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Effect of a Probiotic Preparation Based on Lactic and Propionic Acid Bacteria on the Growth of Young Rainbow Trout *Oncorhynchus Mykiss* in Aquaculture

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ABSTRACT

Providing valuable fish species in aquaculture with high-quality feed is the main factor in reducing production costs and increasing the economic efficiency of fish farms. The costs associated with feed are the most expensive component of fish production. The main task of commercial trout farming is the cultivation of fish in the shortest possible time and with minimal costs. This paper investigates the effect of probiotic supplements based on lactic acid bacteria *Lacticaseibacillus paracasei* Wf-2, *Limosilactobacillus pontis* Wf-6, *Lacticaseibacillus casei* Wf-10, and *Lacticaseibacillus paracasei* Wf-20 and propionic acid bacteria *Propionibacterium freudenreichii* P-8 on the growth rates of young rainbow trout in aquaculture. The values of the indicators of cheap trout feed with the introduced probiotic supplement differed slightly, and their properties were not inferior to those of expensive feed. A significant reduction in the content of biogenic substances in the variant with a probiotic supplement was shown. The results of the study indicate the high efficiency and prospects of the use of probiotic preparations in the fattening of young trout in aquaculture.

Key words: Aquaculture, Lactic acid bacteria, Probiotic supplements, Rainbow trout.

INTRODUCTION

At present, the general trend of world fisheries is to increase the production of food fish products due to the development of aquaculture, which is the fastest-growing industry in the world (Puszkarski and Śniadach 2022). According to the Food and Agriculture Organization, aquaculture is developing most intensively in China, India, Vietnam, Norway, etc. (FAO 2020). The decrease in commercial fish stocks in natural reservoirs and the increase in the need for food require increased development of industrial aquaculture (D'Agaro et al. 2022). The lack of local resilient fish stock material and expensive imported compound feed are also problems for some countries (Gabriel et al. 2007).

Providing valuable grown fish species with high-quality feed that can meet their nutritional needs and optimize growth is an important prerequisite for increasing productivity and the economic efficiency of fish farms and reducing production costs (Zhang et al. 2023). The costs associated with aquaculture are the most expensive component of production. Global climate change also contributes to this issue, worsening the situation by increasing water temperature (Simionov et al. 2021).

Rainbow trout is one of the most common objects of world fish farming and is intensively cultivated in many countries (Farabi et al. 2022). In trout cultivation in pond farms, basins, and cages, the diet must necessarily include feeds that contain a lot of protein. The importance of rainbow trout for fish farmers is associated with the ability of rainbow trout to adapt to changing conditions, actively consume artificially prepared feed mixtures, and give high body mass gains (Vasiliev et al. 2021).

The main task of commercial trout farming is the cultivation of fish in the shortest possible time and with minimal costs. One of the main factors influencing the rapid growth of poikilothermic animals is the maintenance of an optimal temperature for nutrition and growth. Their metabolic rate depends on temperature and so do digestion and growth rates. The second equally important factor in the full-cycle cultivation of rainbow trout is the need to use animal protein (mainly fish meal, which makes up to 50% of the feed mixture). The consumption of oxygen by

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rainbow trout is directly proportional to the water temperature and inversely proportional to the mass of the fish. Reducing the dissolved oxygen content can slow down the development and growth of trout. However, rainbow trout can tolerate water saturation with pure oxygen up to 300-350% and higher (McArley et al. 2021).

Modern trout farming is a highly intensive form of industrial farming based on the cultivation of fish with compacted holding using granular feed and favorable environmental conditions. The level of intensification of production processes in trout farming is determined by the multiplicity of water exchange in fish tanks, the quality of feed used, feeding methods, and the degree of mechanization of labor in the cultivation of trout groups of different ages. The nutritional needs of fish farming feed, namely protein, amino acids, fat, carbohydrates, energy, mineral elements, and vitamins, depend on the species of fish, their age, and the combination with natural feeds. With industrial methods of fish cultivation, the increase in bioproducts occurs due to the feed introduced. The lack of high-quality feed increases the costs produced and ultimately negatively affects the cost and payback of fish farming. More affordable feed is required, as well as the development of supplements that improve the quality of feed. One of the directions for improving the quality of artificial fish feeds is the inclusion of special nutritional supplements (probiotic preparations) in their composition (Simionov et al. 2021).

