass is determined by the marbling of muscle tissue on which its price depends on the market. Marbling, which is used to predict the initial quality of meat from cattle in Ukraine, does not have a positive effect on the sensory and culinary properties of beef, which consumers are interested in. The tenderness, taste, and juiciness of meat are based on the content of adipose tissue in the middle of the muscles. Since animals have the genetic potential to develop marbling, regardless of their feeding and maintenance, they reach the amount of it that they can develop. In beef, marbling is better formed by intensive feeding of animals with concentrated feeds with a high energy content, only after "excess" adipose tissue accumulates in the middle of the abdomen, under the skin and between the muscles. Since the quality characteristics of carcasses are more sensitive to changes in the management of animal rearing, compared to the quality of

beef, the optimal combination of them can be achieved under different conditions of feeding (Beck *et al.,* 2022) and keeping (Soulat *et al.,* 2022) livestock.

In Ukraine, there are many problems in evaluating the carcasses of Ukrainian Black-and-White dairy cattle by the marbling of beef, including the deterioration of many of its qualitative characteristics. Despite recent advances in the world regarding the possible regulation of the development of muscle tissue colour in cattle to improve the quality of beef, this problem remains insufficiently solved in Ukraine and deserves further investigation. The results of researchers show that it is possible and necessary to manage the quality of carcasses and beef through various methods of breeding, feeding and keeping animals. In this regard, the question arises of solving the problem of producing high-quality beef with high-quality characteristics of carcasses from dairy animals, which are fattened in large numbers for slaughter.

Conclusions

The best class of marbling development in the middle of the *m. longissimus dorsi* muscle of Ukrainian Black-and-White bulls aged 18-24 months affects consumer preferences and the likelihood of purchasing beef, but does not characterise its technological, sensory and culinary properties. When improving the marbling class in the carcass, only the content of muscle tissue was higher by 3.0 ($p > 0.99$), respectively, and bone – by 2.0 percentage points ($p > 0.95$). There was a tendency to increase the second grade pulp by 1.4 points, fat tissue by 1.5 points, tendons and ligaments by 0.1 points, and to improve the conformation (meatiness) of carcasses by 6.1%, the colour of muscle (by 1.9%), and fat tissue (by 2.1%). During the increase in the marbling class of beef, there was a tendency to reduce the content of muscle tissue of the highest (by 0.9 points) and first grades (by 0.2 points), water binding capacity (by 0.7 points), boiling (by 1.1) the content of dry matter in meat (by 2.1), protein (by 1.8), and total fat content (by 0.6 points). The best marbling of meat reduced its penetration (by 19.8%), tenderness (by 3.1%), meat residue after chewing (by 6.7%), taste (by 6.9%) and acidity of meat (by 2.1%), which are important technological indicators for further processing of beef and the quality characteristics of the product made from it. The increase in beef marbling did not affect the strength of the broth, but there was a tendency to improve sensory characteristics (taste and aroma) during tasting. The obtained data confirm the possibility of using beef marbling to predict the physical, technological, and tasting characteristics of meat.

In the future, research should be aimed at determining the quantitative and qualitative characteristics of beef, depending on its marbling, in livestock of other breeds of Ukraine, as this will complement the visual and sensory assessment of carcasses and meat quality. It is necessary to conduct research on the establishment of management factors for the cultivation of cattle of common breeds in Ukraine to achieve optimal marbling values and compromise with technological and sensory characteristics, and chemical composition of meat. Such data will provide consumers with additional information when choosing beef. This will become the theoretical basis for introducing the marbling index of muscle tissue into the classification system of beef carcasses in Ukraine.

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None.

Conflict of Interest

None.

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Якісні ознаки яловичини залежно від її мармуровості

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Анотація. Мармуровість м'язів є цінною ознакою окремих відрубів туш великої рогатої худоби, але в українських породах залишається не дослідженим, як співвідноситься вміст внутрішньом'язового жиру із хімічним складом, ознаками туші та показниками технологічності м'яса, важливими під час промислової переробки та виробництві м'ясних продуктів. Метою роботи було встановити залежність ознак забою, хімічного складу, фізико-технологічних і сенсорних властивостей яловичини від її мармуровості. У 34 тушах 18-24 – місячних бугайців фермерського господарства (ФГ) «Журавушка» Броварського району Київської області оцінено мармуровість м'язової тканини, вміст у ній загального жиру і маси золи, вологи, протеїну, кислотність (pH), пенетрацію. У вареному м'ясі 8-м дегустаторів визначили аромат, соковитість, ніжність, легкість жування, а у бульйоні із нього колір, смак і міцність. Отримані дані свідчать, що за поліпшення класу мармуровості вміст у туші м'язової тканини був більшим на 3,0 ($P > 0,99$) пункти, а кісток на 2,0 пункти ($P > 0,95$). Проявлялася тенденція до збільшення м'якуша другого сорту на 1,4 пункти, жирової тканини – на 1,5, сухожилок і зв'язок – на 0,1 пункти, та поліпшення конформації (м'ясистості) туш на 6,1 %, кольору м'язової (на 1,9) і жирової тканин (на 2,1 %). За підвищення мармуровості яловичини проявляється тенденція до зменшення у ній м'язової тканини вищого (на 0,9 пункти) і першого сортів (на 0,2), водозв'язуючої здатності (на 0,7), уварювання (на 1,1), сухої речовини (на 2,1), протеїну (на 1,8) загального вмісту жиру (на 0,6 пункти), пенетрації (на 19,8 %), ніжності м'яса (на 3,1), залишку його після розжовування (на 6,7), смаку (на 6,9), кислотності (на 2,1 %). Практичне значення роботи полягає в можливості використання отриманих даних для сортування туш бугайців української чорно-рябої молочної породи відповідно до призначення за урахування зв'язків між мармуровістю яловичини та ознаками забою, хімічними і фізико-технологічними властивостями, сенсорними характеристиками вареного м'яса та бульйону із нього

Ключові слова: велика рогата худоба; м'ясо; конформація; туші; сенсорні характеристики

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Meat cattle breeding in Ukraine (climate impact, breeding features, efficiency improvement strategies)

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Abstract. Ten breeds of meat and combined productivity are bred in Ukraine, of which six are cross-border breeds and four are Ukrainian breeds developed through combination crossbreeding of local breeds with cross-border breeds. These breeds are located in different natural and climatic and agricultural zones, so it is important to investigate the indicators of meat productivity of breeds

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and the factors that influence them. The purpose of the study was to determine the influence of the breed, agricultural climate zone (zone) and calendar year (year) on the studied characteristics of meat cattle and to evaluate statistical indicators of relationships between them. To achieve this goal, the study applied the methods of multivariate analysis of variance, correlation and regression analysis. The indicators of efficiency of beef cattle production are: 1) live weight of cows after the third calving and older; 2) milk yield of cows after the first calving, which is defined as the live weight of a calf at day 210 after birth; 3) milk yield of cows after the third calving and older. It has been established that the flat landscape of Ukraine has a moderately continental climate, with five agricultural climatic zones: 1) severely arid; 2) moderately arid; 3) insufficient moisture; 4) sufficient moisture; 5) excessive moisture. These zones differ in the amount of precipitation, reserves of productive moisture in the soil, temperature fluctuations over the periods of the year, and have a certain potential to provide livestock with feed resources, especially in summer. The perspective is considered to be the keeping of animals in compost barns in winter, which meets the requirements of animal welfare and ensures high growth rates for fattening beef cattle. The practical significance of the results obtained lies in the possibility of taking into consideration the influence of the breed, agricultural climate zone, and calendar year on the meat cattle characteristics under study, as well as the possibility of predicting the values of some indicators of meat productivity based on the values of others

Keywords: meat cattle; red meat; milk yield; agricultural climatic zones; degree of influence; efficiency assessment; technology of maintenance

Introduction

According to S.Y. Ruban *et al.* (2021) and P.L. Greenwood (2021), declining pastures and environmental constraints continue to put pressure on beef producers worldwide, leading to a search for more efficient production systems. Chicken is gradually replacing other types of meat due to the low price, which is conditioned by the lower cost of industrial production. The average level of meat consumption per capita in North America is 78.6 kg, up to 52.1 kg in Europe and 9.6 kg in the African continent (Statista, n.d.). Beef remains an important source in the human diet for providing macro- and micro-elements in an easily accessible form, which includes haem iron, zinc, selenium, and vitamins D and B. In countries with a high standard of living, according to S. Hongbing & C.M. Weaver (2021), there is a prevalence of Fe-deficient anaemia, which leads to poor health, especially among women and children. Thus, an increase in the level of iron deficiency anaemia in the United States over the past almost 20 years is associated with a decrease in the concentration of Fe in food and a change in the diet itself. It is noted that beef consumption has recently decreased by 15.3% (the main source of haem iron), and chicken meat consumption has increased by 21.5%, which has negatively affected people's health. In recent years, in the meat balance of an ordinary resident of Ukraine, 27 kg is occupied by poultry meat, 19.8 kg – pork, 7.4 kg – beef, 1.5 kg – meat of other types, which with a total consumption of 55.7 kg is not enough for a medically valid norm of 80 kg, where beef should occupy 39% or 31.3 kg of physical weight (Ruban *et al.*, 2021).

The only way to achieve the above indicators is the development of a specialised branch of beef cattle breeding, which is based on the seasonal use of pastures in various agricultural and climatic zones of Ukraine, and education of potential consumers about the importance

of consuming "red meat", which primarily includes beef.

Beef cattle breeding is popular in most regions of Ukraine with the possibility of using pastures and especially in areas with sufficient moisture. Most breeding farms plan to breed a new generation of calves in the shortest possible time (seasonally), which falls at the end of the first and beginning of the second quarter of the calendar year, which allows using cheap natural forage land in the summer. Thus, the mating season usually falls on August-October, when 83% of females use natural mating, and about 17% are artificially inseminated, as noted by O.M. Jukorskiy *et al.* (2023). A low level of artificial insemination occurs in farms of Dnipropetrovsk, Odesa, Rivne, and Chernivtsi oblasts. In natural mating, the average load per bull is 32 of breeding cows. Most calves are born in the spring, which are weaned from their mothers at 5-7 months. According to the researcher, pasture keeping of livestock in most climatic zones of Ukraine is used from April to November and is stopped under appropriate conditions when the height of basal plant remains averages from 5 to 8 cm. The duration of grazing in breeding farms ranges from 150 to 270 days, and the shortest duration is observed in farms of severely and moderately arid zones of Donetsk (150 days), Odesa (170-210 days), and Kherson (180-200 days) oblasts. The longest grazing time (235-270 days) is carried out in farms of the Lviv Oblast, which belongs to the agroclimatic zone of sufficient moisture (Pankeev & Liashevska, 2020).

According to J.B. Glaze (2019), 38% of U.S. farmers who breed beef cattle use crossbreeding with other breeds. Thus, R. Favero *et al.* (2019) indicate that the use of crossbreeding in beef cattle breeding can significantly increase the productivity characteristics and quality of carcasses. The more advanced beef industries in the United States and Australia maintain a high level of flexibility in production options, especially in the face of constant climate change. The selection of breeds and use of various crossbreeding options for cattle, including feed supply, allow adapting cattle breeding to economic and environmental challenges (Greenwood, 2021).

According to S.A. Berça *et al.* (2021), successful pasture management and feed waste management practices minimise environmental, social impacts, and guarantee resource savings. S.A. Terry *et al.* (2021) note that diet modification and genetic selection have led to better results of beef cattle breeding, although flexible management methods, considering the unique ability of ruminants to use pasture in different environmental conditions, and the simultaneous production of high-quality protein, are the main advantage of this industry. Recently, considerable attention in beef cattle breeding has been paid to indicators of feed efficiency. According to P.V.B. Ramos *et al.* (2024), feed efficiency plays an important role in the overall profitability and sustainability of the cattle breeding industry, as it is directly related to reducing animals' need for input resources and reducing methane emissions. The use of new technological approaches and an efficient feeding system in the beef cattle breeding of Ukraine, especially in winter, is partially "borrowed" from farms that are engaged in breeding dairy cattle. Thus, keeping animals on long-term litter, or compost cowsheds with feeding in the middle of the room, is becoming very popular among farmers. In addition, global experience of regional genetic improvement programmes, grazing systems depending on landscape characteristics, and housing is considered (Greenwood, 2021).

Thus, the analysis of the state of meat cattle breeding in Ukraine with an assessment of the impact of the main natural and human-organised factors on the efficiency of the industry is of constant interest with options for finding effective approaches to stable production of highly valuable food products. The purpose of the study was to determine the influence of the breed, agricultural climate zone (zone) and

calendar year (year) on the studied traits of beef cattle and to evaluate statistics of relationships between them.

Materials and Methods

The research material was based on the data from the State register of breeding subjects in animal husbandry for 2019-2022 (State register of breeding subjects..., n.d.). Zonally, the enterprises included in the State register of breeding subjects in animal husbandry were located in different agricultural and climatic zones. In total, in the conditions of the sharp continental climate of Ukraine, there are five agricultural and climatic zones, each of which is characterised by its own characteristics (Table 1).

Table 1. *Main characteristics of agricultural and climatic zones of Ukraine*

Agroclimatic characteristics	Agroclimatic zones				
	severely arid	moderately arid	insufficient moisture	sufficient moisture	excessive moisture
Agroclimatic resources for the growing season of plants					
Sum of active temperatures °C	3,000 – 3,700	2,800 – 3,200	2,400 – 3,000	2,400 – 2,800	2,400 – 2,600
Precipitation during the warm period (mm)	200 – 280	250 – 300	260 – 320	300 – 380	360 – 430
Duration of the active growing season (days)	175 – 190	170 – 185	160 – 180	160 – 175	150 – 170
Duration of the frost-free period on the soil surface (days)	155 – 210	135 – 180	135 – 160	140 – 170	135 – 160
Agro-hydrological resources					
Productive moisture reserves in a metre layer of soil (mm)	110 – 160	120 – 160	140 – 200	160 – 220	180 – 260
Adverse and natural meteorological events					
Repeatability of atmospheric drought,%	40 – 55	35 – 45	20 – 40	10 – 30	8 – 12
Number of days with dry weather	1 – 20	16 – 20	9 – 15	1 – 10	0 – 4
Number of days with a thaw in winter	50 – 70	30 – 60	30 – 55	40 – 55	40 – 50

Source: developed by the authors based on Maps of Ukraine (n.d.); APK Inform (n.d.); The National Centre for Biotechnology Information (n.d.)

Depending on the region of location, farms were assigned to the five specified agricultural and climatic zones, with breed and livestock productivity data recorded (Table 2).

Table 2. *General data on the distribution of farms and the corresponding number of cows of different breeds depending on agricultural and climatic zones*

Agricultural and climatic zones	Region (oblast) that is part of the agroclimatic zone	Number of farms*	Main breeds
Severely* arid	Kherson, Zaporizhzhia, Autonomous Republic of Crimea	2	Southern Meat, Ukrainian Grey
Moderate	Kharkiv, Luhansk, Odesa, Dnipropetrovsk, Donetsk, Mykolayiv,	6	Southern Meat, Ukrainian Grey, Blonde d'Aquitaine, Ukrainian Meat

Table 2. Continued

Agricultural and climatic zones	Region (oblast) that is part of the agroclimatic zone	Number of farms*	Main breeds
Insufficiently moistened	Sumy, Vinnytsia, Cherkasy, Poltava, Kirovohrad,	4	Aberdeen-Angus
Sufficient moisture	Volyn, Rivne, Zhytomyr, Kyiv, Chernihiv, Lviv, Ternopil, Khmelnytskyi,	36	Aberdeen-Angus, Volynian Meat, Polissian Meat, Limousin, Charolais, Simmental
Excessive moisture	Ivano-Frankivsk, Chernivtsi,	3	Simmental, Aberdeen-Angus, Polissian Meat

Note: Farm data was considered for the last four years (2019-2022)
Source: developed by the authors

For the analysis, traits characterising the efficiency of beef cattle breeding (main productive traits) over the past four years were taken, namely: 1) live weight of cows after the third calving and older; 2) milk yield of cows after the first calving, which was defined as the live weight of a calf at 210 days of life after birth; 3) milk yield of cows after the third calving and older.

Analysis of variance of the influence of the breed, agricultural climate zone of breeding, and calendar year on the main productive characteristics was carried out using a linear model:

$$y_{ij} = a_i + b_j + c_k + e_{ij}, \quad (1)$$

where y_{ij} – alternate by year values based on: 1) live weight of cows after the third calving and older; 2) milk yield of cows after the first calving; 3) milk yield of cows after the third calving and older, belonging to the *i*-th breed in the *j*-th breeding zone, c_k- certain year; a_i – effect of the *i*-th breed; b_j – effect of the *j*-th climate zone; c_k – effect of the *k*-th year; e_{ij} – residue.

The degree of influence of factors on the studied traits of beef cattle was calculated by the equation:

$$\eta 2 = \left(\frac{SSA}{SSD}\right) \cdot 100\%, \quad (2)$$

where *SSA* – sum of the squares of deviations due to the influence of the factor; *SSD* – total sum of the squares of deviations.

Statistical analysis (descriptive statistics, analysis of variance, correlation and regression analysis) was performed using RStudio software.

Results

The most popular breeds in Ukraine are Aberdeen-Angus, Polissian Meat, Volynian Meat, and Limousin (Table 4), which indicates the high adaptability of these breeds to different agro-climatic zones. According to the average live weight of cows after the third calving and older, high rates were observed for such breeds as Charolais, Simmental, Hereford, and Volynian Meat (Table 4).

At of the beginning of 2023, there were 1.32 million cows in Ukraine, and according to the State register of breeding subjects in animal husbandry for a number of years (State register of breeding subjects..., n.d.), the breeding stock of beef cattle is concentrated in more than 70 farms, where four domestic breeds created by crossbreeding are kept (Table 3, Fig. 1), and four cross-border beef breeds and one of dual-purpose productivity (Fig. 2).

