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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 rearing. O.A. Dyudyaeva (2021) 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 efficiency remains open and relevant. O.A. Dyudyaeva (2021) 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 consider the negative impact of these factors and in the background of the anthropogenic load on the ecosystem in the global sense. In addition, 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 transformations 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, eutrophication of water bodies, their contamination with toxic substances of anthropogenic origin, the arrival of toxic compounds with wastewater, 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).

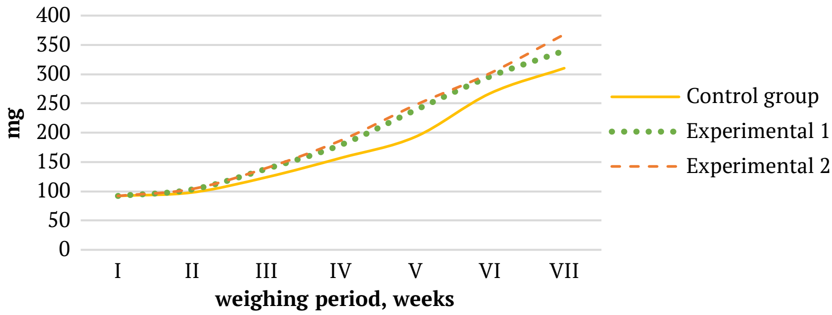

Figure 1. Analysis of the influence of feed factors of various nature on the growth rate of rainbow trout in ontogenesis (x ± SD)

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.

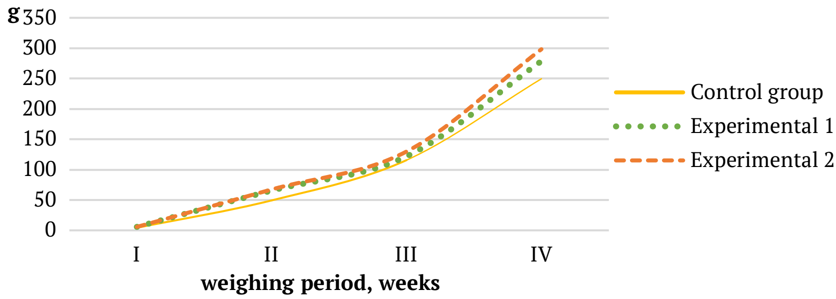

Figure 2. Analysis of the influence of feed factors of various nature on the growth rate of rainbow trout in ontogenesis (x ± SD)

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	$y = 110.3\ln(x) - 564.9$	$R^2 = 0.917$	$y = 162.4\ln(x) - 865.8$	$R^2 = 0.954$
Total protein	$y = 88.84\ln(x) - 444.2$	$R^2 = 0.804$	$y = 121.8\ln(x) - 635.0$	$R^2 = 0.989$
Erythrocyte content	$y = 1.044\ln(x) - 47.519$	$R^2 = 0.930$	$y = 0.716\ln(x) - 0.1169$	$R^2 = 0.933$
Haemoglobin content	$y = 179.1\ln(x) - 886.9$	$R^2 = 0.904$	$y = 212.6\ln(x) - 1{,}084.4$	$R^2 = 0.939$

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).

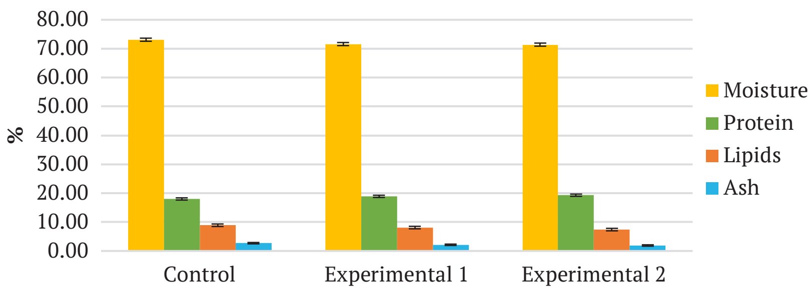

Figure 3. Analysis of the biochemical composition of the muscle part of rainbow trout under the influence of the feed factor, x ± SD
Source: developed by the authors

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".

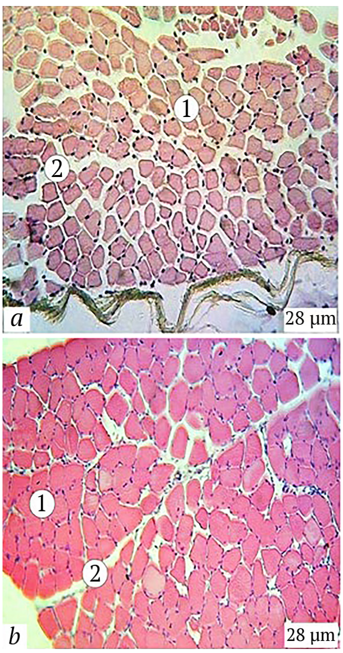

Figure 4. Structure of a fragment of the muscle bundle of the dorsal part of the rainbow trout's body

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

The authors declare no potential conflict of interest regarding the authorship or publication of this manuscript. This study did not receive any special grants from financial institutions in the public, commercial, or non-profit sectors.

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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