Probiotics are commonly referred to as preparations based on live microbial cultures used to enhance immunity and prevent a wide range of diseases (Nozrdin et al. 2023). The practice of using probiotics has shown their biological and economic efficiency, the possibility of producing fish food products of improved nutritional quality, and safety for human health (Sarsembayeva et al. 2021; Zhanar et al. 2021).

The mechanisms of action of probiotic microorganisms include the production of metabolites with antagonistic activity, detoxification, colonization of the intestinal epithelium and thus prevention of intestinal infections, improved digestibility of feed due to the production of enzymes, participation in the synthesis of hormones, increased nutritional value due to the production of vitamins and other biologically active compounds, correction of mineral, salt, and vitamin metabolism, and improved water quality due to the modulation of its microbiota (Vasyliuk et al. 2023). Probiotics can play a significant role in the morphological and functional restoration of intestinal mucosa cells (Gavrilova et al. 2023). The whole complex of effects contributes to a significant increase in the natural resistance of the body (Smolovskaya et al. 2023).

Industrial fish farming requires a particular attitude to several stressful factors including transportation, fishing, transplanting, fish-holding density, compound feed, medicines, imported planting material, and fish farming tools and equipment. One of the methods to prevent stress factors is the use of balanced compound feeds. Biologically active substances, which include probiotics, are of great importance in the balance of the essential nutrients of feed for growing physiologically complete young fish. Probiotics not only cause an increase in the body's resistance to various diseases but also contribute to the manifestation of anti-allergenic action and the ability to regulate and stimulate digestion. Thus, feed assimilation increases, and fish growth is stimulated (Karaseva et al. 2000; Pavlov and Maksimenkova 2019).

Despite the positive results of the use of probiotics in aquaculture, many questions remain. For instance, there is no clear answer to the question of which preparations (of terrestrial or aquatic origin) are preferable for fish farming. On the one hand, a higher efficiency of species-specific probiotic preparations is known. On the other hand, strains of microorganisms isolated from aquatic animals must fully meet safety requirements in terms of lack of pathogenicity. Ehere is still no consensus on the advantages of single-component and multicomponent preparations, and the optimal doses and duration of use of preparations have not yet been determined.

The purpose of this work was to determine the effectiveness of the developed probiotic supplement included in the composition of artificial production feed on fish-breeding indicators of young trout grown in basins.

MATERIALS AND METHODS

Ethical Approval: The protocol of the study was discussed and approved at the meeting of the local ethical commission of the Research and Production Center of Microbiology and Virology on September 21, 2020 (protocol no. 10) at the Research and Production Center of Microbiology and Virology and Fisheries Research and Production (Almaty, Kazakhstan).

Study Location and Water Quality: The study was carried out at the Kapshagayskoye fish farm NVH-1973 Limited Liability Partnership (LLP) located in the Almaty region, Kazakhstan (fish breeding zone V). The object of the study was young trout. The water source in the Kapshagayskoye NVH-1973 LLP was an artesian well, the water from which was supplied to the fish-breeding site.

Hydrochemical analysis of the quality of artesian water was carried out in the laboratory of hydroanalytics of the Research and Production Center of Fish Farming LLP. The studies included the determination of the gas regime, as well as the ionic and biogenic composition of water (ammonia, nitrites, nitrates, phosphates, bicarbonates, chlorides, sulfates, calcium, magnesium, sodium, and potassium). The content of the main ions was determined using titrometry. The concentrations of biogenic substances were determined using a Hach DR-2400 spectrophotometer. The physicochemical and hydrochemical parameters (biogenic elements and salt composition) were determined following generally accepted regulatory documents and methods (Gosudarstvennyi Kontrol 2003).

During the entire experimental period (30 days), the main hydrochemical parameters of the water in the basins were monitored daily in the morning and the evening. To assess the influence of abiotic environmental factors on trout cultivation during the experiment, four main hydrochemical parameters were determined, namely, the dynamics of temperature, oxygen content, pH, and oxygen saturation in the water coming from an artesian well. These hydrochemical parameters were measured using a Horiba U-50 portable analyzer.