Table 3. *List of beef breeds bred by combination crossing in Ukraine in recent years*

Breed	Breeds involved in the crossbreeding		Region of breeding
	Local	Cross-border	
Volynian Meat	Black-and-White, Polish Red	Aberdeen-Angus, Hereford, Limousin	West of Ukraine, Polissia
Southern Meat	Red Steppe	Hereford, Charolais, Santa Gertrudis, Siboney de Cuba	East and South of Ukraine
Polissian Meat	Simmental, Ukrainian Grey	Charolais, Chianina, Angus	West of Ukraine Polissia
Polissian Meat (Znamiankaintrabreed group)	Red Steppe	Simmental, Aberdeen-Angus, Charolais	Chernihiv Oblast
Ukrainian Meat	Ukrainian Grey	Charolais, Chianina, Simmental	Central regions of Ukraine

Source: developed by the authors

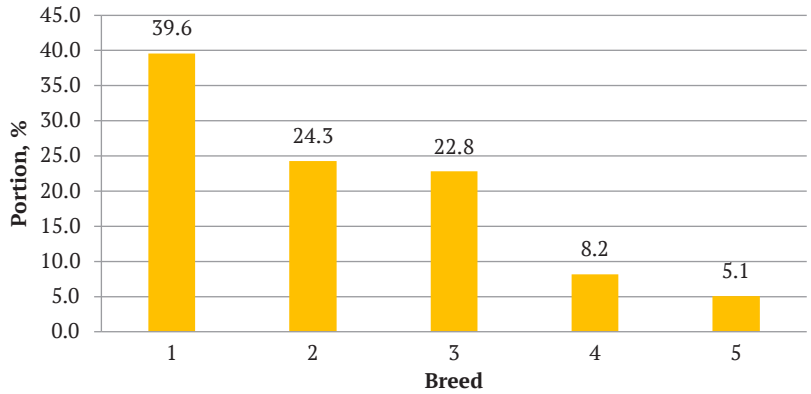

Figure 1. Share of breeding cows of domestic beef and native breeds in Ukraine

Note: 1 – Polissia Meat breed; 2 – Volynian Meat; 3 – Southern Meat; 4 – Ukrainian Grey (native breed); 5 – Ukrainian Meat, (total number of cows is 3,258 units)

Source: (State register of breeding subjects..., n.d.)

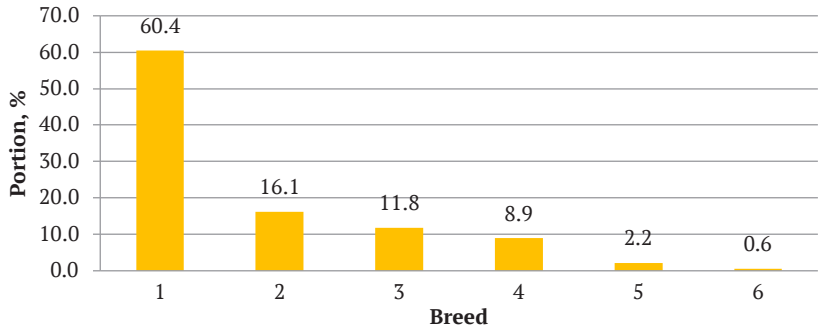

Figure 2. Share of breeding cows of cross-border meat and combined breeds in Ukraine

Note: 1 – Aberdeen-Angus; 2 – Limousin; 3 – Charolais; 4 – Simmental (combined breed); 5 – Hereford; 6 – Blonde d'Aquitaine (total number of cows is 6,650 units)

Source: (State register of breeding subjects..., n.d.)

Such cross-border breeds as Aberdeen-Angus, Hereford, Limousin, Blonde d'Aquitaine, Charolais, and Simmental are generally recognised in the world, exceeding Ukrainian breeds in terms of total number and productivity due to more intensive breeding and a larger total number not only in farms of Ukraine, but also abroad. The general descriptive statistics are presented in Table 5 and indicate the influence of a wide range of genetic, environmental and organisational factors (keeping conditions) on the dynamics of variability of productive traits. The average milk yield after the third calving and older slightly exceeded the average milk yield after the first calving, but the latter value was characterised by greater variability (Table 5).

Table 4. *Main productivity traits of breedingood cows by breed*

Breed	Indicators				
	number of cows, head	number of farms	average milk yield of cows, after the first calving, kg	average milk yield of cows, after the third calving and older, kg	average live weight of cows after the third calving and older, kg
Aberdeen-Angus	4,017	16	197.5	212	548.5
Volynian Meat	793	3	216.5	222.5	581
Hereford	145	1	225	228	587
Limousin	1,065	5	220	235.5	562.5
Southern Meat	743	4	200.5	230	515
Polissian Meat	1,290	7	215	224	570.5
Grey Ukrainian	266	2	166	176	538
Blonde d'Aquitaine	43	1	206	216	550
Simmental	594	4	218	224	610
Ukrainian Meat	166	1	208	216	566
Charolais	786	4	235	251	628
Total by breed:					
– cross-border	6,650	31	217.0	227.8	581.0
– Ukrainian	3,258	17	201.2	213.7	554.1

Source: developed by the authors

Table 5. *Descriptive statistics of the traits under study (total sample size – 9.908 animals)*

Indicator	N*	M ± m	σ^2	σ	Cv, %
Average live weight of cows after the third calving and older, kg	46	571.04±6.67	2,046.66	45.24	7.9
Average milk yield after the first calving, kg	43	210.21±2.55	280.69	16.75	8.0
Average milk yield after the third calving and older, kg	46	223.67±2.40	265.56	16.30	7.3

Note: N – number of farms in the total sample, M – mean, m – standard error of the mean, σ^2 – variance, σ – standard deviation, Cv – coefficient of variability

Source: developed by the authors

The general results of the influence of such fixed factors as "Breed", "Agricultural climate zone", and "Year" on the studied indicators of meat cattle are given in Table 6.

Table 6. *Influence of the breed, agricultural climate zone (zone), and calendar year (year) on the beef cattle traits under study*

Factor, trait	Sum of squares of deviations	Number of degrees of freedom	Average square of deviations	Fischer's F-test	η^2, %
Average live weight of cows after the third calving and older					
Breed	37,050	11	3,368	8.44***	35.0
Zone	5,600	4	1,400	3.51**	5.3
Year	3,876	3	1,292	3.24**	3.7
Residue	57,020	143	399		
Average milk yield after the first calving					
Breed	6,791	11	617	19.90***	56.6
Zone	432	4	108	3.48**	3.6
Year	321	3	107	3.45**	2.7
Residue	4,446	142	31		
Average milk yield of cows for the third calving and older					
Breed	6,911	11	628	27.30***	58.7
Zone	756	4	189	8.22**	14.7
Year	345	3	115	5.0**	3.1
Residue	3,178	141	23	11,190	

Note: *** – P>0.999, ** – P>0.99
Source: developed by the authors

It was found that all the studied factors significantly affect the productivity traits, with the greatest effect of the "Breed" factor: the degree of influence ranged from 35% (average live weight of cows after the third calving and older) to 58% (average milk yield of cows after the third calving and older). The "Zone" factor is less influential: from 3.6% (average milk yield after the first calving) to 14.7% (average milk yield for cows after the third calving and older). The least influential factor was "year" or fluctuations by year, with the degree of influence from 2.7% (average milk yield after the first calving) to 3.7% (average live weight of cows after the third calving and older). Thus, the correct choice of breed mainly determines the success of beef cattle breeding ahead of natural fluctuations, which is caused by the creation of more comfortable conditions for housing both young and adult cattle.

In recent years, farms that raise livestock use the technology of housing on straw bedding (Fig. 3) when, regardless of weather conditions and time of year, it is possible to reduce the negative impact of weather on the growing process, with stable productivity traits. Such a system involves combining a pasture system and a system of loose housing in comfortable premises with ensuring the comfort of animals during the summer heat or winter cold.

Additionally, the relationship between the average live weight of cows after the third calving and older, the average milk yield after the first calving, and the average milk yield after the third calving and older were estimated (Table 7).

Figure 3. Fragment of a room for housing young animals on fattening with the use of straw bedding in the recreation area and a feed table for feeding (Terezine agricultural enterprise)
Source: photo taken by the authors

Table 7. *Coefficients of correlation between the traits under study*

Indicators		Average live weight of cows after the third calving and older, kg	Average milk yield after the first calving, kg
Average milk yield after the first calving, kg	n	43	
	r	0.5225	
	m_r	0.1332	
	t	3.9241***	
Average milk yield after the third calving and older, kg	n	46	43
	r	0.3965	0.8164
	m_r	0.1384	0.0902
	t	2.8653**	9.0529***

Note: n – number of observations, r – correlation coefficient, mr – standard error of the correlation coefficient, t – probability criterion of the correlation coefficient, ** – P > 0.99, *** – P > 0.999
Source: developed by the authors

The values of the coefficients of correlation were significant, since the closest positive relationship was between the average milk yield after the first calving and the average milk yield after the third calving and older. This indicates a high repeatability of the milk production of cows with a larger live weight, which is what the selection system in breeding farms is aimed at. The lowest coefficient of correlation was between the average live weight of cows after the third calving and the average milk yield after the third calving and older. Coefficients of regression between the studied traits were calculated, which reflect the rate of change of one trait when another changes (Table 8).

Table 8. *Coefficients of regression between the traits*

Influencing indicator	Dependent indicator	$b \pm m_b$
Average milk yield after the first calving, kg	Average live weight of cows after the third calving and older, kg	$1.41095 \pm 0.3719^{***}$
Average milk yield after the first calving, kg	Average milk yield after the third calving and older, kg	$0.79411 \pm 0.0907^{***}$
Average milk yield after the third calving and older, kg	Average live weight of cows after the third calving and older, kg	$1.10088 \pm 0.3842^{**}$

Note: b – regression coefficient, mb – standard error of the regression coefficient, ** – P > 0.99, *** – P > 0.999
Source: developed by the authors

All coefficients of regression are significant. The obtained coefficients of regression allow simulating changes in the main productive traits over time according to the following trends:

- an increase in the average milk yield of cows after first calving by 1 kg leads to an increase in the average live weight of cows after calving and older by 1.41095 kg;
- an increase in the average milk yield of cows after first calving by 1 kg leads to an increase in the average milk yield after the third calving and older by 0.79411 kg;
- an increase in the average milk yield of cows after the third calving and older by 1 kg leads to an increase in the average live weight of cows after the third calving and older by 1.10088 kg.

The assessment helped to identify the degree of influence of environmental factors (agricultural climate zone, fluctuations by year) and genetic factors (breed) on the efficiency of cattle breeding, which affects the overall dynamics and number of breeds. The perspective is considered to be the housing animals in premises that meet the requirements of animal welfare and provide high growth rates for fattening. The results of the conducted research indicate that the traits of meat productivity (the average live weight of cows after the third calving and older), and the maternal qualities of cows of beef breeds (the average milk yield after the first calving and after the third calving and older) depend on both genetic factors (breed) and environmental factors (agricultural climate zone and calendar year). This conclusion is in line with the findings of A.E.O. Malau-Aduli *et al.* (2022), who, based on beef cattle data from Northern Australia, found that both feeding conditions and genetics influence meat quality, and manipulating these factors can contribute to achieving the desired properties of beef, including softness, taste, juiciness, meat yield, and marbling.

Correlation and regression analysis showed the presence of probable phenotypic relationships both between traits of milk yield of cows at different ages and between indicators of milk yield and live weight. According to J.B. Mulliniks *et al*. (2020) selection for increased dairy productivity in cattle increases calf weight at weaning, however, the response to selection varies greatly under different environmental conditions. The researchers note that constant selection for milk synthesis in beef cows is aimed at increasing calf weight during weaning, but increases food stress during critical physiological periods such as early lactation (the period of early suckling), and ultimately negatively affects the level of reproduction, which increases the productive costs of both maintaining productivity and the level of reproduction. In addition, selection for high milk yield can have a long-term negative impact on the feed efficiency after weaning.

According to S.Y. Ruban *et al*. (2021), in recent years, the system of housing cattle on straw bedding has gained popularity in a number of countries. The cows are provided with free space for movement in the recreation area,

rather than being kept tethered. In the recreation area, the surface mixture of organic bedding and bovine excrement is mixed 1-3 times a day, absorbing fresh manure, which contributes to the aerobic composting process, as confirmed by L. Leso *et al.* (2020), D.T. Eberl *et al.* (2024). Such a system functions well when the optimal density of animals in the zone of free movement ranges from 7.4 to 15 m^2/cow depending on several climatic zones, litter type, herd management, and cow breed. The data by S.Y. Ruban *et al.* (2021) proved that compost litter, compared with conventional systems, has the potential to improve the well-being of cows, improve rest comfort and feet health, and promote the production of high-quality organic fertilisers.

According to F.A. Damasceno *et al.* (2022) the compost cowshed management system is relatively simple but "tied" to a specific climate zone and provides thermal comfort, especially in winter, and better hygiene conditions for animals. Wood waste was the most optimal material for bedding, and the level of contamination with *E. coli,Bacillus* and *Streptococcus* were observed in bedding with a lower moisture content. According to research by B. Yameogo *et al.* (2021) conducted during the wet winter season in Brazil, when one compost cowshed (A) was closed using ventilation of horizontal aerodynamic shafts that created negative pressure, and the second (B) with open natural ventilation, without curtains but with fans in the recreation area, which proved the advantage of the first cowshed (A).

According to P.R.F. Adkins *et al.* (2022), the relationship of the housing conditions with the level of bacteria on the teats of animals and bedding proved that long-unchanged bedding with its aeration mode provides less bacterial contamination compared to other housing technologies. According to U. Emanuelson *et al.* (2022), analysis of 32 dairy herds in different climatic zones of Europe, found that herds with a housing system on compost had fewer veterinary problems.

As stated by C. McManus *et al.* (2021), the possibility of creating a gene bank for cattle of beef breeds based on their adaptability to specific environmental conditions (ambient temperature, humidity, precipitation, altitude, and feed production) is of great importance, because it helps to increase the adaptation of beef cattle to certain climatic zones and climate changes in general. Considering the supply of a sufficiently large amount of crop residues (straw) in Ukraine in the production of grain, the combination of housing cattle on compost litter in winter with grazing in summer, allows producing meat cattle products at a fairly low cost, providing fairly comfortable conditions for animals in terms of their well-being and health.

According to G. Di Vita *et al.* (2024), despite the significant role of beef in the European agri-food industry, its intensification is changing environmental sustainability, which is the goal of general agricultural policy in the near future. Balancing the importance of the industry and its sustainability is crucial. The goal is to identify environmentally friendly practices that are consistent with the best efforts to protect the environment in agricultural settings in the European Union and Ukraine.

The results showed that the best models, regardless of climate zones, show significant differences in terms of agricultural intensity, geographical distribution, and economic profitability, highlighting a certain polarisation between economic and environmental sustainability.

Conclusions

The analysis of live weight and milk yield traits of cows of the main meat breeds of Ukraine, whose livestock is concentrated in breeding farms, was carried out. The average milk yield after the third calving and older slightly exceeded the average milk yield after the first calving. The most popular breeds in Ukraine are Aberdeen-Angus, Polissian Meat, Volynian Meat, and Limousin, which indicates the high adaptive capabilities of these breeds.

The analysis of variance showed the significant influence of all the studied factors (breed, climate zone and year) on the signs of productivity of beef cattle, all the studied factors significantly affect the productivity traits, so the most influential factor is the breed: its degree ranges from 35% (average live weight of cows after the third calving and older) to 58% (average milk yield of cows after the third calving and older). The climate zone is less affected: from 3.6% (average milk yield after the first calving) to 14.7% (average milk yield for cows after the third calving and older). The least influential factor was "year" or fluctuations by year, with the degree of influence from 2.7% (average milk yield after the first calving) to 3.7% (average live weight of cows after the third calving and older).

Statistically significant estimates of coefficients of correlation between all the traits under study are established. The closest positive relationship was between the average milk yield after the first calving and the average milk yield after the third calving and older. A less close positive relationship is observed between the average live weight of cows after the third calving and older and the average milk yield after the first calving. The lowest correlation coefficient is found between the average live weight of cows after the third calving and the average milk yield after the third calving and older.

Regression analysis showed that the highest coefficient of regression was found between the average live weight of cows after the third calving and older and the average milk yield after the first calving. The coefficient of regression between the average live weight of cows after the third calving and older and the average milk yield for the third calving and older has a slightly lower value. All coefficients of regression are significant.

Further research may be related to the investigation of breed factors, climate zone, climatic features of the year on an expanded set of traits of the beef cattle industry where the technology of housing in compost cowsheds, especially in winter, will provide a compromise between economic and environmental sustainability.

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Conflict of Interest

The authors declare no conflict of interest.

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М'ясне скотарство України (вплив клімату, особливості розведення, стратегії підвищення ефективності)

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Анотація. В Україні розводять десять порід м'ясного та комбінованого напрямів продуктивності, з яких шість відносяться до транскордонних та чотири – українські породи, виведені на основі комбінаційного схрещування місцевих порід з транскордонними. Зазначені породи розміщені в різних природньо-кліматичних та аграрних зонах, таким чином вивчення показників м`ясної продуктивності порід та факторів, які на них впливають є актуальною темою досліджень. Метою дослідження було визначення впливу породи, аграрної

кліматичної зони (зона) і календарного року (рік) на досліджувані ознаки м`ясної худоби, а також оцінка статистичних показників зв'язків між ними. Для досягнення поставленої мети використовували методи багатофакторного дисперсійного аналізу, а також кореляційний та регресійний аналізи. За показники ефективності ведення м'ясного скотарства взято: 1) живу масу корів після третього отелення і старше; 2) молочність корів за першим отеленням, яка визначається як жива маса теляти на 210 день життя після народження; 3) молочність корів за третім отеленням і старше. Встановлено, що в рівнинному ландшафті України визначають помірно континентальний клімат, з п'ятьма аграрними кліматичними зонами: 1) суворо посушлива; 2) помірно посушлива; 3) недостатнього зволоження; 4) достатнього зволоження; 5) надмірного зволоження. Ці зони відрізняються кількістю опадів, запасами продуктивної вологи в ґрунті, температурними коливаннями по періодах року, і мають певний потенціал забезпечення кормовими ресурсами худоби і особливо в літній період. Як перспектива розглядається утримання тварин в компостних корівниках в зимовий період, що відповідає вимогам добробуту тварин та забезпечує високі показники приросту на відгодівлі м'ясної худоби. Практична значимість отриманих результатів досліджень полягає в можливості врахуваннявпливу породи, аграрної кліматичної зони і календарного року на досліджувані ознаки м`ясної худоби, а також можливості прогнозування значень одних показників м`ясної продуктивності на основі значень інших

Ключові слова: м`ясна худоба; червоне м'ясо;молочність; аграрні кліматичні зони; ступінь впливу; оцінка ефективності; технологія утримання

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Sports achievements and morphometric characteristics of Oldenburg horse lines

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Abstract. The Oldenburg horse breed, due to its versatility, is a promising object for scientific research. Identification of regular relationships between genealogical characteristics, morphometric indicators and athletic achievements of representatives of this breed is critical for the development of effective breeding programmes. The purpose of the study was to analyse the influence of line affiliation on the morphological characteristics and athletic performance of Oldenburg horses and to identify links between morphological traits and athletic performance. The study was conducted at the equestrian complex "Schockemoehle" (Germany), including 90 Oldenburg horses, divided by sex and lineage. Morphometric indicators and sports achievements are analysed. The results show the dominance of the Cor de la Bryere lineage (48.9% of the total sample), which indicates the success of breeding programmes in improving its characteristics. Other significant lines had a share of 15.6% to 10.0% in the sample structure. Morphometric analysis showed high uniformity among horses in height at the withers and metacarpal circumference, with slight differences between the sex groups: height at the withers ranges from 168.13 cm to 169.2 cm, and metacarpal circumference – from 20.85 cm to 20.99 cm. Analysis of sporting achievements showed that geldings are highly effective in overcoming high obstacles, reaching the Grand Prix level (⩾155 cm) in 23% of cases, compared to 10% among stallions and

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mares. Stallions and mares usually reach the level of 130-140 cm, with some predominance of mares in this category. The study of different lines shows that the Diamant de Semilly and Almé Z lines have advantages in morphometric parameters, such as height at the withers and metacarpal circumference, which can affect athletic performance. The Capitol I line has the largest number of competitions, but needs to be improved to achieve better athletic performance. The practical significance of the results lies in the possibility of optimising the breeding strategies of sports horses to achieve better achievements in competitions

Keywords: half-breeds; sport horse breeding; breeding programmes; body measurements; genealogical analysis; heritability, competition

Introduction

Modern sports horse breeding is defined by the growing demands on the performance of horses, in particular on their motor characteristics, which are crucial for achieving success at the international level. In the conditions of modern competitions, breeding efforts are aimed at creating horses that not only meet breed standards, but also demonstrate high athletic results.

One of the key aspects in the development of a sports horse is the interaction of numerous factors such as genetics, morphology, physiology, and environmental conditions, including conditions of maintenance and training. In this context, the research conducted by M. Ablondi *et al.* (2019b), which highlights the interaction of these factors and their impact on the athletic characteristics of horses, is important. The authors demonstrate that training efficiency and keeping conditions are crucial for optimising horse performance, along with their genetic and morphological aspects.

The Oldenburg breed is distinguished by its versatility and high sporting achievements. In particular, horses of this breed are actively used in such disciplines as show jumping and triathlon. The International Equestrian Federation (FEI, 2021) emphasises that show jumping combines the courage, control, and technical skills that are necessary for successful performances in international competitions. Y. Neumann *et al.* (2021) additionally note that success in such competitions depends on a set of factors, including the makings, training of the horse, and the experience of the rider.

Despite the great interest in specific breeds and national competitions, there is not enough research to generalise the athletic performance of horses. J.E. Sackman & K.A. Houpt (2019) and M. Vidament *et al.* (2021) point to the need to expand research beyond individual breeds and national athletic quality tests to better understand the factors that drive athletic achievement internationally. In particular, E. Sobotková *et al.* (2022) note that a horse's breed, age, and sex are important factors that affect its ranking in international obstacle course competitions.

One of the main methods used in breeding Oldenburg horses is line breeding. C. Cochran (2024) and W. Nolte *et al.* (2019) confirm that line breeding allows the concentration of desired alleles in individual lines, which leads to the development of populations with predicted characteristics. The history of breeding the Oldenburg breed, which includes the use of Frisian mares and imported stallions, has significantly influenced the current breed phenotype. K. Bintz (2024) demonstrates that these historical aspects of breeding in the Oldenburg breed contributed to the development of modern sports horses.

An important aspect is also the study of the influence of genealogical factors on athletic performance. S. Vosgerau (2022) focuses on the need to consider not only morphometric

characteristics, but also genealogy to improve breeding programmes. Nowadays, breeding of the Oldenburg horses focuses on the exterior and temperament of the horse, in particular, on the harmonious structure of the body and jumping technique. Identifying the genetic basis of athletic qualities is a critical task. A. Gemma (2019) emphasises that identifying genetic components that correlate with high athletic performance can significantly improve the efficiency of the breeding process. C. Hector (2024) adds that motor characteristics are key to a horse's performance in competition, but success also depends on other factors. European countries such as Germany and the Netherlands demonstrate leadership in sports horse breeding through effective breeding programmes (Oldenburger Verband, 2023; WBFSH, n.d.). Specialised selection for different disciplines leads to the development of separate subpopulations with pronounced differences in the development of traits.

Therefore, the purpose of this study was a comprehensive assessment of the genealogical impact on the morphological and athletic characteristics of Oldenburg horses, and an analysis of the situation at international obstacle course competitions. The main hypothesis was that the proportion of thoroughbred horse blood in the pedigree, breed, age, gender of the horse and exterior data affect the athletic performance of horses at the world level. The results of this study will contribute to understanding current trends in international competitions to overcome obstacles and improve breeding programmes, which is important for the development of sports horse breeding.

Materials and Methods

The study was conducted at the specialised equestrian complex "Schockemoehle" in Germany, which provides optimal conditions for raising and training sport horses of half-breeds. The equestrian complex "Schockemoehle" is engaged in breeding and training sports horses, in particular the Oldenburg breed, using specific methods, such as embryo transplantation for older mares and conventional mating for young horses. These methods are aimed at improving breeding results and breed development in general. Careful selection of breeding horses with an emphasis on pedigree plays an important role here. The selective approach involves a combination of conventional and innovative techniques to preserve and improve the characteristics of the breed.

The study was conducted in accordance with the European Convention for the Protection of Vertebrate Animals Used for Research and other Scientific Purposes (1986) and Procedure for Conducting Research and Experiments on Animals by Scientific Institutions (2012). During the study, a sample of 90 horses of the Oldenburg breed was established, which met certain criteria for age, athletic performance, and origin. The horses must be over seven years old, have participated in at least ten show jumping competitions, and have been born and raised in the specified complex.

Horses from this sample were divided into three groups by gender with 30 animals in each group (stallions, mares, geldings). Each gender group was additionally divided into five groups based on line affiliation (Cor de la Bryere, Diamant De Semilly, Capitol I, Almé Z, Furioso II). This division helped to conduct a comparative analysis of sports achievements and morphological characteristics of horses of different lines. Each of the 90 selected individuals was analysed according to the following indicators: bloodiness for a thoroughbred horse breed, height at the withers, metacarpal circumference, number of competitions, number of wins, number of prizes, amount of winnings in EUR.

Genealogical analysis involved identifying horses using breeding passports and open databases of breeding and sports associations (WBFSH, FEI, Hippomundo) to determine the pedigree and lineage of each horse. The thoroughbred horse blood test was used as one of

the key features for evaluating half-breed horses. Morphometric analysis was performed with the study of height at the withers and metacarpal circumference.

The analysis of the sports results of competition horses was carried out considering data on the number of competitions to overcome obstacles, the level of competitions (by the height of obstacles) achieved results. The number of wins, prizes, and the amount of prize money were considered using the Hippomundo open database (n.d.).

Statistical analysis was performed using methods of variational statistics for large samples. Mean values, standard deviations, and coefficients of variation for each of the studied indicators were calculated. Appropriate statistical tests were used to compare the groups.

Thus, the study provided a comprehensive analysis of the impact of genetic, genealogical, gender and exterior characteristics on the athletic performance of Oldenburg horses and their compliance with modern equestrian requirements.

Results and Discussion

A detailed analysis of the population structure of Oldenburg horses obtained in "Schockemoehle" revealed a clear dominance of the Cor de la Bryere line, which is a key aspect in understanding breeding work and its results. In the population structure of the Oldenburg breed presented in Table 1, the Cor de la Bryere line occupies an extremely significant share, accounting for almost half of the sample – 48.9% of the total number of horses. This high level of representation is a clear indication of the success of breeding programmes aimed at consolidating and improving the desired traits in this line.

Table 1. *Sample structure, distribution by gender and line affiliation*

No.	Line	Stallions		Mares		Geldings		In general	
		n	%	n	%	n	%	n	%
1	Cor de la Bryere	16	17.8	14	15.6	14	15.6	44	48.9
2	Diamant de Semilly	5	5.6	6	6.7	3	3.3	14	15.6
3	Capitol I	2	2.2	2	2.2	5	5.6	9	10.0
4	Alme Z	4	4.4	5	5.6	4	4.4	13	14.4
5	Furioso II	3	3.3	3	3.3	4	4.4	10	11.1

Source: developed by the author

The high sporting achievements of Cor de la Bryere horses can be attributed not only to the influence of outstanding breeding stallions such as Cassall ASK and Cornet Obolensky, but also to the overall genetic stability of this line. The genetic stability and qualitative characteristics of the lineage are also confirmed by the presence of numerous descendants of the outstanding Chacco-Blue in pedigrees, which highlights the importance of these genetic lines for achieving high athletic performance. Compared to the Cor de la Bryere line, other lines have a lower representation in the population. The Diamant De Semilly line accounts for 15.6% of the total number of horses, which is a significant share, but less than the Cor de la Bryere line. The Almé Z line, which also shows significant potential, has a representation of 14.4%. On the other hand, the Capitol I and Furioso II lines have the smallest proportions – 10.0% and 11.1%, respectively, which may be the result of different breeding strategies or historical factors that influenced their development. The marked distribution of particles among the lines indicates the importance of further research to assess their contribution to the overall athletic potential of the Oldenburg breed (Oldenburger Pferde,

n.d.). Further research should focus on analysing the reasons that led to such changes in representation, and on the impact of each of the lines on the overall athletic performance of the breed.

Analysis of morphometric parameters confirms the high uniformity of the population of Oldenburg horses in the main line parameters, in particular, the height at the withers and metacarpal circumference (Table 2). This uniformity indicates the effectiveness of breeding programmes aimed at stabilising the physical characteristics of the breed. However, despite this morphological consolidation, there is significant variability in the athletic performance of horses. This variance can be caused not only by genetic factors that are not directly related to morphology (for example, genes that affect temperament or coordination), but also by the influence of the external environment, including the level of training, feeding regime, and overall health of horses.

Table 2. *Morphometric parameters of different sex groups of Oldenburg horses*

	Stallions		Mares		Geldings	
	M ± m	Cv, %	M ± m	Cv, %	M ± m	Cv, %
Bloodline	36.46 ± 0.8	11.97	37.98 ± 0.88	12.71	37.85 ± 0.72	10.36
Height at the withers	169.1 ± 0.72	2.35	168.13 ± 0.68	2.21	169.2 ± 0.93	3.00
Metacarpal circumference	20.94 ± 0.11	2.98	20.85 ± 0.09	2.42	20.99 ± 0.09	2.47
Number of competitions	49.5 ± 6.69	74.07	53.43 ± 6.16	63.17	60.37 ± 7.45	67.60
Number of wins	2.53 ± 0.62	133.45	2.2 ± 0.36	88.85	1.77 ± 0.42	129.32
Number of prizes	16.17 ± 2.69	91.23	19.03 ± 2.77	79.67	17.9 ± 3.37	103.20
Prize money, EUR	7,534.73 ± 3,954.52	287.47	12,479.23 ± 8,011.19	351.62	10,917.03 ± 3,778.4	189.57

Source: developed by the author

Morphometric studies have shown that the height at the withers and metacarpal circumference have little variation among different sex groups. The average values for height at the withers are 169.1 cm in stallions, 168.13 cm in mares, and 169.2 cm in geldlings; for metacarpal circumference, they are 20.94 cm, 20.85 cm, and 20.99 cm, respectively. Low coefficients of variation of these characteristics confirm the high stability of physical parameters among the sex groups.

Determination of the bloodlines of sport horses, according to the thoroughbred breed, is a key aspect of the study in the context of analysing the influence of genetic factors on the sports performance of horses of half-breeds. This parameter helps to assess the extent to which the hereditary characteristics of thoroughbred horses can affect the characteristics of athletic performance, which is critical for the development and improvement of athletic qualities of half-blood horses. The analysis of conditional heritability by thoroughbred in Oldenburg horses shows average variation in all three sex groups with coefficients of variation of 11.97% for stallions, 12.71% for mares, and 10.36% for geldings. High coefficients of variation in athletic performance, such as the number of competitions, places won, and prize amounts, indicate significant variability in athletic performance. This highlights the impact of individual characteristics and level of training on achievements in competitions. In general, the study of morphometric indicators and sports achievements of Oldenburg horses reveals high population uniformity in the main

morphometric parameters. However, there is a significant variability in athletic performance, which highlights the influence of other factors, in particular genetic characteristics and external conditions. Analysis of the distribution of Oldenburg horses by sex and level of training, in particular considering the height of obstacles that horses can overcome (Table 3) showed clear trends in the distribution of horses by gender and their ability to overcome obstacles of different heights, which allows drawing several important conclusions.

Table 3. *Characteristics of horses of different sex groups by their ability to overcome obstacles of different heights*

Sex group	n	Distribution of livestock by maximum obstacle height					
		130-140		145-150		⩾155	
		n	%	n	%	n	%
Stallions	30	15	50	12	40	3	10
Mares	30	17	67	10	33	3	10
Geldings	30	10	34	13	43	7	23
Total	90	42	47	35	39	13	14

Source: developed by the author

Firstly, among the stallions that make up one-third of the sample (n = 30), the majority of horses (50%) successfully participate in competitions on obstacles with a height of 130-140 cm. This shows that stallions mostly show a high level of training for mid-level competitions. Only 10% of horses reach the Grand Prix level (⩾155 cm), which confirms their weaker readiness to overcome too high obstacles compared to other sex groups.

Among mares, which also make up one-third of the sample (n = 30), the situation is somewhat similar, but with some differences. 67% of mares (17 out of 30) participate in competitions with an obstacle height of 130-140 cm, which is a higher percentage compared to stallions. This may indicate that the mares are well trained to overcome mid-level obstacles. However, as with stallions, only 10% of mares reach the Grand Prix level, which again indicates less frequent achievement of high levels of training. In contrast to stallions and mares, geldings, who also make up one third of the sample (n = 30), show a different trend. 34% of geldings (10 out of 30) compete on obstacles with a height of 130-140 cm, which is the lowest percentage of all sex groups. On the other hand, 43% (13 out of 30) of geldings participate in competitions with an obstacle height of 145-150 cm, which indicates their superiority in overcoming obstacles of medium height. A significant percentage of geldings (23%, or 7 out of 30) reach the Grand Prix level (⩾155 cm), which indicates their higher ability to overcome high obstacles compared to stallions and mares.

There is an assumption that castration probably concerns horses that have less breeding value. However, it turns out that better results can be achieved after castration. It is important to note that stallions and mares are selected according to similar criteria, and this hypothesis requires further clarification. Breeding strategies for geldings are also different from those applied to stallions and mares.

Analysis of the data from Table 3 shows that stallions and mares have a similar distribution in terms of athletic performance. However, the findings show that geldings have significant advantages in overcoming high obstacles and are more likely to reach the level of the Grand Prix. Instead, stallions and mares are more likely to participate in mid-level competitions. These results can be determined by both physiological and breeding characteristics of different

sex groups, which highlights the importance of taking the horse's sex into consideration when developing training and breeding strategies to achieve optimal results in competitions.

The morphometric analysis presented in Table 4 shows different levels of physical characteristics and athletic performance among Oldenburg horse lines. These results highlight differences in the ability of horses to succeed in competition, which can be explained by both morphological features and breeding strategies applied to each lineage.

Table 4. *Morphometric indicators of representatives of the Oldenburg breed of various line affiliation*

Line	Cor de la Bryere	Diamant de Semilly	Capitol I	Alme Z	Furioso II
Indicator	**M ± m**	**M ± m**	**M ± m**	**M ± m**	**M ± m**
Bloodline	38.03 ± 0.64	36.74 ± 1.49	36.21 ± 1.42	38.38 ± 1.23	35.59 ± 0.90
Height at the withers	167.95 ± 0.64	171.29 ± 1.31	167.78 ± 0.91	169.08 ± 1.03	169.7 ± 1.35
Metacarpal circumference	20.80 ± 0.08	21.21 ± 0.15	20.88 ± 0.17	21 ± 0.15	21.06 ± 0.14
Number of wins	2.39 ± 0.44	1.57 ± 0.48	1.78 ± 0.91	2.54 ± 0.69	1.9 ± 0.80
Number of competitions	53.48 ± 5.18	53.5 ± 12.10	64.33 ± 14.46	56.62 ± 9.45	48.2 ± 12.60
Number of prizes	19.20 ± 2.63	16.14 ± 4.84	18.67 ± 4.88	13.46 ± 2.68	17.9 ± 5.25
Prize money, EUR	8,786.57 ± 3,023.96	18,713.5 ± 17,132.39	6,308.44 ± 2,381.36	5,133.54 ± 2,149.32	15,582 ± 9,737.17

Source: developed by the author

An analysis of the sporting achievements of horses of various lines shows that the cor de la Bryere and Diamant De Semilly lines have the most significant potential for achieving high results in various disciplines of equestrian sports. This may be due both to the specific genetic characteristics of these lines and to their popularity among breeders, which provides access to high-quality training programmes and resources. Despite the numerical representation of the Capitol I line in the study sample, it shows some differences in athletic performance. This may indicate that breeding efforts in this line were aimed at developing specific qualities that do not always meet the requirements of various sports disciplines. Thus, breeding programmes could focus on certain specialised characteristics that affected the overall athletic performance of horses in this line. Analysis of morphometric data of Oldenburg horses separated by lines shows noticeable differences that can significantly affect their athletic performance. A comparison of different lines and their characteristics points to several key trends and differences in the context of generally accepted standards for horses of this breed.

The Diamant De Semilly line is marked by a significant height at the withers, exceeding the Cor de la Bryere and Capitol I lines by 3.34 cm and 3.51 cm, respectively. This indicates optimal physical characteristics for horses participating in competitions where height is an important parameter. According to the standards, the recommended height at the withers for Oldenburg horses varies between 165 and 175 cm, which confirms the compliance of the Diamant de Semilly line with the upper limit of this range. The Alme Z line has a height of 2.21 cm less than the Diamant de Semilly, which can affect the ability of its representatives to show athletic results in overcoming obstacles.

The Diamant de Semilly line also has the largest metacarpal circumference, exceeding Cor de la Bryere by 0.41 cm and Capitol I

by 0.33 cm. This may indirectly indicate the strength of the constitution and the superiority of horses of this line in physical fitness, which is crucial for achieving high results in competitions. The Alme Z line has a 0.21 cm smaller metacarpal circumference compared to the Diamant de Semilly, which may reduce its athletic potential, as smaller sizes can limit physical endurance.

The Capitol I line has the highest average number of competitions, surpassing the Diamant de Semilly line by 10.85 competitions. This indicates a high athletic activity of horses of this line. While the Furioso II line shows a significantly smaller number of competitions (less by 16.13 cm), which may be due to lower opportunities or other strategies for participating in competitions.

The Alme Z line shows the highest average win, surpassing the Diamant de Semilly and Capitol I lines by 1.15-1.11 wins. This indicates the high competitiveness of horses of this line. However, the Diamant de Semilly line, although it has fewer wins compared to Alme Z, still surpasses Cor de la Bryere and Furioso II, which confirms its high potential in sporting achievements. The Diamant De Semilly line has the highest average prize money, surpassing the Cor de la Bryere and Furioso II lines by EUR 10,926.93 and 10,448.46. This may indicate a high level of success in the competition. The Alme Z line has a significantly lower average prize amount (compared to Diamant de Semilly), which may be due to lower competitiveness or competition type.