Conditions for Growing Young Rainbow Trout: Rectangular basins with a length of 3m, a width of 0.7m, and a height of 0.5m were used for trout cultivation (Fig. 1A). The used water underwent forced degassing and aeration in degassing tanks, where molecular nitrogen was released and most of it was removed from the water. Then the water was fed into an aerator tank, where it was enriched with oxygen by passing through fillers. Next, the aerated water was fed through reinforced hoses to the fish-breeding basins (Fig. 1B). The drainage of the water from the basins was carried out through a bent pipe (Fig. 1C). To prevent the trout from leaving the basin, a net was installed on the spillway (Fig. 1D), and the basin was covered with a mesh cloth from above (Fig. 1E). The basin was cleaned three times a day (Fig. 1F and G), and trout was fed manually six times a day (Fig. 1H). The study and evaluation of the trout growth rate were carried out according to the results of the test and final fishing (Fig. 1I-K).

In the experiment, the material was young rainbow trout *Oncorhynchus mykiss* with an initial average mass of 12g. The experimental batch included 440 specimens. The young trout were divided into four groups. Each group was kept in an individual basin with a holding density of 110 fish per basin. The variant with the addition of the probiotic was studied in two basins. The conditions of keeping trout in the basins were identical.

Fish-breeding and biological morphometric studies, as well as trout weighing, were carried out. The study and evaluation of the growth rate were carried out based on the results of the test and final fishing. After the test fishing, the trout were subjected to visual inspection. The trout cultivation was carried out following the regulatory and technological literature (Ponomarev and Ponomareva 2003; Ponomarev et al. 2007; Jokumsen and Svenden 2010; Kamilov 2014).

Making the Probiotic Preparation: In this study, we used the probiotic preparation based on lactic acid bacteria *Lacticaseibacillus paracasei* Wf-2, *Limosilactobacillus pontis* Wf-6, *Lacticaseibacillus casei* Wf-10, and *Lacticaseibacillus paracasei* Wf-20 and propionic acid bacteria *Propionibacterium freudenreichii* P-8. Monocultures of lactic acid bacteria were grown separately in De Man, Rogosa, and Sharpe (MRS) broth at 37°C for 48 hours. Propionic acid bacteria were grown on skimmed milk at 30°C for 48 hours. After 48 hours, a consortium of lactic and propionic acid bacteria was formed in the ratio 1:1:1:1:2. The consortium was sown on Williams medium (WM) (g/L: wheat flour: 200.0; corn flour: 50.0; yeast extract: 10.0; glucose: 8.0; peptone: 5.0; sodium acetate: 5.0; NaCl: 3.0; $MgSO_4$: 0.1) and cultivated at 30°C for 24 hours. The number of colony-forming units (CFU) in the final liquid preparation was 1×10^{12} CFU/mL.

The probiotic in the amount of 100mL was introduced into 1kg of feed placed on sterile paper with a layer of 1cm, sprayed over the surface, thoroughly mixed, and dried at room temperature during the day under aseptic conditions. After that, the feed was stored in a cooler at 5°C for one week.

Applied Feeds and Variants of the Experiment: Three types of artificial feed were used for feeding the trout: the Extra Trout AST 45/15 trout feed (Aqua Alliance LLP, Kazakhstan) with the probiotic supplement (basins 1 and 2), which was added at the rate of 100ml per 1kg of feed, Extra Trout AST 45/15 without the probiotic supplement (basin 3), and the BioMar EFICO Alpha 792 trout feed (Denmark) (basin 4). The composition of Extra Trout AST 45/15 includes fish meal, yeast, wheat flour, flour of animal origin, feed wheat, rice, barley, fish oil, rapeseed/sunflower oil, vitamins, and minerals. BioMar EFICO Alpha 792 includes soybean oil, fish meal, poultry flour, blood meal, feather flour hydrolysate, sunflower cake, fish oil, wheat gluten, vitamins, and trace admixtures. The levels of the essential nutrients and minerals are shown in Table 1.

BioMar EFICO Alpha 792 is an extruded high-calorie feed with medium and high digestibility, recommended for almost any growing conditions. The feed contains high-quality ingredients from a wide range of well-tested raw materials that provide the necessary trace elements and a balanced amino acid profile for good growth. The high growth rate of trout, good palatability, and excellent physical qualities of feed pellets are the most important key characteristics of this popular feed.

The amount of feed and the frequency of feeding were calculated considering the physiological state of the fish and changes in temperature and oxygen regimes. The daily feeding ration was calculated based on the results of test fishing, considering the recommendations and based on Deuel's table. Regular monitoring of feed consumption was carried out.