According to the results of the study, significant differences were found between the lines of the Oldenburg breed in morphometric indicators and athletic performance. The Diamant de Semilly and Alme Z lines show advantages in various aspects, such as height at the withers, metacarpal circumference, number of wins, and amount of prize money. The Capitol I line shows high sports activity, but does not achieve such significant results in winnings and prize money. The Cor de la Bryere and Furioso II lines have average performance, which allows them to be used as a basis for further improvement of breeding programmes. Thus, the results of morphometric indicators and sports achievements indicate that each line has its own unique features and potential. The Diamant de Semilly and Furioso II lines, with their outstanding physical characteristics, can be focused on achieving high results in various competitions. The Capitol I line, although it shows a large number of competitions, needs to improve the training process to improve academic performance. The Cor de la Bryere line shows the effectiveness of breeding work due to the stability of its sporting results. But the Alme Z line, despite a significant number of wins, shows limited financial results. This phenomenon can be explained by the fact that horses of this line often participate in lower-level competitions with less competition, which leads to a smaller prize pool, although the number of wins is significant. Thus, these results can be due to both limited sporting opportunities and the specifics of the level of competitions in which horses of this line are represented. The conclusion from this analysis suggests that breeding and training horses should consider not only physical characteristics, but also individual characteristics that affect their athletic performance. The results of the study highlight the importance of line affiliation in the development of athletic qualities of horses and can be useful for further improvement of training and breeding programmes.

The results of studies on the influence of line affiliation on the level of training and athletic achievements of Oldenburg horses, presented in Table 5, confirm the influence of line affiliation on the ability of horses to overcome obstacles of different heights. These data are related to both morphological and sporting features of each line, which allows evaluating their effectiveness in competitions of different levels of complexity.

Table 5. *Distribution of horses of different lines of Oldenburg breed by training levels, considering the maximum height of obstacles*

No.	Line	Total individuals, n	Distribution of livestock by maximum obstacle height					
			130-140		145-150		⩾155	
			n	%	n	%	n	%
1	Cor de la Bryere	44	19	43	19	43	6	14
2	Diamant de Semilly	14	8	58	3	21	3	21
3	Capitol I	9	3	33	5	56	1	11
4	Alme Z	13	6	46	6	46	1	8
5	Furioso II	10	6	60	2	20	2	20

Source: developed by the author

The Cor de la Bryere line shows a relatively balanced distribution of livestock between training levels. The vast majority of horses in this line (43%) participate in steeplechase competitions with heights of 130-140 cm and 145-150 cm. Only 14% of horses reach the Grand Prix level (⩾155 cm). This may indicate the versatility of the line, which performs well in mid-level tasks, but requires additional training to achieve higher results. The Diamant de Semilly line is characterised by a high proportion of horses that successfully overcome obstacles with a height of 130-140 cm (58%). A smaller proportion of horses can overcome obstacles of 145-150 cm and ⩾155 cm. This suggests that horses of this line have some advantages in mid-level competitions, but their potential for achieving the highest results is limited.

The Capitol I line is mainly represented by horses that successfully pass obstacles with a height of 145-150 cm (56%). Only 11% of horses reach the Grand Prix level. This may indicate that the breeding work of this line is focused on developing qualities that ensure success in competitions relative to the average level, but there is a need for additional efforts to improve the Alme Z line. 130-140 cm and 145-150 cm, with a small proportion of horses reaching the Grand Prix level (8%). This indicates that horses of this line are mostly successful at the average level of competition, but are less likely to achieve higher results.

The Furioso II line has a high proportion of horses that successfully overcome obstacles with a height of 130-140 cm (60%), and a lower proportion of horses that can overcome higher obstacles. This may indicate that horses in this line are mostly good at mid-level tasks, but less likely to succeed at the highest levels of competition.

Thus, the findings show that different lines have their own characteristics in terms of the level of training and sports achievements. Lines like Cor de la Bryere and Alme Z have a fairly balanced distribution between average training levels, while Diamant de Semilly and Furioso II show a higher proportion of horses overcoming mid-level obstacles. The Capitol I line shows strengths at the mid-level of competition, but has less success at the higher levels. These findings suggest that breeding strategies and training programmes for each line can be adapted to improve athletic performance depending on the specific characteristics and potential of the horses.

The results of the study emphasise the importance of an integrated approach to assessing the athletic potential of Oldenburg horses, in particular in the context of the impact of different lines on athletic performance. The analysis of the distribution of shares among the lines showed that there are significant variations in the representation of horses of different lines, which indicates the need for a more detailed study of their contribution to the overall

sporting potential of the breed. If the studies by A. Tavernier (1990; 1991) and J. Duensing *et al*. (2014) showed that variations in athletic performance can be caused by both genetic and training factors, then C. Cochran (2024) and W. Nolte *et al.* (2019) confirm that line breeding allows the concentration of desired alleles in individual lines, which leads to the development of populations with predicted characteristics.

The results of the current study confirm the high uniformity of morphometric parameters among horses of different genealogical groups, which indicates the effectiveness of the influence of breeding on the stability of physical characteristics, which correlates with the results obtained by M. Ablondi *et al.* (2019a) and B.J. Ducro *et al.* (2007). However, variability in athletic performance highlights the influence of functional characteristics that do not always correlate with morphological features (Viklund *et al*., 2015). This coincides with the conclusions of E. Bartolomé *et al.* (2018) and Y. Neumann *et al.* (2021), who note that individual characteristics and level of training play a key role in athletic performance.

In particular, the results show that geldings have an advantage in overcoming high obstacles and reaching the Grand Prix level, which may be due to their specific physiological characteristics and breeding characteristics. According to E. Sobotková *et al.* (2022), physiological factors such as greater muscle mass and more stable temperament, promote increased endurance and coordination, which are key to successfully performing challenging exercises and overcoming high barriers. This is consistent with the findings of E.P.C. Koenen *et al.* (2004), who found that geldings, due to their neutral hormonal system, have more stable energy levels and better ability to concentrate, which reduces the risk of mistakes during competition.

K. Schöpke *et al.* (2013) emphasise that genetic parameters such as inheritance certain alleles responsible for strength, stability, and the ability to quickly recover from exercise play an important role in achieving high athletic performance. In addition, breeding approaches aimed at preserving and improving these desired traits in offspring are also important, which allows not only increasing the effectiveness of training processes, but also creates prerequisites for stable success in sports.

At the same time, stallions and mares that are more focused on average competition levels require adaptation of training and breeding strategies to achieve optimal results, as noted by A.M. Haberland *et al.* (2012). Stallions have high energy and greater muscle strength, which can be an advantage in dynamic, short-term competitions, but they can also be prone to impulsivity, which affects their stability during long-term competitions or when overcoming difficult obstacles. Mares usually have more balanced mental characteristics, which contributes to better cooperation with the rider and performing technically complex maneuvers, but they may need more specialised training programmes to reach the level of endurance and strength required for high results.

The study of different lines such as Diamant de Semilly, Furioso II, Capitol I, Cor de la Bryere and Alme Z shows that each of them has its own strengths and requires a specific approach to training and preparation. The Capitol I line, which demonstrates significant potential at medium obstacle levels, needs to improve the training process to improve academic performance at high levels, which is consistent with the findings of S. Vosgerau *et al.* (2022). However, the Cor de la Bryere and Alme Z lines, which show stable results, require optimisation of training processes to increase competitiveness. The results of the current study are also consistent with the conclusions of A. Gemma & C. Hector (2019), who emphasise that identifying the genetic components associated with high athletic performance can significantly improve the efficiency of the breeding process.

Thus, the results expand the understanding of the relationship between genetic,

morphological, and training factors that affect the athletic performance of Oldenburg horses. The identified variations in athletic performance require additional research to determine the specific effects of genealogical lines on the level of results in different types of competitions. The need for this approach is supported by the results of animal genetics research, which suggests that individual differences due to genetic background can play a crucial role in predicting athletic success (Hamann & Distl, 2008; Próchniak *et al.,* 2021).

The study also highlights the importance of a selection and training approach that considers both genetic factors and the horse's physical fitness and psychological state. This is in line with modern approaches to the training of sports horses, where the integration of comprehensive analysis of animal data helps to optimise the training process, reducing the risk of injury and increasing the chances of achieving maximum athletic results, as noted in numerous studies.

Conclusions

The study highlights the need for a comprehensive approach to assessing the athletic qualities of horses, which considers not only the genetic potential, but also individual aspects of their development and training. For successful breeding and improving athletic performance, it is important to consider all these factors together, as this will allow creating more accurate breeding and training programmes.

The apparent dominance of the Cor de la Bryere line in the structure of the Oldenburg breed is explained by the high sporting achievements of horses of this line and the success of outstanding breeding stallions such as Chacco-Blue. The Diamant de Semilly and Alme Z lines also show potential, although their athletic performance and achievements may vary. An important aspect is that physical characteristics, in particular height at the withers and metacarpal circumference, have low variability, which indicates the stability of the line within the breed standard. However, a significant variation in athletic performance highlights the importance of an individual approach to the training process. In general, the morphological uniformity of the population indicates the success of breeding to stabilise physical characteristics.

However, significant fluctuations in athletic performance indicate that success in competition can be driven not only by genetic factors, but also by environmental conditions such as exercise, nutrition, and overall health. Each of the studied lines has its own unique features that affect the sporting achievements of its representatives. The analysis shows that although some lines, such as Diamant de Semilly and Furioso II, show high physical performance, their athletic performance may vary. The Capitol I line, despite the large number of participants in the competition, has certain differences in results, which may indicate the need to improve training approaches to improve efficiency. The distribution of horses by training level shows that representatives of different lines have different potential to achieve high athletic results. In particular, horses of the Cor de la Bryere and Alme Z lines show high performance at the average levels of competition, while horses of the Diamant de Semilly line are more likely to achieve success in competitions of the highest level.

Therefore, to achieve high athletic results, it is necessary to consider both the genetic potential of the horse and the individual characteristics of its development and training, which will help optimise breeding and training strategies. Prospects for further research in the field of equine sports genetics include several key areas. Firstly, it is important to conduct a more detailed genetic analysis aimed at identifying specific markers that correlate with high athletic performance. This will help to better understand which genes and their variations have the greatest impact on the athletic performance of horses. Secondly, it is necessary to investigate the epigenetic mechanisms that

affect the development of athletic qualities. Epigenetic modifications can significantly alter the manifestation of genetic information, so studying their role in the formation of athletic abilities will help to identify new aspects of the impact of the environment on training results. Thirdly, it is important to analyse the interaction between genetic factors and paratypical (environmental) factors in the development of the sports horse phenotype. This approach will allow understanding how external conditions, such as nutrition and training, affect the manifestation of genetic inclinations, and will contribute to the development of individual training programmes for horses.

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Conflict of Interest

None.

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Спортивні досягнення і морфометричні характеристики ліній коней ольденбурзької породи

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Анотація. Ольденбурзька порода коней, завдяки своїй універсальності, є перспективним об'єктом для наукового дослідження. Виявлення закономірних зв'язків між генеалогічними характеристиками, морфометричними показниками та спортивними досягненнями представників цієї породи є критично важливим для розробки ефективних селекційних програм. Мета дослідження полягала в аналізі впливу лінійної належності на морфологічні характеристики та спортивні результати коней ольденбурзької породи, а також у виявленні зв'язків між морфологічними ознаками та спортивними досягненнями. Дослідження проведено на базі кінноспортивного комплексу «Schockemoehle» (Німеччина), включало 90 ольденбурзьких коней, розподілених за статтю та лінійною приналежністю. Проведено аналіз морфометричних показників та спортивних досягнень. Результати демонструють домінування лінії Cor de la Bryere (48,9 % загальної вибірки), що свідчить про успіх селекційних програм у вдосконаленні її характеристик. Інші значні лінії мали частку в структурі вибірки від 15,6 до 10,0 %. Морфометричний аналіз показав високу однорідність серед коней за висотою в холці та обхватом п'ястка, з незначними відмінностями між статевими групами: висота в холці коливається від 168,13 см до 169,2 см, а обхват п'ястка – від 20,85 см до 20,99 см. Аналіз спортивних досягнень виявив, що мерини мають високу ефективність у подоланні високих перешкод, досягаючи рівня Гран-Прі (≥155 см) у 23% випадків, порівняно з 10% серед жеребців і кобил. Жеребці та кобили зазвичай досягають рівня 130-140 см, з деяким переважанням кобил у цій категорії. Вивчення різних ліній показує, що лінії Diamant de Semilly і Almé Z мають переваги в морфометричних параметрах, таких як висота в холці і обхват п'ястка, що може впливати на спортивні досягнення. Лінія Capitol I має найбільшу кількість змагань, але потребує покращення для досягнення вищих спортивних результатів. Практичне значення результатів полягає в можливості оптимізації селекційних стратегій спортивних коней для досягнення кращих досягнень у змаганнях

Ключові слова: напівкровні породи; спортивне конярство; селекційні програми; проміри тіла; генеалогічний аналіз; частка спадковості; конкур

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Productive qualities of young quails with the use of fennel oil (*Foeniculum vulgare*) in compound feed

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Abstract. Due to the emergence of antibiotic resistance of microorganisms, it is important to study the effectiveness of phytobiotics in poultry feeding. The aim of the study was to identify the ideal dosage of fennel oil (*Foeniculum vulgare*) for feeding meat quail. To conduct the study, 4 groups of quails of day-old age were formed, 100 birds each. The first group consumed basic compound feed and was therefore a control group. In the mixed feed of experimental group 2, 0.1% of vegetable oil was replaced with fennel oil, in experimental groups 3 and 4 – 0.2% and 0.3%, respectively. The average daily gains during the growing period were the largest in experimental group 4 – 0.46 g or 7.07% more than the control group. The advantage over the control of quails in experimental group 3 was 0.43 g or 6.61%, and in experimental group 2 – 0.34 g or 5.22%. Throughout the experiment, birds in the experimental groups consumed 2.41-4.49% more feed compared to the control group. However, the feed cost per kilogram of body weight gain was 5.04-6.97% lower than in the control group. Quails in experimental group 2 showed an advantage over the control group, with breast muscle weight higher by 2.5 g (5.22%) and leg muscle weight by 1.1 g (3.74%). The birds of experimental group 3 were ahead of the control in terms of breast muscle weight by 3.5 g or 7.31%, and leg muscles – by 1.5 g or 5.10%. Quails in experimental group 4 surpassed the control group, showing a 3.9 g (8.14%) increase in breast muscle weight and a

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1.9 g (6.46%) increase in leg muscle weight. Thus, the introduction of fennel oil in a dose of 0.1-0.3% into the composition of quail compound feed allows improving growth and achieving better productivity indicators

Keywords: phytobiotics; essential oils; poultry meat; slaughter indicators; productivity; body weight gain

Introduction

The extensive use of antibiotics as feed additives to promote growth in livestock and poultry over the past half-century has led to a major negative outcome: the emergence of antibiotic-resistant microflora. Researchers from all over the world, including M. Barrahi *et al*. (2020), concerned that humanity faces the risk of transmission of antibiotic-resistant bacteria from animals to humans through consumption of livestock and poultry products.

In the early 2000s, the use of antibiotics to stimulate animal growth was banned in most developed countries of the world, which created new difficulties – outbreaks of infectious diseases among animals became more frequent. According to M. Murshed *et al*. (2023), the need to protect animals from pathogenic microflora led to the development of a new approach to the problem of antibiotic resistance and led to the search for alternatives to antibiotics that would not have side effects, but reliably protect the health of animals and ensure their high productivity.

Thus, the positive effect of using various herbal preparations in feeding animals was established to protect their health and ensure high productivity. N. Abdelli *et al.* (2021) emphasise that nowadays more than a dozen different plants have been studied and recommended for use in animal husbandry as an alternative to antibiotics. They do not have a negative impact on the quality of products, and accordingly on the person. The most common phytobiotics used in animal feeding, according to W.A.A. El-Ghany (2020), include nutmeg (*Myristica fragrans*), cinnamon (*Cinnamomum zeylanicum*), clove (*Syzygium aromaticum*), parsley (*Petroselinum crispum*), peppermint (*Mentha piperita*), black cardamom (*Amomum subulatum*), celery (*Apium graveolens*), coriander (*Coriandrum sativum*), chili pepper(*Capsicum annuum*), black pepper (*Piper nigrum*), cumin (*Cuminum cyminum*), anise (*Pimpinella anisum*), gunba/fenugreek (*Trigonella foenum-graecum*), horseradish (*Armoracia rusticana*), black mustard (*Brassica nigra*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), rosemary (*Rosmarinus officinalis*), thyme (*Thymus vulgaris*), asparagus (*Asparagus racemosus*), leptadenia (*Leptadenia reticulata*).

R.G.D.S. Deminicis *et al.* (2021) note that the content of active substances and chemical composition of phytobiotics in final products can vary greatly depending on biological factors (plant species, place of cultivation, and harvesting conditions); the parts of the plant used (seeds, leaves, etc.); the method of production (extraction, distillation, and stabilisation); storage conditions (light, temperature, oxygen tension, and time); geographical origin; harvest season. A significant role is also played by the type of animal, dosage, time and method of administration. The action of these compounds is primarily aimed at preventing pathogenic infections and, as a result, improving animal welfare.

M. Murshed *et al.* (2023) note that herbal preparations do not have a significant nutritional value for animals, but they have a positive effect on feed conversion, contribute to improving animal productivity and product quality. The primary effect of exposure to phytogenic drugs is the fight against potential pathogenic pathogens and by increasing the

number of beneficial intestinal microflora. It is this mechanism of action that gives phytobiotics antibacterial, antifungal, antiviral, and anticoccidial properties. The secondary effect of these herbal preparations is to improve the health and general condition of animals and reduce the cost of veterinary care and treatment. R.G.D.S. Deminicis *et al*. (2021) highlight that the incorporation of phytobiotics can induce beneficial changes in intestinal morphology, such as elongation of villi and increased depth of intestinal crypts. In many instances, they also regulate the host's immune response by activating cellular components of the innate immune system, including macrophages and heterophils, which protect against gastrointestinal infections. Additionally, they may stimulate the production of pro-inflammatory cytokines that influence adaptive immunity or stabilize the gut microbiome. The primary goal of using immunomodulatory feed additives is to minimize local inflammation, enhance immune function, and ultimately improve the health and productivity of animals. The purpose of the study was to investigate the effect of feeding fennel oil *(Foeniculum vulgare)* on the meat productivity of quails.

Materials and Methods

In furtherance of this goal in the conditions of a small agricultural enterprise in the Weissenburg-Gunzenhausen district "Schambachtal Alpakas" in Germany, a scientific and economic experiment was conducted to determine the optimal levels of this feed agent. To organise the experiment, 400 quails of the Pharaoh breed of day-old age, analogues in age and live weight, which ranged from 9 to 11 grammes, were selected. When forming the groups, the sex of the quails was considered. The birds were assigned to four analogous groups, with the first serving as the control group and the remaining three as experimental groups. The experiment spanned 42 days, divided into two phases: the first phase from day 1 to day 21, and the second from day 22 to day 42. This division corresponded to changes in the quails' feeding standards starting at 22 days of age.Quail growth was monitored every 7 days during the experiment. The planning and execution of the experiment were conducted in accordance with the guidelines provided by O.S. Yaremchuk *et al*. (2019).

During the entire scientific and economic experiment, the experimental bird was invariably kept in single-tier cage batteries of 50 animals in a cage measuring 750×500×250 mm. Thus, the design of the cage provided each individual with 75 cm^2 of floor space and a feeding front with 1.5 cm tray feeders. The bird was provided with water using vacuum drinkers. Quails were provided with unrestricted access to both water and feed. For quail feeding, complete feeds were used, produced at a feed mill according to the recipe provided (Table 1). To ensure adequate feeding, the quail rearing period was divided into two age half-periods: up to and including 21 days of age and after that. To ensure high levels of energy and crude protein during the first three weeks of rearing, quails were fed a significant amount of animal-based feed – fish and blood meal. The only difference between the control quail and those from the experimental groups was the concentration of vegetable oil and fennel oil.

Table 1. *Composition of compound feeds for quail feeding, %*

Indicator	Quail age 1-21 days				Quail age 22-42 days			
	Group							
	control	experimental			control	experimental		
	1	2	3	4	1	2	3	4
Corn	47.41				59.20			
Soy cake CP 43.5%	26.10				20.80			

Table 1. Continued

Indicator	Quail age 1-21 days				Quail age 22-42 days			
	Group							
	control	experimental			control	experimental		
	1	2	3	4	1	2	3	4
Sunflower cake CP 31.3%	5.50				5.50			
Fennel oil	-	0.10	0.20	0.30	-	0.10	0.20	0.30
Vegetable oil	1.55	1.45	1.35	1.25	2.40	2.30	2.20	2.10
Fish meal CP 56.7%	5.00				4.00			
Gluten meal CP 71%	2.00				3.50			
Blood meal CP 82.7%	8.00				-			
Table salt	0.30				0.50			
Monocalcium phosphate	1.00				1.00			
Shells	1.00				1.00			
L-lysine	0.04				0.11			
L-threonine	-				-			
DL-methionine	0.10				0.02			
Premix	2.00				2.00			

Source: developed by the authors

The nutritional value of the compound feeds in both the first and second growth periods closely aligned with the recommended feeding standards for meat quails outlined in the guidelines (Bratyshko *et al.*, 2014). Thus, poultry aged 1-21 days consumed mixed feed, the nutritional value of which was 12.5 MJ of metabolic energy per 1 kg. The chemical composition of these mixed feeds was as follows: crude protein – 18.0%, crude fat – 6.5%, crude fibre – 3.5%, nitrogen-free extractives – 42.4%, lysine – 1.79%, methionine with cystine – 1.01%, threonine – 1.15%, tryptophan – 0.35%, calcium – 1.0%, phosphorus – 0.8%, sodium – 0.4%. Quails aged 22-42 days consumed compound feed with a content of 12.9 MJ of metabolic energy per 1 kg, 20.5% crude protein, 7.3% crude fat, 3.4% crude fibre, 49.6% nitrogen-free extractives, 1.03% lysine, 0.74% methionine with cystine, 0.77% threonine, 0.21% tryptophan, 1.0% calcium, 0.8% phosphorus, 0.5% sodium. The content of trace elements and vitamins was the same in the composition of compound feeds of all groups, since it was provided by the introduction of premix for quails.

During the scientific and economic experiment, poultry feed consumption was monitored and feed costs per unit of production (body weight gain) were calculated. The feeding, drinking, housing, care, and disease prevention conditions for the animals involved in the experiment adhered to European legislation regarding animal welfare and comfort (Council Directive 1999/74/EC; Council Directive 1998/58/EU; Council Directive 2010/63/EU). At the conclusion of the second phase of the scientific and economic experiment, a controlled slaughter of the experimental poultry was performed. For this, four animals (two females and two males) were selected from each group based on body weights that were close to the average values for their respective groups. Animal studies were conducted in accordance with the "General Ethical Principles for Conducting Animal Experiments," which were endorsed by the 1st National Congress on Bioethics (Law of Ukraine No. 3447-IV, 2006), and the provisions of the European Convention for the Protection of Vertebrate Animals Used for Experimental and Scientific Purposes (1986).

Results and Discussion

In quails whose rearing purpose is to produce meat, the main indicator of productivity is body

weight and its changes during the rearing period. Therefore, the main indicators used to assess the effectiveness of using fennel oil productivity in quail feeding were the average daily weight gain (Table 2). In the first week of consuming mixed feeds with varying concentrations of fennel oil, the poultry in the experimental groups showed a significant increase in productivity compared to the control group. Experimental group 2 exhibited an advantage of 0.16 g or 3.73% over the control quails in this regard. The body weight of representatives of experimental group 3 per day increased by 0.20 g or 4.66% more than the control analogues. The greatest difference was in the average daily weight gain between quails of the control and experimental group 4 – by 0.24 g or 5.59% in favour of the latter. The difference was statistically significant.

Table 2. *Changes in the average daily weight gain of experimental quails, in grams*

Group	A ge, days						
	1–7	8–14	15–21	22–28	29–35	36–42	1–42
Control 1	4.29 ± 0.038	7.70 ± 0.027	7.87 ± 0.258	7.61 ± 0.083	5.58 ± 0.092	6.03 ± 0.204	6.51 ± 0.105
Experimental 2	4.45 ± 0.037**	7.99 ± 0.035***	8.24 ± 0.190	8.02 ± 0.083***	6.06 ± 0.175*	6.38 ± 0.110	6.85 ± 0.098*
Experimental 3	4.49 ± 0.037***	8.06 ± 0.028***	8.34 ± 0.185	8.12 ± 0.101***	6.18 ± 0.185**	6.51 ± 0.128*	6.94 ± 0.101**
Experimental 4	4.53 ± 0.035***	8.08 ± 0.028***	8.33 ± 0.195	8.12 ± 0.099***	6.26 ± 0.144***	6.55 ± 0.203*	6.97 ± 0.110**

Note: *P < 0.05, **P < 0.01, ***P < 0.001 compared to control group 1
Source: developed by the authors

The next age period (8-14 days) was characterised by an increase in the advantage of poultry from experimental groups over the control group for average daily weight gain in physical terms. A reduction in the disparity between the animals in experimental groups 3 and 4 was observed. During that week, the quails in experimental group 2 outperformed the control birds by 0.29 g, or 3.77%. However, the indicators of animals of experimental group 3 were higher than the control ones by 0.36 g or 4.68%, and experimental group 4 – by 0.38 g or 4.94%. All the recorded difference was significant.

At the age of 15-21 days, quails of experimental groups 3 and 4 had almost the same average daily gains, which, respectively, were 0.47 and 0.46 g or 5.97 and 5.84% higher than the control indicators. This difference was not statistically significant. There was also no significant difference between the control and animals of experimental group 2 – 0.37 g or 4.70% in favour of the latter. The age period of 22-28 days was characterised by a decrease in the average daily weight gain in animals of all groups due to changes in mixed feed. During this time, quails in experimental groups 3 and 4 displayed identical metrics, surpassing the control group by 0.51 g, or 6.70%. During this period, poultry in experimental group 2 outperformed the control group by 0.41 g, which is equivalent to a 5.39% increase. The difference in this indicator at the age of 22-28 days was statistically significant.

During the penultimate week of rearing, which coincided with the age period of 29-35 days, the average daily weight gain in quails from experimental groups significantly decreased compared to previous periods. Poultry of experimental group 4 outperformed the control group according to this indicator by 0.68 g or 12.19%. The advantage of quails in experimental group 3 was somewhat less, at 0.60 g, representing an increase of 10.75%. Animals of experimental group 2 prevailed the least – by 0.48 g or 8.60%. All the differences between the experimental and control animals were statistically significant.

The last week of poultry rearing was characterised by an increase in daily body weight gain in animals of all groups, which is physiological at this time for quails of meat

productivity. Poultry of experimental group 2 outnumbered control analogues by 0.35 g or 5.80%. It is important to highlight that this difference was not statistically significant, unlike the differences observed between the animals in experimental groups 3 and 4 compared to the control group, which were 0.48 g or 7.96% and 0.52 g or 8.62%, respectively.

An analysis of daily weight changes in quails throughout the entire rearing period revealed that the highest measurements were recorded in the animals from experimental group 4, which surpassed the control group by 0.46 g or 7.07%. Experimental group 3 showed a slightly lower advantage over the control group, with an increase of 0.43 g or 6.61%. Animals of experimental group 2 prevailed the least – by 0.34 g or 5.22%. All the difference is statistically significant. A key economic metric is the total feed intake of the experimental birds, as well as the quantity of mixed feed consumed per unit of body weight gain (Table 3).

Table 3. *Indicators of feed consumption*

Group	Age, days						
	1-7	8-14	15-21	22-28	29-35	36-42	1-42
	Mixed feed consumption, g/animal/day						
Control 1	3.95	12.07	19.22	25.24	34.03	31.97	21.17
Experimental 2	4.18	12.55	19.65	25.89	34.71	32.47	21.68
Experimental 3	4.42	12.95	19.96	26.28	35.17	32.88	22.12
Experimental 4	4.36	12.84	19.91	26.23	35.24	32.86	22.05
	Feed consumption per unit of body weight gain, g/g						
Control 1	1.315	1.694	2.277	3.315	4.035	10.090	3.788
Experimental 2	1.322	1.692	2.230	3.228	3.892	9.217	3.597
Experimental 3	1.378	1.730	2.240	3.237	3.890	9.011	3.581
Experimental 4	1.343	1.710	2.236	3.232	3.864	8.759	3.524

Source: developed by the authors

The table shows that during the first week of life, the birds in the experimental groups had a higher feed consumption of the mixed feed compared to the control group. Thus, the advantage in terms of the amount of feed consumed during this period was for quails of experimental group2 – 0.23 g/animal/day or 5.82%, experimental group 3 – 0.47 g/animal/day or 11.90%, and experimental group4 – 0.41 g/animal/day or 10.38%. During the age period of 7-14 days, poultry of all groups increased their feed intake compared to the previous period. As before, quails of the experimental groups dominated the control indicators for feed consumption. Animals of experimental group 3 consumed the most compound feed at this time – 0.88 g/animal/day or 7.29% more than their control analogues. The advantage of quails of experimental group 4 was slightly lower – 0.77 g/animal/day, or 6.38%. Quail of experimental group 2 prevailed least over the control analogues – 0.48 g/animal/day or 3.98%.

The third week of life of experimental quails was characterised by a further increase in the amount of daily consumption of mixed feed. The leading positions in terms of the amount of feed consumed continued to be held by the birds of experimental group 3, ahead of the control analogues by 0.74 g/animal/day or 3.85%. The birds in experimental group 4 outperformed the control group by 0.69 g per animal per day, or 3.59%, while those in experimental group 2 exceeded the control by 0.43 g per animal per day, or 2.24%.During the fourth week of the scientific and economic experiment, the bird further increased the amount of feed consumed, despite the fact that during this period there was a change in mixed feed recipes. Animals of experimental group 3 were consistently in the lead in terms of the amount of feed

consumed, surpassing the control by 1.04 g/animal/day or 4.12%. In addition, the animals of experimental group 2 were the least likely to exceed the control indicator – by 0.65 g/animal/day, or 2.58%. During this period, quails in experimental group 3 surpassed the control group by 0.99 g per animal per day, which is equivalent to 3.92%.

During the penultimate week of rearing, poultry of all groups consumed even more mixed feed. As in the course of previous age periods, quails of experimental group 2 differed least from the control – 0.68 g/animal/day or 2.00% in favour of the latter. Quails of experimental groups 3 and 4 outnumbered control animals, respectively, by 1.14 g/animal/day or 3.35% and 1.21 g/animal/day or 3.56%. During the last week of the scientific and economic experiment, the advantage of animals from experimental groups 2, 3, and 4 over the control in terms of the amount of feed consumed per day was 0.50 g, 0.91 g, and 0.89 g, respectively, or 1.56%, 2.85%, and 2.78%. Analysing the results of quail feed consumption during the entire scientific and economic experiment, it can be argued that this indicator was highest in poultry of experimental group 3 – 0.95 g/animal/day or 4.49% more than the control. The advantage of poultry in experimental group 4 over the control group was slightly lower at 0.88 g per animal per day, or 4.16%. Meanwhile, the smallest advantage was observed in experimental group 2, where the animals consumed 0.51 g or 2.41% more feed per day than the controls.

During the first week of life, the poultry of the control group spent the least feed on body weight gain, less than the animals of experimental group 2 by 0.007 g or 0.53%; less than experimental group 3 – by 0.063 g or 4.79%; and less than experimental group 4 – by 0.028 g or 2.13%. Analysis of feed costs per unit of quail body weight gain during the second week of life showed a slightly different pattern. The lowest feed consumption per unit of body weight gain was in quails of experimental group 2 – 0.002 g or 0.12% less than the control indicator. Animals of experimental groups 3 and 4, on the contrary, exceeded the analogues of control group, respectively, by 0.036 g or 2.13% and 0.016 g or 0.94%.

During the third week of the scientific and economic experiment, the animals of the control group took the leading positions in terms of the amount of feed spent per unit of body weight gain, surpassing quails of experimental groups 2, 3, and 4, respectively, by 0.047 g or 2.06%, 0.037 g or 1.63%, and 0.041 g or 1.80%. At the 4t^{h} week of life, the leadership of the animals of the control group 1 in terms of the amount of feed consumed per body weight gain was maintained. Quails of experimental group 2 during this period consumed the least feed – by 0.087 g or 2.62%. Poultry of experimental groups 3 and 4 showed very similar indicators during this period, losing to the control group, respectively, by 0.078 g or 2.35% and 0.083 g or 2.50%. During the 5th week of poultry rearing, the highest feed costs per unit of body weight gain were in animals of the control group, and the lowest – analogues of experimental group 4. During this period, experimental group 2 was inferior to the control group according to this indicator, respectively, by 0.143 g or 3.54%, experimental group 3 – by 0.145 g or 3.59%, experimental group 4 – by 0.171 g or 4.24%.

In the final week of poultry rearing, the control group demonstrated a distinct advantage in terms of feed efficiency for body weight gain. Conversely, among the experimental groups, the amounts of feed consumed were inversely related to the proportion of oil included in their diet.

Thus, the quails of experimental group 4 differed the most from the control – they were inferior by 1.331 g or 13.19%. Animals of experimental group 3 were 1.079 g or 10.69% inferior to the control group according to this indicator. Poultry of experimental group 2 spent 0.873 g or 8.65% less feed on body weight gain than their control counterparts. For the entire peri-

od of quail rearing from the 1st to the 42nd day inclusive, representatives of the control group spent the most feed per unit of body weight gain, and analogues of experimental group 4 spent the least. The poultry of experimental group 2 spent 0.191 g or 5.04% less feed per increase during the experiment period than the control analogues. Animals of experimental group 3 were 0.207 g or 5.46% behind the control group, and 0.264 g or 6.97% behind experimental group 4.

The main products of meat poultry are meat and other edible parts of the carcass. Consequently, a scientific and economic experiment was conducted to evaluate the effectiveness of varying levels of fennel oil in quail feeding, which included an analysis of the indicators from the control slaughter (Table 4).

Table 4. *Slaughter indicators of quails*

Indicator	Group			
	control	experimental		
	1	2	3	4
Pre-slaughter body weight, g	284.6 ± 1.72	298.3 ± 1.18**	302.3 ± 1.06***	303.0 ± 1.32***
Weight of uneviscerated carcass, g	249.1 ± 2.09	262.1 ± 1.65**	266.2 ± 1.38**	267.3 ± 1.60**
Weight of semi-eviscerated carcass, g	230.5 ± 1.95	242.0 ± 1.52**	245.7 ± 1.35**	246.4 ± 1.50**
Weight of eviscerated carcass, g	210.0 ± 1.97	220.6 ± 1.66*	224.0 ± 1.47**	224.9 ± 1.70**
Output of semi-eviscerated carcass, %	81.0 ± 0.20	81.1 ± 0.20	81.3 ± 0.18	81.3 ± 0.15
Output of eviscerated carcass, %	73.8 ± 0.25	74.0 ± 0.27	74.1 ± 0.25	74.2 ± 0.25
Breast muscles, g	47.9 ± 0.68	50.4 ± 0.69	51.4 ± 0.55*	51.8 ± 0.67*
Leg muscles, g	29.4 ± 0.27	30.5 ± 0.83	30.9 ± 0.46	31.3 ± 0.48*
Skin, g	17.9 ± 0.28	18.6 ± 0.27	18.9 ± 0.30	19.2 ± 0.15*
Internal fat, g	2.2 ± 0.11	2.4 ± 0.07	2.5 ± 0.11	2.5 ± 0.15
Liver, g	6.8 ± 0.09	7.1 ± 0.11	7.2 ± 0.08*	7.3 ± 0.08*
Lungs, g	2.5 ± 0.06	2.6 ± 0.12	2.7 ± 0.09	2.7 ± 0.08
Kidneys, g	1.5 ± 0.05	1.6 ± 0.07	1.7 ± 0.09	1.7 ± 0.13
Gizzard stomach, g	5.2 ± 0.09	5.8 ± 0.12*	5.8 ± 0.14*	6.0 ± 0.12**
Heart, g	2.2 ± 0.05	2.4 ± 0.11	2.5 ± 0.29	2.5 ± 0.17

Note: *P < 0.05, **P < 0.01, ***P < 0.001 compared to control group 1
Source: developed by the authors

For the control slaughter, birds were selected with a body weight that corresponded to the group average. The sex of quails was also considered, since there is a fundamental difference between males and females. That is why the pre-slaughter body weight of the bird of experimental group 2 was 13.7 g or 4.81% higher than that of the control group. Representatives of experimental group 3 also dominated the control – by 17.7 g or 6.23%. This indicator was highest in poultry of experimental group 4 – by 18.4 g or 6.47%. The difference between the control group and all study groups in terms of pre-slaughter body weight was statistically significant. The weight of an uneviscerated carcass, that is, already without plumage and blood, but before the removal of internal organs and the separation of certain parts of the body, was predicted to be directly related to the pre-slaughter body weight of quail. Therefore, the poultry from experimental groups 2, 3, and 4 in this indicator was larger than the control analogues, respectively, by 13.0 g, 17.1 g, and 18.2 g, which in percentage terms is 5.22%,

6.86%, and 7.31%, respectively. Such a difference was statistically significant.

According to the weight of the semi-eviscerated carcass (without plumage, blood, intestines, ovary, and oviduct), similar to the two previous indicators, quails of experimental group 4 had the highest result, surpassing the control by 15.9 g or 6.90%. A slightly smaller advantage was the poultry of experimental group 3 – 15.2 g or 6.59%. Animals of experimental group 2 prevailed the least – by 11.5 g or 4.99%. The statistical probability of this difference was also confirmed during calculations. The weight of the eviscerated carcass, namely without plumage, blood, all internal organs, head and neck, legs on the ankles, was also the largest in the bird of experimental group 4 – 14.9 g or 7.10% more than the control. A similar result, namely an advantage over the control group by 14 g or 6.67%, was demonstrated by quails of experimental group 3. By 10.6 g or 5.05% exceeded the control analogues by weight of the eviscerated carcass of the animal of experimental group 2. The difference between the experimental animal groups and the control group was statistically significant.