Evaluation of Trout Growth Indicators: To evaluate the growth rate, the indicators of the general production mass accumulation coefficient (C_m) and the specific growth rate (SGR) were calculated (Shcherbina and Gamygin 2006; Kupinskii 2007). C_m was calculated using formula (1):

$$Cm = (\sqrt[3]{Mf} - \sqrt[3]{Mi}) \times 3/\Delta T \quad (1)$$

where M_i and M_f are the initial and final fish mass, g; ΔT is the duration of the growing period, days.

In SGR calculations, the difference between the natural logarithms of the final and initial fish mass is used. This indicator was calculated using formula (2):

$$SGR = (\ln Mf - \ln Mi) \times 100/\Delta T \quad (2)$$

Where M_i and M_f are the initial and final fish mass, g; ΔT is the duration of the growing period, days.

Statistical Analysis: Statistical processing and analysis of information material were carried out according to generally accepted methods using Microsoft Excel 8.0 (Barulin et al. 2016; Kharkova and Solovev 2017). To assess the reliability of the differences between the fish mass in the experimental variants, we used a single-factor analysis of variance (ANOVA). To assess the reliability of the differences between the pairs of experimental variants, a Student's t-test was calculated.

Fig. 1: A: basins for trout cultivation, B: water supply to the basins from the aerator tank, C: spillway from the basin, D: net on the spillway, E: mesh cloth on top of the basin, F: cleaning the bottom of the basins, G: siphon for cleaning the basin, H: trout feeding.

Table 1: Composition of the used feed, %.

Indicator	BioMar EFICO Alpha 792 (Denmark)	Extra Trout AST 45/15 (Kazakhstan)
Protein	44	45
Fat	25	15
Ash	6.4	9
Fiber	1.9	1.5
Phosphorus	1.04	ND
Calcium	1.59	ND
Sodium	0.15	ND
Metabolizable energy, MJ	18.9	18.5

RESULTS

Hydrochemical Parameters of the Water of the Artesian Well: According to the results of the hydrochemical analysis, the value of the hydrogen index (8.0 units) was within the normal range when trout were grown. The concentration of biogenic elements did not exceed the permissible values for fishery reservoirs. Among the biogenic elements, nitrates (NO_3^-) prevailed (0.6 mg/l). The amount of nitrites (0.004 mg/l) was within the optimal limits. Phosphates were also found in minimal amounts. The results of the hydrochemical analysis of selected water samples for the determination of salts, nitrites, nitrates, sulfates, chlorides, sodium, and potassium showed that these indicators were within the optimal values. Based on its technical properties, the artesian water belongs to the "very soft" category, with a total content of calcium and magnesium equaling 0.6 mg-eq/l.

Evaluation of the Dynamics of the Main Hydrochemical Indicators in the Basins: The daily dynamics of hydrochemical parameters of the artesian water (temperature, pH, oxygen content, oxygen saturation) in the basins during the experiment

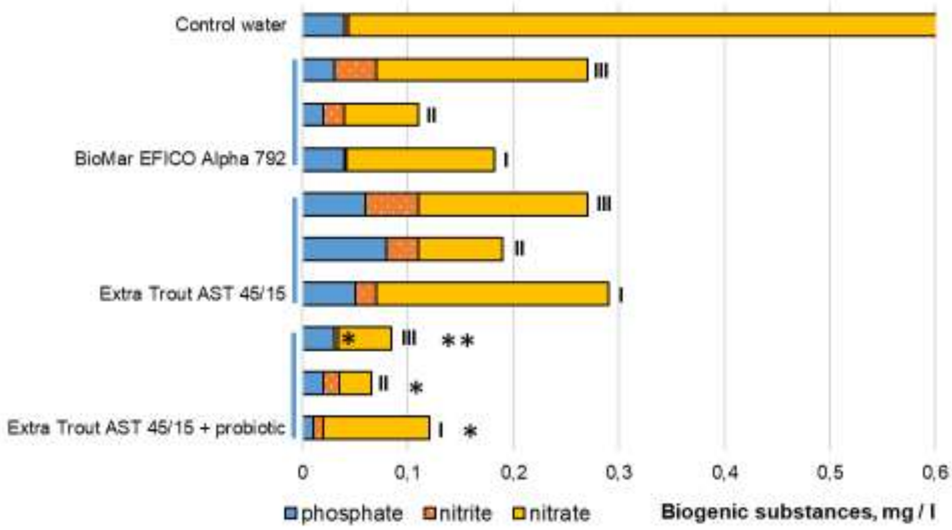

Fig. 2: Content of biogenic elements in basin water by decades (1st, 2nd, 3rd) in the variants of the experiment. *p<0.05, **p<0.005.