Quails of experimental groups 3 and 4 had the same yield indicators of semi-eviscerated carcass, in which they outnumbered their control counterparts by 0.3 %. The advantage of poultry of experimental group 2 over the control for this indicator was 0.1%. The yield of eviscerated carcass in quails of groups 3 and 4 was different, and the advantage of animals of these groups over the control was 0.3% and 0.4%, respectively. The yield of eviscerated carcass in poultry of experimental group 2 was 0.2% higher than the control indicator. The most desirable product that is obtained by raising young quails is meat, namely the muscle tissue of the breast and legs. The breast muscles of quails of experimental group 2 were heavier than the same indicator of animals of the control group by 2.5 g or 5.22%. The advantage of poultry in experimental group 3 over the control group was 3.5 g or 7.31%, and in experimental group 4 – 3.9 g or 8.14%. The difference between the control animals and representatives of experimental groups 3 and 4 was statistically significant.

In terms of muscle weight of the lower extremities (femoral), quails of experimental group 4 also occupied the leading positions, surpassing the control by 1.9 g or 6.46%. According to this indicator, only the difference between the analogues of the control and experimental group 4 was statistically significant. Quails in experimental group 3 had an advantage of 1.5 g or 5.10% compared to the control group. According to this indicator, the control was least exceeded by poultry of experimental group 2 – by 1.1 g or 3.74%. It is logical to increase the skin weight in the animals of the experimental groups, since these quails were larger in size. Therefore, the advantage of poultry of experimental group 2 in the control group was 0.7 g or 3.91%, experimental group 3 – 1.0 g or 5.59%, experimental group 4 – 1.3 g or 7.26%. It is worth noting that according to this indicator, the difference between the control and animals of experimental group 4 was statistically significant.

Similar to previous indicators, with an increase in body weight and the concentration of fennel oil in mixed feed, the mass of internal fat in the body of birds also increased. Thus, quails of experimental group 2 according to this indicator surpassed the control group by 0.2 g or 9.09%, experimental groups 3 and 4 – by 0.3 g or 13.64%. Statistically significant is the difference between animals of experimental groups 3 and 4 and controls, by liver weight. It was, respectively, 0.4 g or 5.88% and 0.5 g or 7.35% in favour of the latter. Quails of experimental group 2 also dominated the control for this indicator, but only by 0.2 g or 4.41%. By lung weight, animals of experimental groups 3 and 4 also showed the same results, which were higher than the control indicator by 0.2 g or 8.00%. A slightly smaller advantage was the poultry of experimental group 2 over the control – 0.1 g or

4.00%. The kidney weight was also the same in poultry of experimental groups 3 and 4 – 0.2 g or 13.33% more than the control indicator. However, the advantage of quails of experimental group 2 was 0.1 g or 6.67%.

Quails of experimental groups 3 and 4 also had a common heart weight index, which exceeded the control by 0.3 g or 13.64%. The advantage of poultry of experimental group 2 over the control group was slightly less – 0.2 g or 9.09%. The gizzard stomachs of birds of experimental groups 2 and 3 had the same weight, exceeding the control by 0.6 g or 11.54%. According to this indicator, quails of experimental group 4 outperformed control analogues by 0.8 g or 15.38%. It is worth noting that the difference in weight of the gizzard stomach between the control and experimental groups of poultry was statistically significant. Thus, feeding meat quails with feed containing 0.1-0.3% fennel oil had a positive effect on their growth and slaughter indicators. This effect can be explained by the antioxidant and antimicrobial effects of fennel essential oil (Anwar *et al*., 2009; Brenes & Roura, 2010; Saki *et al*., 2014).

The research results demonstrated the beneficial impact of diets with varying levels of fennel oil (*Foeniculum vulgare*) on the average daily weight gain, slaughter quality, and feed costs per unit of production in young quail raised for meat. Throughout the entire growth period, the birds in the experimental groups showed an average daily weight gain that exceeded that of the control group by 5.22% to 7.07%. The highest average daily weight gain was observed in the poultry from experimental group 4, which received a complete mixed feed formulation containing 0.3% fennel oil.

Recently, phytogenic substances, which are biologically active compounds, have garnered increasing interest as feed additives, particularly in poultry farming. This is due to their ability to enhance feed efficiency by promoting digestive secretions and improving nutrient absorption, while also reducing pathogenic load in the intestines and alleviating the immune burden on animals (Adbelli *et al*., 2021). Literature provides evidence for the use of fennel (*Foeniculum*) feed additives as phytogenic supplements in poultry diets. Among these, fennel oil stands out as one of several phytobiotics that warrants further scientific investigation.

After analysing a significant number of scientific papers in their review, M. Kumar *et al*. (2014) noted that phytobiotics improve digestibility, exhibit antimicrobial, anti-inflammatory, antioxidant, and immunostimulating activity. They are desirable not only in feeding animals, but also in feeding people. The findings are consistent with the data on the positive effect of introducing fennel oil into the poultry diet by other researchers.

Thus, a group of researchers led by R.U. Khan *et al.* (2022) presented a number of research papers that showed an increase in productivity, feed consumption, and a decrease in conversion for the consumption of fennel oil in mixed feeds for broiler chickens, laying hens, and quails of various productivity areas. In particular, the results of experiment by H.R. Gharehsheikhlou *et al.* (2018) showed that adding 0.15 and 0.25 g/kg of fennel oil to broiler chicken feed has a positive effect on growth rates. The highest increase in this case was achieved by animals whose diet contained 0.25 g/kg of fennel oil. Their average daily weight gain was 11.07% higher than the control, while with a dose of 1.5% fennel oil in the diet, quail weight gain increased by only 1.63%, which is consistent with the results of the present study. Similar data were obtained during the experiment on turkeys conducted by O.S. Yacoub *et al*. (2016). The positive effect of introducing 0.2 and 0.5 g of fennel oil to 1 kg of turkey diet was found, which contributed to an increase in body weight and average daily weight gain of experimental poultry. Whereas, S.S. Cengiz *et al.* (2016) found that feeding fennel oil in the amount of 0.1 g/kg did not affect the productivity and slaughter indicators of broiler chickens.

Instead, A.R. Ghiasvand *et al.* (2021) obtained the opposite result. The researchers found that when 0.2 g/kg of fennel oil was introduced into mixed feed, a negative dynamics of changes in the body weight of broiler chickens was noted.

Feeding quails mixed feeds with different levels of fennel oil was conditioned by the fact that during the experiment period, the poultry of the experimental groups consumed more feed than the analogues of the control group by 2.41-4.49%. However, feed costs per kilogramme of body weight gain were less than the control by 5.04-6.97%. This is due to its antibacterial and antifungal properties, which ultimately result in a reduction of pathogenic microbes in the digestive system, along with enhanced immunity and productivity in chickens. The reduction in feed consumption per unit of production is influenced by the specific types of phytobiotics incorporated into the poultry diet. Feeding young quails diets with different levels of fennel oil resulted in an increase in liver weight by 4.41-7.35%, heart weight by 9.09-13.4%, and kidney weight – 6.67-13.33%. This is consistent with the results of H.R. Gharehsheikhlou *et al.* (2018), who report that feeding broiler chickens fennel oil *(Foeniculum vulgare)* in the amount of 0.15 and 0.25 g/kg contributed to an increase in the weight of internal organs. Thus, the heart weight was 0.17% higher than the control at the doses of 0.15 g/kg and 5.97% at the doses of 0.25 g/kg of fennel oil. The increase in kidney weight was 3.38% and 11.86%, respectively.

A number of studies have been conducted using fennel seeds. Thus, according to A.M. Henda (2014), among the studied doses of fennel seeds (0.25, 0.50, or 0.75 g/kg of feed), 0.5 g/kg was the most optimal. However, all concentrations of phytobiotic had a positive effect on the productive qualities of quails under 42 days of age, and it was proved that fennel seeds increase hunger, stimulate endogenous digestive enzymes, and cause an immunological response. In the course of experiments by Indian researchers K. Premavalli & A.V. Omprakash (2020), a positive effect on the productivity of young quails at 0.5, 1.0, and 1.5% of fennel seeds in mixed feed was confirmed. The most optimal doses were 1.0 and 1.5% of quails that consumed mixed feed with such a content were 4.4-5.1% superior to control analogues by live weight.

Improvements in the growth rates of broiler chickens were recorded by other Indian researchers L. Saleh *et al.* (2018), feeding poultry 0.5, 1.0, and 1.5% fennel seeds in mixed feed. The positive effect of including fennel seeds in the amount of 1, 2, and 3 g/kg of mixed feed of broiler chickens was noted by A. Mohammed & R.G. Abbas (2009). The results of their experiments recorded a significant improvement in the body weight of broilers. Significant differences in the weight of the gizzard stomach and pancreas were noted. Among Ukrainian researchers, a large effort to study the effectiveness of phytobiotics in quail feeding was carried out by R.A. Chudak *et al.* (2020). According to the results of experiments, a positive effect of pale purple coneflower supplements on the productivity of quails in various areas of productivity was noted. When using this feed additive, quail body weight gains increased in the range of 14.3-23.1%, and feed conversion decreased by 9.7-14.9%. The breast muscles mass of quails that consumed mixed feed with an optimal level of feed additive was 23.3% higher than the control. The weight of the muscles of the lower extremities exceeded the control indicator by 15.4%. It is worth paying attention to the weight of the gizzard stomach, which was 17.0% higher than the control, the liver, whose weight was 15.3% higher than the control indicator, the kidneys, whose weight was 27.2% higher than the control analogues, and the heart, which exceeded the control by 19.0%.

Therefore, the effectiveness of using phytobiotics as feed additives in animal and poultry diets is influenced by the specific type and form of the additive. This makes the investigation of their impact on the productive traits of animal groups or species especially relevant

today, given the heightened demands for the quality of end products. The results obtained align well with findings from other researchers and demonstrate the beneficial effects of fennel oil *(Foeniculum vulgare*) at concentrations of 0.1%, 0.2%, and 0.3% on the meat productivity of quails, leading to improvements in both quantitative and qualitative product indicators, as well as a reduction in feed conversion rates.

Conclusions

The experiment concluded that incorporating compound feed with fennel oil into the diet of young quail aimed at meat production positively impacts their meat productivity, yield of the finished product, and feed efficiency. Experimentally, it was found that the optimal level of fennel oil in mixed feed of young quails under the age of 42 days is 0.3%. However, the results obtained for the introduction of 0.2 and 0.1% fennel oil in the composition of mixed feeds of young quails also indicate a positive effect on poultry productivity compared to the control group. At the concentration of 0.3% fennel oil in the diet of young quails, an increase in the average daily weight gain of 0.46 g or 7.07% ($p < 0.01$), the yield of eviscerated carcass – by 0.4%, the weight of breast muscles – by 3.9 g or 8.14% ($p < 0.05$), the muscle weight of the lower extremities – by 1.9 g or 6.46% ($P < 0.05$), the liver weight – by 0.5 g or 7.35% ($p < 0.05$), and weight of the gizzard stomach – by 0.8 g or 15.38% ($p < 0.01$) compared to the indicators of control animals whose mixed feed did not contain the feed additive under study. There was a decrease in feed costs for body weight gain by 0.264 g or 6.97% compared to the control. An increase in poultry productivity and a reduction in feed costs per unit of body weight gain were achieved due to the antimicrobial, anti-inflammatory, antioxidant, and immunostimulating effects of fennel oil. Thus, given the positive effect of fennel oil on the growth and productivity of young meat quails, it would be appropriate to conduct further research on the influence of fennel oil and other feed additives on the productivity and quality of the resulting products of animals and poultry of other species and groups.

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None.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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Продуктивні якості молодняку перепелів за використання олії фенхелю (*Foeniculum vulgare*) у складі комбікормів

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Анотація. У зв'язку з виникненням антибіотикорезистентності мікроорганізмів актуальними є дослідження ефективності використання фітобіотиків у годівлі сільськогосподарської птиці. Метою досліджень було встановлення оптимальної дози олії фенхелю (Foeniculum vulgare) у годівлі перепелів м'ясного напряму продуктивності. Для проведення дослідження було сформовано 4 групи перепелів добового віку по 100 голів у кожній. Перша група споживала базовий комбікорм і тому була контрольною. У комбікормі 2-ї дослідної групи 0,1 % рослинної олії замінили на олію фенхелю, 3-ї та 4-ї дослідних груп – відповідно, 0,2 та 0,3 %. Середньодобові прирости за період вирощування були найбільшими у 4-ї дослідної групи – на 0,46 г або 7,07 % більше контролю. Перевага над контролем перепелів 3-ї дослідної групи становила 0,43 г або 6,61 %, а 2-ї дослідної групи – 0,34 г або 5,22 %. Протягом досліду птиця дослідних груп спожила більше корму, ніж аналоги контрольної групи на 2,41-4,49 %. Проте, витрати корму на кілограм приросту маси тіла були меншими за контроль на 5,04-6,97 %. Відмічено перевагу перепелів 2-ї дослідної групи над контрольної за масою грудних м'язів на 2,5 г або 5,22 %, м'язів лап – на 1,1 г або 3,74 %. Птиця 3-ї дослідної групи випереджала контроль за масою грудних м'язів на 3,5 г або 7,31 %, м'язів лап – на 1,5 г або 5,10 %. Перепели 4-ї дослідної групи за масою грудних м'язів переважали контрольних аналогів на 3,9 г або 8,14 %, за масою м'язів лап – на 1,9 г або 6,46 %. Таким чином, уведення до складу комбікорму перепелів м'ясного напряму продуктивності олії фенхелю у дозі 0,1-0,3 % дозволяє покращити ріст та досягнення кращих показників продуктивності

Ключові слова: фітобіотики; ефірні олії; м'ясне птахівництво; забійні якості; продуктивність; приріст маси тіла

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Analytical review of the market of raw materials and innovative technologies of health-improving food products of plant origin

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Abstract. In the modern world, interest in health products has increased due to increased attention to a healthy lifestyle and a balanced diet. However, there is a need to master technologies for the production of health products to preserve the maximum amount of useful substances and use innovative methods of processing raw materials. That is why the purpose of this study was to review and analyse existing technologies for the production of health-improving food products, in particular, with the use of plant raw materials. Scientific and technical literature and regulatory documentation served as materials and methods. A sample of individual periods was created and analysed according to selected indicators, namely the volume of food production, the dynamics of

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vegetable, fruit, and berry crops, the commodity structure of the wholesale turnover of processed fruits and vegetables, the volume of baby food and dietary food production, the volume of cocoa, chocolate, and sugar confectionery production, and the average daily consumption of basic micro- and macro-nutrients in certain food products by the population. It was determined that the volume of the health food market for the period 2015-2020 increased by 1.3 trillion USD in value terms, while the range of traditional food products expanded by an average of 2-3% per year. The production of vegetable crops by households in 2021 exceeded the production of enterprises by 6.2 times, in 2020 – 5.5 times and in 2019 – 5.2 times. The production of fruit and berry crops in Ukraine in 2021 was 6.3% more than in 2020, and in 2020 – 8.7% more than in 2019. The dynamics of the average daily intake of protein, fat, iron, niacin, ascorbic acid, thiamine, riboflavin, calcium, retinol, β-carotene equivalents, retinol and β-carotene (RET+ 1/6 B-CARQ) in food products help to determine the deficit and surplus of macro- and micro-nutrients in the diet of consumers. In general, the use of health food products, including children's and dietary nutrition, is promising and competitive, and the feasibility of using plant-based raw materials in health nutrition and the development of new health products is also confirmed

Keywords: functional nutrition; fruits; vegetables; food; food production

Introduction

The World Health Organisation estimates that 600 million people, or almost every 10th inhabitant of the planet, suffer from the consumption of low-quality food products. Every year, 420,000 people die from eating dangerous food. Diarrhoeal diseases are the most common diseases that develop as a result of eating dangerous food: 550 million people get sick and 230,000 die from dangerous food each year (State Enterprise Centre of Public Health..., 2024). Due to the development of information technology, people have become more conscious of the food they consume. Since there is a shortage of health products and a surplus of junk food in the mass market, the consumer often lacks such functional elements as vitamins, carotenoids, natural antioxidants, proteins, fatty acids, polysaccharides, etc. One of the reasons for this imbalance, as defined by M. Sychevsky (2019) studying the food industry as the basis of food security and state development, it is the production by industry of a large number of products that do not meet the requirements for indicators of biological value.

Exploring the functionality of food components and new technologies C. Galanakis (2021) presents nutritional and functional food ingredients, and provides widely used terms bioactivity, bioavailability, and biological digestibility. The influence of non-thermal technologies on the functional properties of proteins, carbohydrates, lipids, minerals, vitamins, polyphenols, glucosinolates, polyphenols, aromatic compounds, and enzymes was also discussed. Non-thermal technologies, as new methods of food production, can maintain the bioavailability of food components, improve functional and technological properties, and increase crop yields.

Individual studies by D. Granato *et al*. (2020) were devoted to the investigation of functional food products, their development, technological trends, and testing for effectiveness and safety. Food manufacturers invest resources in developing processed foods that can provide additional functional health benefits to consumers. Due to national regulations and target expiration dates in different countries, the meaning and definition of this term is still ambiguous around the world. M. Gallego *et*

al. (2018) described the most common functional ingredients, such as polyunsaturated fatty acids, probiotics/prebiotics/synbiotics, antioxidants, and the technical means of adding them to food. Researchers also provide a number of recommendations and steps that food companies should take to ensure that the products they develop are truly functional and healthy. L. Brown *et al*. (2018) indicate that there are unique challenges in clinical trials of the use of functional foods.

Herbal medicines, such as herbal products and nutraceuticals, can often be considered low-risk due to their long history of human use. Reviewing the available information and reports on side effects and clinical studies with herbal products in the literature review process, it can be concluded that they are constantly increasing, but many reports are incomplete and contradictory. For example, botanical preparations, in particular herbal products, are complex products that contain more than one active ingredient. Research in this area can be confusing due to various manufacturing processes and formulations, including cosmetics and food additives; the environment; chemotypes; misidentification or falsification.

According to Resolution No. 189 (2011) regarding the concept of the State scientific and technical program "Biofortification and functional products based on plant raw materials for 2012-2016" among the results of research introduced into production were new varieties of plants, bred considering the biofortification strategy; bread, bakery, and flour confectionery products containing vitamins of group B, A, E, calcium, iron, iodine and selenium; milk and dairy products containing multivitamin complexes, lactic acid bacteria and starter cultures; low-calorie fat and oil products containing functional ingredients; soft drinks with extracts of medicinal plants. A nutrition action plan has also been adopted to eliminate chronic deficiencies in essential vitamins, minerals, and other essential compounds in the diet.

Technologies of health products with the addition of plant raw materials can include various methods of processing, manufacturing and extraction, which are aimed at enriching products with biologically active substances, preserving the useful properties of plant components, improving their effectiveness on the human body, reducing waste from the production of analogues based on artificial or animal raw materials, increasing economic efficiency, creating jobs, and increasing the range and meeting the needs of consumers. The study by A. Antoniv *et al*. (2022) showed how bread quality indicators have changed due to the replacement of sugar with rapeseed honey for production. It was found that the use of honey in the recipe accelerates the fermentation of dough by 1.5-2.0 times, it was found that yeast is more active in the honey environment, and the sensory characteristics of the prototypes met the requirements of national standards of Ukraine.