were in a stable optimal condition for 30 days. The difference between the oxygen content in the morning and the evening was insignificant and amounted to 0.09 mg/L. Fluctuations in the values of oxygen saturation did not decrease below 140.4% and did not increase above 151.7% and corresponded to the permissible values. The difference between the indicators of oxygen saturation in the basins in the morning and the evening was insignificant and amounted to 0.9%. The temperature values were stable and varied from 17.8°C in the 1st decade to 18.8°C in the 3rd decade. The stability of the values was also noted for the pH which equaled 7.6-7.9. An important hydrochemical indicator for oxyphilic trout, the oxygen content was constant and was within the limits of the normative values for trout of 7.9 mg/L in the 3rd decade, 8.0 mg/L in the 2nd decade, and 8.1 mg/L in the 1st decade. The values of the oxygen saturation index were normal and changed slightly from 144.6 to 146.8%.

The dynamics of biogenic anions in basins in the three experimental variants are presented in Fig. 2. The ammonia in the control water was 0.12 mg/L; no ammonia was detected in the experimental versions.

Our hydrochemical studies showed that the content of biogenic elements in the basins of all three variants of the experiment was within the acceptable standards. The nitrate content exhibited a notable decrease when compared to the control water. The effect was most pronounced in the 3rd decade. One should note the significant reduction in the level of nitrites when using probiotics in the 3rd decade. In other variants, the level of nitrites consistently increased with each decade. The change in the nitrate level had similar dynamics with a decrease by the end of the 2nd decade and an increase in the 3rd decade. However, in the variant with the probiotic, the nitrate content was the lowest in all decades and increased by the end of the 3rd decade to only 0.03 to 0.05 mg/L, while in the variant with the same feed, but without the probiotic, the increase was from 0.08 to 0.16 mg/L. The level of nitrates in the variant with Extra Trout AST 45/15 enriched with the probiotic was 3.2 times lower by the end of the 3rd decade compared to the variant without the probiotic and 4 times lower than with BioMar EHICO Alpha 792 (P<0.005). The level of nitrites by the end of the 3rd decade was also statistically significantly lower by 10-12 times in the variant with the probiotic. The phosphate level was twice as low as with the probiotic when using the same feed.

Evaluation of the Effectiveness of the Developed Probiotic Supplement: Based on our results, we evaluated the effect of the probiotic supplement included in Extra Trout AST 45/15 on the fish-breeding and biological indicators of trout grown using basin technology. The results obtained in the experiment were compared with control data, where artificial trout feeds without probiotic supplements were used (Extra Trout AST 45/15 and more expensive BioMar EFICO Alpha 792).

The results of trout cultivation in basins using artesian water at the Kapshagayskoye NVH-1973 LLP with the use of various artificial trout feeds are presented in Table 2. Trout grown at the Kapshagayskoye NVH-1973 LLP during the experiment is shown in Fig. 3.

Thus, we found that in 30 days in all variants, young trout reached standard values according to the main fish-breeding indicators. The trout actively reacted to artificial feeds and consumed them well showing a high survival rate (99-100%).

The initial average mass at the time when they were put in basins was the same and equaled 12g. At the end of the growing period, the final mass in the 1st variant significantly increased by 70.8%, in the 2nd variant by 66.9%, and in the 3rd variant by 73.3%. The average mass of one fish in the variant with Extra Trout AST 45/15 and the probiotic was 13% higher compared to the mass in the variant with the same feed but without the probiotic (P<0.05). Despite the higher average weight of young trout in the variant with BioMar EFICO Alpha 792 (by 9%), compared to the cheaper feed with the probiotic supplement, there were no statistically significant differences between these indicators.

According to our results, the values of the absolute and average daily growth ranged from the best in the following order. The absolute growth in the 3rd, 1st, and 2nd variants was 33.0, 29.1, and 24.3g, respectively, and the average daily weight gain was 1.1, 0.97, and 0.81g, respectively. The results on the feed ratio and mass accumulation coefficient were also higher in the variants with Extra Trout

Fig. 3: Trout after monthly fattening using Extra Trout AST 45/15 with (A) and without (B) the probiotic supplement.