Especially relevant today is the creation of health-improving desserts and confectionery products that have an enriched nutritional composition, reduced or changed sugar content. One of the ways to achieve this is the use of vegetable raw materials. Therefore, the purpose of this study was to analyse the raw material market and existing innovative food technologies for health products made from plant raw materials.

Materials and Methods

The research was conducted at the laboratories of the Department of Standardisation and Certification of Agricultural Products of the Faculty of Food Technology and Quality Control of Agricultural Products of the National University of Life and Environmental Sciences of Ukraine during January-February 2024.

The material for writing the paper was scientific, technical, and official statistical information, analysed and generalised using theoretical and statistical research methods. In the course of the study, generally accepted methods

and techniques were used: abstract and logical, inductive and deductive, analytical, synthetic, analogue and comparative methods, and methods of analysis and synthesis. Scientific and technical literature on scientometric and abstract databases Scopus, Web of Science and Google Scholar, the Ministry of Agrarian Policy and Food of Ukraine, the Ministry of Economy of Ukraine, the National Academy of Agrarian Sciences of Ukraine was processed. Regulatory and technical information was used from relevant institutions, organisations and departments, in particular the Institute of Food Resources of the National Academy of Agrarian Sciences of Ukraine, the State Statistics Service of Ukraine. The initial data were obtained upon request from the State Statistics Service of Ukraine. Statistical processing and comparison of the obtained data were performed using the built-in statistical functions of MS Excel and are shown in figures 1-10.

To determine the volume of food production, information from the State Statistics Service of Ukraine (2024) for 2014, 2019-2023 for two periods – January-September and January-December – were analysed. To track the dynamics of vegetable and berry crop production as of December 1, the periods of 2019-2021 were considered for farms of all categories and separately for enterprises and households according to the State Statistics Service of Ukraine, (2024). These intervals were chosen due to the fact that the state statistics service of Ukraine has not yet published all data for the full calendar year 2023 for food production and does not publish the latest changes in vegetable and berry production volumes. In addition, it was also necessary to compare production volumes for the first half of the year and for the whole year to determine when there is an advantage in the production of individual products or crops during the year. In addition, the selected time periods for the study provide data on the situation in various sectors of food and crop production in Ukraine, and a comprehensive analysis, comparison and general conclusions regarding the purpose of this study. Separately, the commodity structure of wholesale trade in processed fruits and vegetables for 2018-2021, the volume of production of baby food and dietary food products for 2019-2023 for two periods – January-September and January-December – were determined. The production volumes of cocoa, chocolate, and sugar confectionery products were determined for 2014, 2019-2023 also for two periods – January-September and January-December. Additionally, the average daily intake of the main micro- and macro-nutrients in all food products and separately in plant-based food products was analysed, including caloric content, calcium, retinol, β-carotene equivalent, retinol and β-carotene equivalent (RET+ 1/6 B-CARQ), ascorbic acid, protein, fats, iron, niacin, thiamine, and riboflavin in the context of 2000-2020 according to Balances and consumption of the main food products by population of Ukraine (2021).

Results and Discussion

Trends in the health food market. The increase in demand for health products has ensured the rapid development of the industry over the past 10 years. According to T. Molodid (2021), there is a steady growth of the industry in the world, as in 2015 the value of the wellness market was USD 3.7 trillion, and as of 2020, its value exceeded USD 5 trillion. The main task of the health-improving food industry market is to create safe, affordable, and balanced food products. Analysis conducted by H. Mokhonko & K. Klymenko (2020) of global market trends shows that the expansion of the range of traditional food products was 2-3% per year, while health products by 40-50%. As indicated by A.A. Dyskina & Ya.V. Bohachenko (2016), the increase in demand is conditioned by consumers' awareness of the importance of healthy eating and the use of environmental technologies.

To consider the trends in the health food market, it was important to first determine the volume of food production (measured in millions of UAH excluding VAT and excise). Thus, the volume of food production in Ukraine is shown in Figure 1.

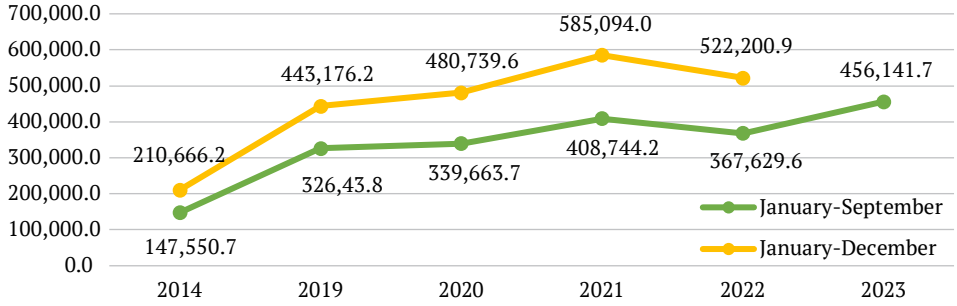


Figure 1. Food production volume, mln. UAH
Source: created by the authors based on the State Statistics Service of Ukraine (2024)

As can be seen from Figure 1, food production volumes during the study periods were unstable and varied. This was influenced by a number of factors, including the financial viability of the population of Ukraine, established market trends, state support for the production of social groups of products, the geopolitical situation and the full-scale aggression of the Russian Federation against Ukraine. In general, comparing production volumes for the period January-September 2023 with the same period in 2014, volumes increased by 3 times. The volume of food production in 2022 was 10.7% less compared to 2021, which is most likely due to the beginning of a full-scale war between Russia and Ukraine. But already for 9 months of 2023, there was a positive trend and the difference was 12.6% less compared to the indicators for the whole of 2022, and for the same period the volume was 24% more. Since the State Statistics Service of Ukraine has not yet presented the final data for 2023, it is likely that food production will return to the pre-war level and continue to grow.

Most of the health products are made up of products made from vegetable raw materials or its addition. Research by L.H. Byshovets & O.H. Oliferchuk (2020) confirms that such a product can be suitable for all age and cultural groups, because the vast majority of such products quickly satisfy hunger are affordable and ergonomic. Analysis of the market of health products of plant food, which was conducted by H.O. Simakhina (2018) includes an investigation of key trends, factors of influence, competitive environment, and prospects for the development of this sector.

In line with the growing demand, companies from different countries are beginning to actively expand the production of health products of plant origin considering the expansion of technological support, which is also highlighted by O.V. Kovalenko & N.S. Kotkova (2020). This applies not only to basic foods such as vegetables, fruits, and cereals, but also to various alternatives to meat, dairy, and sweets. New and improved products are emerging on the market that meet the demand for healthy and functional food products. As indicated by O. Dikhtiar *et al*. (2023), these can include superfoods, speciality drinks, alternative meat and dairy products, vegan snacks, healthy desserts, etc. Clearly, with the growing popularity of health-improving nutrition, competition between companies in the market is also growing. This leads to the emergence of

more brands and products, the development of marketing strategies, and continuous improvement in quality and innovation. The review by M.P. Sychevsky (2019) on the growth of demand and competition points to the improvement and regulation of the market for health products, in particular regarding labelling, safety and quality of products. Overall, the health food market is a dynamic and rapidly growing sector of the food industry, attracting the attention of consumers, manufacturers and regulators.

To find out the prospects for using Ukrainian vegetable raw materials for organising the production of health-improving food products, the dynamics of vegetable crop production was determined (Fig. 2).

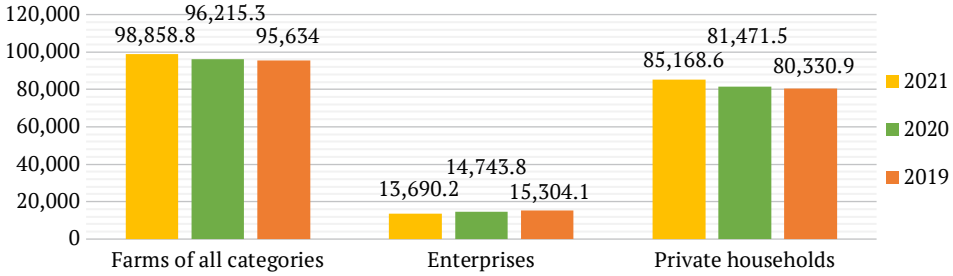


Figure 2. Dynamics of vegetable crop production as of December 1, thous. hwt
Source: created by the authors based on the State Statistics Service of Ukraine (2024)

Based on the data from Figure 2, the main producers of vegetable crops in Ukraine are specialised enterprises and households, the predominant number of vegetable crops in Ukraine is produced by households. Thus, in 2021, they produced 6.2 times more products than enterprises, in 2020 – 5.5 times, in 2019 – by 5.2 times. In addition, production volumes for the study period increase annually. Thus, 3% more vegetable crops were produced in 2021 compared to 2020, and 0.6% more in 2020 compared to 2019. Considering the data obtained, there is a constant increase in the production of vegetable crops, mainly at the expense of households, which can positively affect its use in health-improving nutrition.

The dynamics of the production volume of fruit and berry crops is shown in Figure 3.

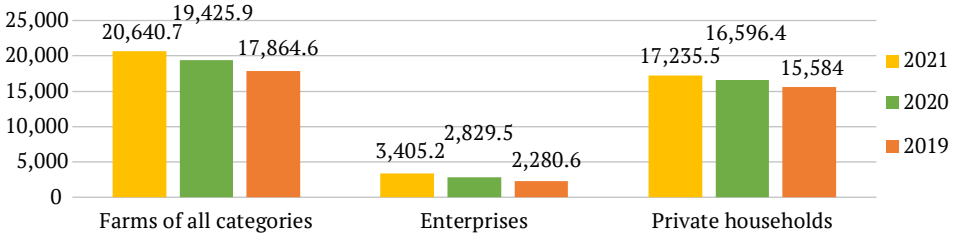


Figure 3. Dynamics of fruit and berry crop production as of December 1, thous. hwt
Source: created by the authors based on the State Statistics Service of Ukraine (2024)

Considering the data in Figure 3, the production of fruit and berry crops in Ukraine occupies smaller volumes compared to vegetable crops, but their dynamics are much higher. Thus, there is an increase in the production of fruit and berry crops by both specialised

enterprises and households, although households also occupy leading positions. Comparing the dynamics by year, it can be noted that in 2021 the production of fruit and berry crops increased by 6.3% compared to 2020, and in 2020 it increased by 8.7% compared to 2019. Therefore, based on the data obtained, there are opportunities to provide the plant with raw materials, in particular vegetable, fruit and berry crops for the production of food products for healthy nutrition.

Additionally, during the study of trends in the market of health-improving food products, the commodity structure of wholesale trade in fruits and vegetables processed by Ukrainian enterprises was determined (Fig. 4).

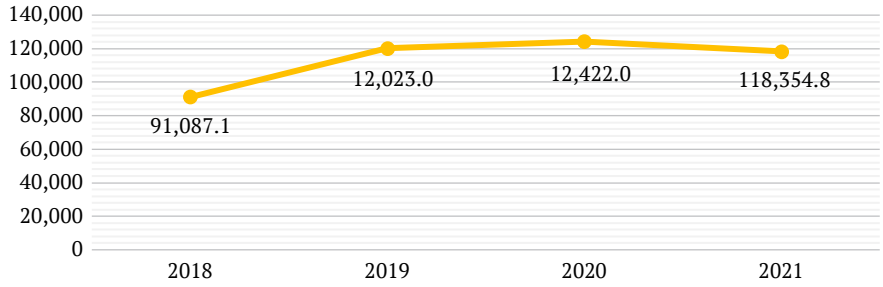


Figure 4. Commodity structure of wholesale turnover of processed fruits and vegetables, t
Source: created by the authors based on the State Statistics Service of Ukraine (2024)

As can be seen from Figure 4, the commodity structure of wholesale turnover of processed fruits and vegetables tends to increase. Thus, from 2018 to 2021, it increased by 29.9%, despite a slight decrease in the period 2020-2021 – by 4.7%. This indicator is also important when reviewing the market and technologies of health products with the addition of vegetable raw materials, because it allows regulating the production of goods as well.

One of the areas in which health food products are used is in children's and dietary nutrition. Figure 5 shows the production volumes of baby food and dietary food products.

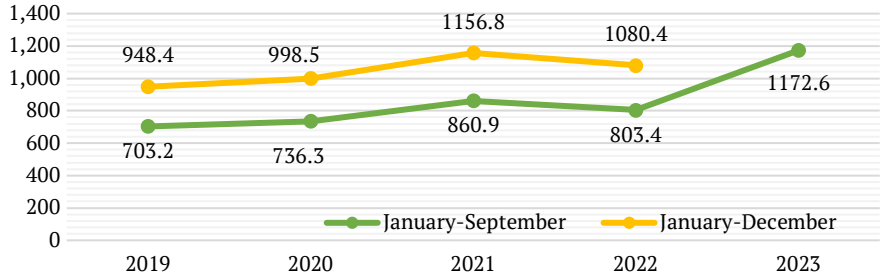


Figure 5. Volume of production of baby food and dietary food products, mln. UAH
Source: created by the authors based on the State Statistics Service of Ukraine (2024)

As can be seen from the data in Figure 5, despite critical developments in the country, there is a rapid increase in the production of baby food and dietary food products and income generation. Thus, without final data for 2023, the volumes for the period January-September already exceed by 8.5% the volumes of the entire 2022. In general, in monetary terms, since 2019, the production of baby food and dietary food products has increased by 66.7%.

According to the results obtained, there are prospects for the use of health products, including in children's and dietary nutrition.

Innovations in food technologies for health improvement. New trends in food technology include fortified and functional products, additive manufacturing, cultured meat, precise fermentation, and personalised nutrition. According to A. Hassoun *et al.* (2024a), other food trends are expected to emerge in the future and increase consumer interest in the transition to sustainable food development and innovative environmental strategies. S. Khan *et al.* (2024) report the start of implementation of smart food monitoring, which consists of intelligent packaging and instant testing technology to detect spoilage and contamination at the product's location.

Innovative food technologies, as described by B. Liu *et al*. (2024), include the use of hydrogels as functional food products in various types of products, with a particular focus on their use in edible shells, saturating gels, nutrient delivery systems, food colouring adsorption, and food safety monitoring. In addition, D.B. Berdahl & J. McKeague (2015) investigated the effects of rosemary and sage extracts as antioxidants for food preservation. A. Hassoun *et al.* (2024B) point to the spread of Food Traceability 4.0 (FT 4.0) in food technology, which is food tracking in the era of the Fourth Industrial Revolution. The main assets of FT 4.0 are blockchain, the Internet of Things, artificial intelligence, and big data.

Overview of the most common innovative food technologies using vegetable raw materials. Modern food technologies have significantly expanded the possibilities of creating health-improving products with the addition of plant raw materials, which contributes to improving the quality of life and ensuring the health of consumers.

Extraction using green technologies. This technology is an environmentally friendly approach to extracting useful compounds from plant raw materials. This method helps to save more useful substances and minimise the negative impact on the environment compared to conventional chemical extraction methods. F. Suvanova *et al*. (2023) report on the use of various extraction methods. The use of water extraction methods instead of organic solvents can be harmful to the environment and health. Thus, green technologies are based on the use of water or aqueous solutions as a solvent. This reduces the risk of contamination and promotes safe processing of raw materials by extraction using ultrasound or microwave radiation, as indicated by M.S. Arshad *et al.* (2023), used to improve efficiency, reduce the time and temperature required for the extraction process, which contributes to the preservation of more biologically active substances in the product.

Extraction using supercritical solvents, which was described by H.W. Huang *et al*. (2013) is a method of using high pressure and temperature to increase the dissolution of beneficial compounds in a plant. It allows to get high-quality extracts with less solvent and a higher concentration of useful substances. The use of supercritical solvents is a method based on the use of solvents that are in a state above their critical pressure and temperature point. As indicated by M.E. Braga *et al*. (2023), they allow the extraction of substances that cannot be extracted by other methods. Such green extraction technologies allow obtaining high-quality health products from plant raw materials, while maintaining the maximum amount of useful substances and reducing the negative impact on the environment.

Fermentation technology and the use of prebiotics to make health products from plant-based raw materials is an effective method for creating products that promote gut health and overall well-being. A.M. Solomon *et al*. (2020) note that during fermentation, micro-organisms such as bacteria or fungi break down complex substances in the plant into simple components through chemical reactions.

This process can increase the bioavailability of plant nutrients, such as vitamins and antioxidants, and create new beneficial compounds. Prebiotic substances include those that are not absorbed by the body, but serve as food for beneficial bacteria in the gut. These can be certain carbohydrates, such as inulin, fructan, and oligosaccharides. H.O. Simakhina (2019) notes that adding prebiotics to health products can support gut health and stimulate the growth of beneficial bacteria. During fermentation, some microorganisms that are produced or added to the product can become probiotics. Probiotics are live microorganisms that are useful for restoring gut health. During fermentation, new aromatic and flavouring compounds can also be synthesised, making health products more attractive to consumers. Fermentation can change the texture of a product, giving it a certain consistency or softness.

Nanotechnology. The use of nanotechnology for the production of health products from plant raw materials opens up wide opportunities for improving the quality, effectiveness and safety of such products. Adding nanoparticles to health products, as described by V.K. Bajpai *et al*. (2018), may increase their bioavailability, i.e., the body's ability to absorb nutrients from a product. For example, nanoparticles can help increase the solubility of fat-soluble vitamins or polyphenols from plant materials.

It is known that the use of nanoemulsions allows creating stable emulsions that improve the safety of the product and increase its shelf life (Bajpai, 2018). This is especially important for plant-based products, which tend to oxidise and spoil. Nanoencapsulation for controlled release of substances, according to L. Taouzinet *et al*. (2023), allows useful substances to be enclosed in nanomaterials, such as liposomes or nanoparticles, which ensures their controlled release in the body. This can be useful for gradually releasing active substances into the digestive tract or for increasing their stability in the product. E. Poeta *et al*. (2023) also provide information that the development of nanosensors allows real-time measurement of the levels of nutrients, antioxidants, and other components in health products. This helps to ensure high quality and safety of the product for the consumer.

The use of nanotechnology in the production of health products with the addition of plant raw materials can significantly improve their properties and effectiveness, which contributes to a healthy lifestyle and the overall well-being of consumers. However, it is important to consider the ethical and regulatory aspects of using nanomaterials in the food industry to ensure the safety and health of consumers.

Replacing animal proteins with vegetable ones. According to C. Floret *et al*. (2023), the use of plant-based proteins and alternative products for the production of health products from plant-based raw materials is becoming increasingly popular and opens up wide opportunities for the development of high-quality and healthy food products. Plant-based protein sources such as soy, peas, nuts, hemp, buckwheat, and others are excellent alternatives to traditional animal proteins. Not only do they have a high nutritional value, but they can also be more environmentally sustainable and ethical to produce. A. Carballo-Casla *et al*. (2024) point out that plant-based milk substitutes such as almond milk, soy milk, oat milk, and others are becoming increasingly popular among consumers looking for alternatives to traditional dairy products due to allergic reactions or ethical reasons. M. Thierry (2020) notes that for those who have avoided or restricted the use of eggs and dairy products, there are many plant substitutes on the market, such as flaxseed, chia seeds, bananas, etc.

These technologies not only help expand the range of health products on the market, but also make them more efficient and affordable for consumers.

Healthy sweets. Instead of traditional sweets, which often contain high amounts

of sugar and saturated fat, researchers S.P. Kraievska & N.O. Stetsenko (2013) and D. Angelino *et al.* (2019) investigated vegetable sweets and desserts with the addition of vegetable raw materials and reported that they can be made using natural ingredients such as fruits, nuts, honey, etc. An atypical combination of local fruits and vegetables allows creating new health products. Thus, the snack "Kalabu" is a food product made by Ismiati *et al*. (2024) from a blend of local (Indonesian) food ingredients kalamansi orange and purple sweet potato. S.S. Sekhavatizadeh (2024) developed a jelly dessert with aloe vera, supplemented with *Lactobacillus curvatus*, encapsulated in mucilage of *Plantago major* and sodium alginate.

Investigating the issues of health products using vegetable raw materials, in particular desserts made from vegetable raw materials, the volume of production of cocoa, chocolate, and sugar confectionery products that meet these criteria was analysed (Fig. 6).

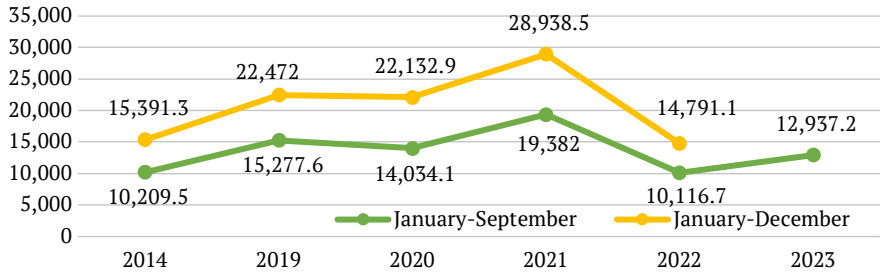


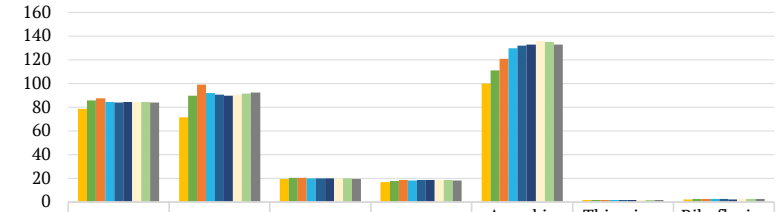
Figure 6. Production volume of cocoa, chocolate, and sugar confectionery products, mln. UAH, excluding VAT and excise tax

Source: created by the authors based on the State Statistics Service of Ukraine (2024)

Analysing the data from Figure 6, it can be seen that production volumes are variable in nature. Thus, from 2014 to 2021, there is an increase in production by 88%, despite a slight decrease in 2020 (23.5% less compared to 2021 and 1.5% less compared to 2019). Since 2022, there has been a reduction in production volumes by almost half, which may be due to martial law and Russia's war against Ukraine. But already for 9 months of 2023, the volume of production was 27.8% more than in the same period of 2022, and the difference with the overall indicators of 2022 remained only 12.5% less. But with the publication of the final information for 2023 by the State Statistics Service of Ukraine, the situation may change. Considering the analysis of information, the production of cocoa, chocolate, and sugar confectionery products returns to the indicators of pre-war periods, which will be expressed positively in monetary terms. Therefore, the production and research of desserts, including those with vegetable raw materials, is promising.

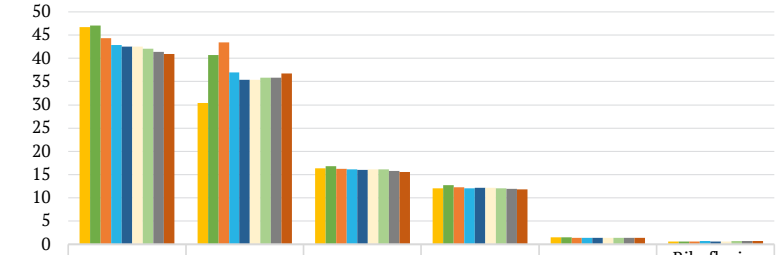
For the completeness of the analytical review of the market and technologies of health products with the addition of plant raw materials, it was advisable to determine the average daily consumption of basic micro- and macro-nutrients in food products, in particular food products of plant origin. Such information helps to determine the food balance of the population and understand which substances are in short supply and which are coming in excessive quantities, to carry out a preliminary assessment of the health of the population, to develop strategies and recommendations for healthy nutrition, the authorities and specialised organisations of the GA can set minimum consumption standards and control the quality of food products based on such data. Moreover, for the food and plant industry, this is important

information that helps to create products with a balanced composition, in accordance with the needs of the population. The consumption of such micro- and macro-nutrients as protein, fat, iron, niacin, ascorbic acid (for all food products), thiamine, riboflavin by the population of Ukraine in the context of 2000-2020 is shown in Figures 7-8.



	Protein, g	Fat, g	Iron, mg	Niacin, mg	Ascorbic acid, mg	Thiamine, mg	Riboflavin, mg
2000	78.6	71.7	19.4	16.8	100	1.81	2.27
2005	86	89.7	20.5	17.9	111	1.9	2.51
2010	87.5	99.2	20.5	18.8	121	1.88	2.55
2015	84.3	92	20.2	18.4	130	1.83	2.56
2016	84.1	90.5	20.1	18.6	132	1.81	2.55
2017	84.3	89.9	20.2	18.6	133	1.81	2.49
2018	84.3	90.8	20.2	18.6	136	1.8	2.6
2019	84.3	91.8	19.9	18.5	135	1.8	2.6
2020	83.9	92.7	19.7	18.4	133	1.8	2.6

Figure 7. Average daily consumption of basic micro- and macro-nutrients in all food products
Source: created by the authors based on Balances and consumption of the main food products by population of Ukraine (2021)

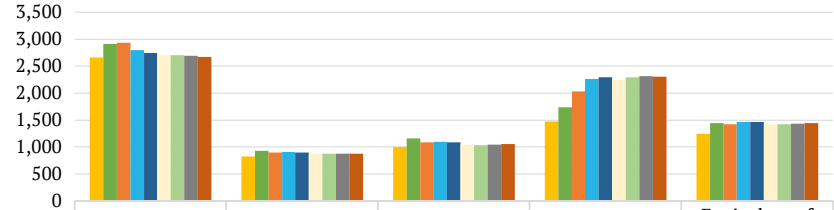


	Protein, g	Fat, g	Iron, mg	Niacin, mg	Thiamine, mg	Riboflavin, mg
2000	46.7	30.4	16.4	12.1	1.52	0.66
2005	47.1	40.7	16.8	12.7	1.52	0.65
2010	44.3	43.4	16.3	12.3	1.45	0.65
2015	42.9	37	16.1	12.1	1.4	0.67
2016	42.5	35.4	16	12.2	1.38	0.66
2017	42.5	35.4	16.1	12.2	1.39	0.66
2018	42.1	35.8	16.1	12.1	1.4	0.7
2019	41.4	35.9	15.8	11.9	1.4	0.7
2020	40.9	36.7	15.6	11.8	1.4	0.7

Figure 8. Average daily consumption of basic micro- and macro-nutrients in food products of plant origin
Source: created by the authors based on Balances and consumption of the main food products by population of Ukraine (2021)

Considering the data from Figures 7-8, it can be seen that over 20 years there is a certain dynamics in the average daily consumption of protein, fat, iron, niacin, ascorbic acid (for all food products), thiamine, riboflavin in the composition of all food products and food products of plant origin was not. Separately, it should be noted that the consumption of plant-based protein in 2020 decreased by 12.4% compared to 2000 and generally decreased over 20 years. As for the protein that entered the human body as part of all food products, its amount increased by 6.7% over the same period. Consumption of vegetable fats as of 2020 increased by 20.7% compared to 2000. In addition, an increase in fat intake was observed in the composition of all food products – by 29.2% in 2020 compared to 2000. The consumption of ascorbic acid in all food products has gradually increased over 20 years and as of 2020 increased by 33% compared to 2000. Regarding the consumption of iron, niacin, and riboflavin in all food products, their amount in 2020 compared to 2000 increased by 1.5%, 9.5%, and 14.5%, respectively. Considering consumption of iron, niacin, and thiamine in plant-based food products, their amount as of 2020 compared to 2000, on the contrary, decreased by 4.8%, 2.5%, and 7.9%, respectively. But the consumption of riboflavin in plant-based food products increased by 6% over the same period.

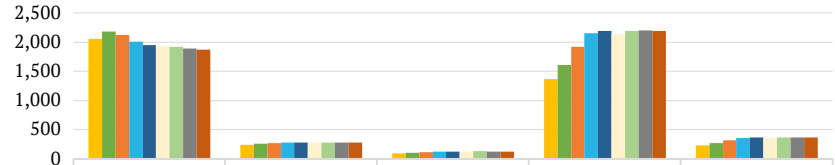
The total caloric content from the consumption of all food products and food products of plant origin, intake of calcium, retinol, β-carotene equivalent, retinol and β-carotene equivalent (RET+ 1/6 B-CARQ) and ascorbic acid (for food products of plant origin) of the population of Ukraine in the context of 2000-2020 is shown in Figures 9-10.



	Calorie content, kcal	Calcium, mg	Ascorbic acid, mg	Equivalent of β-carotene, mcg	Equivalent of retinol and β-carotene (RET+ 1/6 B-CARQ), mcg
2000	2,661	825	1,004	1,472	1,249
2005	2,916	927	1,156	1,735	1,446
2010	2,933	893	1,088	2,035	1,427
2015	2,799	904	1,093	2,260	1,470
2016	2,742	901	1,086	2,298	1,470
2017	2,707	874	1,044	2,241	1,419
2018	2,706	872	1,034	2,297	1,418
2019	2,691	879	1,049	2,310	1,435
2020	2,674	880	1,055	2,301	1,440

Figure 9. Average daily consumption of basic micro- and macro-nutrients in all food products

Source: created by the authors based on Balances and consumption of the main food products by population of Ukraine (2021)



	Calorie content, kcal	Calcium, mg	Ascorbic acid, mg	Equivalent of β-carotene, mcg	Equivalent of retinol and β-carotene (RET+ 1/6 B-CARQ), mcg
2000	2,050	238	94	1,364	227
2005	2,183	257	104	1,612	269
2010	2,124	270	114	1,923	320
2015	2,008	278	123	2,148	358
2016	1,952	277	125	2,186	365
2017	1,926	277	126	2,134	357
2018	1,919	281	129	2,191	366
2019	1,891	280	128	2,202	368
2020	1,872	277	126	2,192	367

Figure 9. Average daily consumption of basic micro- and macro-nutrients in food products of plant origin

Source: created by the authors based on Balances and consumption of the main food products by population of Ukraine (2021)

As can be seen from the data of Figures 9-10, in the period 2000-2005, there was an increase in caloric intake by the population of Ukraine, but since 2005 there has been a gradual reduction in the caloric content of the population's diets. Thus, the caloric content of food products increased by 9.6% as of 2005 compared to 2000, but as of 2020 it decreased by 8.3% compared to 2005. The situation is similar with the caloric content of plant-based foods, with a 6.5% increase in caloric content as of 2005 compared to 2000, and a 14.2% decrease as of 2020 compared to 2005. Regarding the intake of calcium from the consumption of all food products, for the period 2000-2020, it increased by 6.6%, from the consumption of plant-based food products – by 16.4%, although the largest intake of calcium in the composition for all food products was observed in 2015 – 2.7% more than in 2020, and 3.6% more for plant-based food products in 2018 than in 2020. The average daily consumption of ascorbic acid as part of plant-based food products by the population increased by 34% during 2000-2020. The average daily intake of β-carotene equivalent, retinol equivalent, and β-carotene (RET+ 1/6 B-CARQ) increased by 60.7% and 61.7%, respectively, as part of plant-based food products. All foods also showed an increase in intake of β-carotene equivalent, retinol equivalent, and β-carotene (RET+ 1/6 B-CARQ) by 56.3% and 15.3%, respectively. The amount of retinol in all food products increased by 15.1% as of 2005 and by 5% as of 2020 compared to 2000. In general, the analysis of the average daily consumption of basic micro- and macro-nutrients in food products, including plant origin, is important for maintaining and increasing public health, assessing food safety, identifying deficiencies in nutrition, strengthening agriculture, and for maintaining economic stability and competitiveness in the food market.

According to S. Parashar *et al.* (2023), due to a rational and balanced selection of food,

it is possible to reduce the likelihood of occurrence and development of many diseases, improve the growth and development of the body, increase the body's resistance to adverse factors, and the emotional state of a person. That is why, as consumers seek to maintain and improve their health, they have become actively interested in wellness products. However, at the beginning of the cult of healthy eating, there was a lot of speculation and fraud about this type of product, which is associated with the use of questionable components. But with the development of healthy nutrition, the creation of a regulatory framework and consumer awareness, the production of health-improving products has moved to the next stage, namely the expansion and improvement of technologies. Attraction of plant raw materials, as indicated by P. Tangjaidee *et al*. (2023), although it is a basic technology for the production of healthy food, new ways of using it and combining it with animal raw materials are emerging with the emergence of new trends.

The use of plant-based raw materials to create health-improving food products is a promising area, as plant components have great potential to improve health and support physical and mental well-being. Modern technologies, such as extraction using green technologies, fermentation, the use of nanotechnologies, and the use of plant proteins and alternative products, allow maximising the useful properties of plant raw materials and create products that meet the needs of modern consumers. These technologies contribute to the development of the market for health products made from plant raw materials, contributing to the preservation of health and improving the quality of life of consumers and obtaining a safe and high-quality product.

Conclusions

Based on the results of an analytical review of the market and technologies of health products with the addition of vegetable raw materials, the main trends of the health food market were identified. Thus, for 5 years (from 2015 to 2020), the value of the health products market increased by 35%, which in monetary terms amounted to USD 1.3 trillion, in addition to expanding the range of traditional food products, it averages 2-3% per year, and health products by 40-50%. It was determined that the volume of food production for the period January-September 2023 compared to the same period in 2014 increased by 3 times, in 2022 it was 10.7% less compared to 2021, and in 9 months of 2023 the difference was 12.6% less compared to the figures for the whole of 2022, and the volume was 24% higher for the same period.

The main producers of vegetable crops in Ukraine are households that produce the predominant number of products, while specialised enterprises are in second place. It is determined that in 2021 they produced 6.2 times more products than enterprises, in 2020 – 5.5 times, in 2019 – 5.2 times. As for the production of fruit and berry crops in Ukraine, it occupies smaller volumes compared to vegetable crops. In 2021, fruit and berry crops were produced by 6.3% more than in 2020 and by 8.7% more in 2020 compared to 2019. Wholesale trade in processed fruits and vegetables increased by 29.9% from 2018 to 2021, despite a slight decrease of 4.7% in 2020-2021. Rapid growth in the production of baby food and dietary food products and income generation is determined. Volumes for the period January-September 2023 exceeded by 8.5% the volume of the whole of 2022, and in monetary terms, since 2019, the volume of production of baby food and dietary food products has increased by 66.7%. From 2014 to 2021, the production of cocoa, chocolate and sugar confectionery products increased by 88%, despite a slight decrease in 2020. Since 2022, there has been a reduction in production volumes by almost half, but for 9 months of 2023, the volume of production was 27.8% more than in the same period of 2022. Studying the average daily intake of protein, fat, iron, niacin, ascorbic acid,

thiamine, riboflavin, calcium, retinol, β-carotene equivalent, retinol equivalent and β-carotene (RET+ 1/6 B-CARQ) in the composition of all food and plant products revealed certain dynamics and instability of individual indicators. In general, plant-based products had a predominant share in the average daily intake of basic micro- and macro-nutrients by the population.

Considering the analytical review and analysis of the market of raw materials, innovative technologies of health-improving food products, further promising areas of research are the creation of new and improvement of existing health-improving food systems. In the future, it is relevant to develop health-improving desserts, considering the use of vegetable raw materials and other biologically active components for functional nutrition.

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Conflict of Interest

None.

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Аналітичний огляд ринку сировини та інноваційних технологій оздоровчих харчових продуктів рослинного походження

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Анотація. У сучасному світі інтерес до оздоровчих продуктів зріс через збільшення уваги до здорового способу життя та збалансованого харчування. Разом з тим виникає необхідність в освоєнні технологій виробництва оздоровчих продуктів задля збереження максимальної кількості корисних речовин та використанні інноваційних методів оброблення сировини. Саме тому метою цієї роботи було провести огляд та аналіз існуючих технологій виробництва харчових продуктів оздоровчого напряму, зокрема з використанням рослинної сировини. Матеріалами та методами слугували науково-технічна література та нормативна документація. Створювали вибірку окремих періодів, які аналізували за вибраними показниками, а саме обсяг виробництва харчових продуктів, динаміка обсягу виробництва овочевих, плодових та ягідних культур, товарна структура оптового товарообороту фруктів та овочів перероблених, обсяг виробництва дитячого харчування та дієтичних харчових продуктів, обсяг виробництва какао, шоколаду та цукрових кондитерських виробів, а також середньодобове споживання населенням основних мікро- та макронутрієнтів у складі певних харчових продуктів. Визначено, що обсяг ринку оздоровчого харчування за період 2015-2020 років збільшився на 1,3 трлн доларів США у вартісному вираженні, водночас асортимент

традиційних продуктів харчування розширювався в середньому на 2-3% на рік. Виробництво овочевих культур господарствами населення у 2021 році перевищило виробництво підприємств у 6,2 рази, у 2020 році – 5,5 рази та у 2019 році – 5,2 рази. Виробництво плодово-ягідних культур в Україні у 2021 році було на 6,3% більшим, ніж у 2020 році, а у 2020 році – на 8,7% більшим, ніж у 2019 році. Визначена динаміка середньодобового споживання білка, жирів, заліза, ніацину, аскорбінової кислоти, тіаміну, рибофлавіну, кальцію, ретинолу, еквівалентів β-каротину, еквівалентів ретинолу та β-каротину (RET+ 1/6 B-CARQ) у складі харчових продуктах дає змогу визначити дефіцит та профіцит макро- та мікронутрієнтів у харчуванні споживачів. Загалом використання оздоровчих харчових продуктів, включаючи дитяче та дієтичне харчування є перспективним та конкуруючим, також підтверджується доцільність використання рослинної сировини в оздоровчому харчуванні та розробці нових оздоровчих продуктів

Ключові слова: функціональне харчування; плоди; овочі; продовольство; харчове виробництво

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