Table 2: Fish-breeding and biological indicators of trout grown with various artificial feeds.

Indicator	Extra Trout AST 45/15 with the probiotic supplement		Extra Trout AST 45/15	BioMar EFICO Alpha 792
Basin	1	2	3	4
Duration of the experiment, days	30	30	30	30
Fish-holding density, fish/basin	110	110	110	110
Initial mass, g (X±m)	12.0±0.46	12.0±0.47	12.0±0.49	12.0±0.44
C_v	0.21	0.19	0.22	0.2
Final mass, g (X±m)	41.2±1.68	41.0±1.61	36.3±1.54	45.0±1.79
C_v	0.29	0.28	0.30	0.28
Average value of the final mass in one variant, g	41.1			
Absolute mass gain of one fish, g	29.2	29.0	24.3	33.0
Average absolute gain value, g	29.1			
Average daily gain, g	0.97	0.96	0.81	1.1
Average value of the average daily gain, g	0.97			
Relative mass gain, %	243.3	241.7	217.5	275
Average value of the relative gain, %	242.5			
Survival rate, %	100	100	99	100
Feed ratio, units	1.05		1.2	0.98
Mass accumulation coefficient, units	0.1159		0.1013	0.1267
Specific growth rate, %/day	4.1		3.7	4.4
Feeding costs, US$	11.47	11.47	8.52	20.19

AST 45/15 with the probiotic than with the same feed without the probiotic, although they were lower than in the variant with expensive BioMar EFICO Alpha 792.

We showed the advantage of Extra Trout AST 45/15 with the probiotic supplement over the same feed without the supplement (Fig. 4). When using the probiotic supplement in the artificial feed, the values of the final mass were higher by 4.8g and the absolute and average daily gain was higher by 4.8 and 0.16g, respectively. The relative growth was higher with the probiotic by 25%; the mass accumulation coefficient and the SGR exceeded the same indicators in the variant without the probiotic by 0.0146 units and 0.4%/day, respectively.

Our evaluation of the economic efficiency of monthly fattening of young trout showed the probiotic supplement's high efficiency. Thus, an increase in the total mass of trout by 1kg in different variants of the experiment was achieved at different times. With cheaper Extra Trout AST 45/15 feed, the total mass of fish increased by 1kg in 22 days, while with the addition of the probiotic to the feed, this increase was obtained in 16 days and with expensive BioMar EFICO Alpha 792, in 14 days.

The total mass gain was 2.67kg without the probiotic and 3.20kg with the probiotic. The increase compared to the control variant (Extra Trout AST 45/15 without the probiotic) was 20%. With the expensive feed, the total mass gain was 3.63kg, which is 36% higher than in the control variant. However, the cost of fattening trout in this case increased by 2.37 times while the cost of fattening with the cheap feed with the addition of the probiotic increased by 1.35 times.

DISCUSSION

Several studies show that the introduction of various nutritional supplements and other components, such as vitamins, probiotics, prebiotics, minerals, etc., into the fish diet has a positive effect (Yukhimenko and Bychkova 2005; Nechaeva 2010, 2014; Bakhareva 2016; Grozesku 2016; Guseva 2019). Studies conducted in Denmark on young Kamloops rainbow trout show that probiotics have a positive effect on the survival of young fish. The percentage of fish with signs of bacterial damage decreases, and their functional status and general resistance increase.

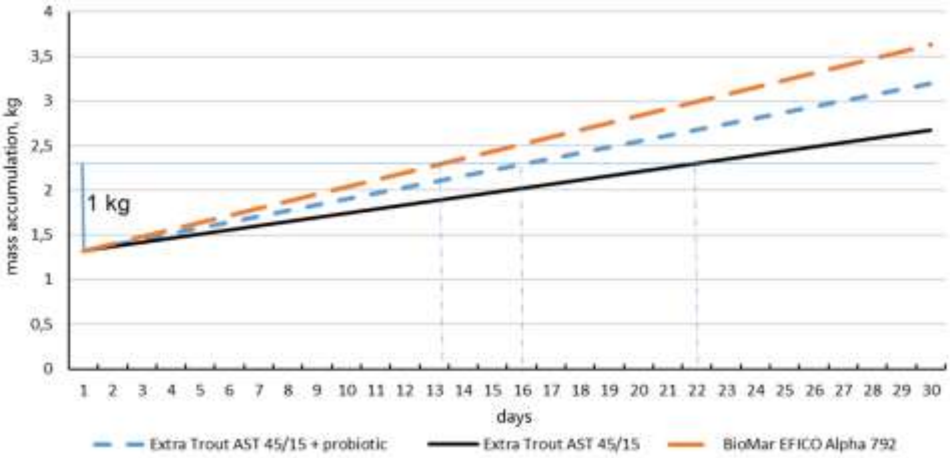

Fig. 4: Accumulation of biomass in young trout during the experiment when using various feeds.

It has also been shown that even the use of killed cultures of lactic acid bacteria has an immunomodulatory effect (Rocha et al. 2023). In our experiment, we demonstrated the advantage of Extra Trout AST 45/15 with the probiotic supplement compared to the same feed without the supplement in terms of final mass, absolute and average daily mass gain, relative mass gain, mass accumulation coefficient, and SGR in rainbow trout.

The hydrochemical analysis showed that by the dominant ions, the water in the artesian well in Kapshagayskoye NVH-1973 LLP belongs to the bicarbonate class and by the cationic composition, to the sodium group, type I ($HCO_3^- > Ca^{2+}$+Mg^{2+}) (Lakin 1990). In the process of trout cultivation, the dynamics of the main biogenic elements in the water were monitored every decade. The observation of the dynamics of biogenic elements in the three variants of the experiment did not show deviations from acceptable standards (Pyrsikov 2017). Comparison with other studies in aquaculture settings highlights the importance of water quality assessment (Neverov et al. 2023). Studies by researchers such as Meychik et al. (2021) and Ongayev et al. (2023) have emphasized that water chemistry, including ion composition, can significantly influence physiology, nutrient uptake, and overall health.

One of the key aspects of this study was the monitoring of biogenic elements in the water throughout the trout cultivation process, with observations taken at regular intervals. These biogenic elements include important compounds like nitrates, nitrites, phosphates, and ammonia, which can significantly impact aquatic ecosystems. The continuous monitoring allowed for the assessment of potential changes in water quality over time (Yesmagulova et al. 2023).

Comparison with the work of Nirmala et al. (2022) and Uddin et al. (2021) indicates that stable biogenic element levels are conducive to optimal fish growth and minimize the risk of waterborne diseases. Deviations from acceptable standards, as observed in some studies (Man et al. 2020), have been associated with adverse effects on fish health and productivity.

Hydrochemical studies show that the nitrate content significantly decreased compared to the control water. In the probiotic variant, the lowest values of biogens were observed ($p<0.05$). This is associated with the presence of the probiotic supplement since there is research data on the improvement of water quality by probiotics (Hassan et al. 2022; Qiu et al. 2023; Yang et al. 2023). Thus, the obtained results show that the use of probiotics can be useful for improving water quality even with the use of expensive feed.

Conclusion

The introduction of a probiotic consortium of microorganisms *L. paracasei* Wf-2, *L. pontis* Wf-6, *L. casei* Wf-10, and *L. paracasei* Wf-20 and *P. freudenreichii* P-8 into the artificial trout feed Extra Trout AST 45/15 showed promising results. Fish willingly consumed this food. The probiotic supplement in the feed statistically significantly improved the main fish breeding and biological indicators of trout and its growth rates.

According to the overall evaluation and the totality of the characteristics of the studied artificial feeds, the expensive BioMar EFICO Alpha 792 feed ranks first, the cheap Extra Trout AST 45/15 feed with the probiotic supplement ranks second, and Extra Trout AST 45/15 without the supplement ranks third. The indicators of the cheap trout feed with the probiotic supplement differed slightly and their properties were not inferior to the expensive feed. The differences in biomass accumulation between the probiotic variant and Extra Trout AST 45/15 and the experimental variant and BioMar EFICO Alpha 792 without probiotics were statistically unreliable.

The use of probiotic preparations as part of compound feeds in the future will ensure the fish's resistance to the harmful effects of environmental factors, improve the quality of fish products, and reduce the cost of producing valuable varieties of fish in aquaculture.

Authors' Contribution: All authors contributed equally to this work.

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