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# Phytobiotic Complex BioFeed-P in Extruded Feed for Rainbow Trout: Development and Efficacy

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## ABSTRACT

Kazakhstan's aquaculture sector requires domestically produced complete feeds for rainbow trout that can reduce dependence on imported diets. This study developed an extruded feed enriched with the phytobiotic complex BioFeed-P and evaluated its nutritional value and its effects on rainbow trout growth performance. The overall study was conducted from June 2024 to November 2025 and included feed formulation, optimization of extrusion technology, laboratory analyses, and a 30-day biological feeding trial with rainbow trout conducted in November 2025. BioFeed-P was incorporated at 0.03 %, 0.06 %, and 0.1 % of feed weight. Feed quality was assessed using near-infrared spectroscopy and organoleptic and physicochemical analyses. The 30-day trial was conducted using one-year-old rainbow trout divided into four groups of 100 fish each: three experimental groups receiving BioFeed-P-supplemented diets and one control group receiving an imported commercial feed. The developed feed contained 43.56 % crude protein and 17.56 % crude fat on a dry matter basis. The moisture content of the feed was 8.21 %. The feed also showed favorable amino acid and vitamin profiles compared with the reference feed. Body weight increased significantly in all groups ($P < 0.001$). The 0.1 % BioFeed-P group showed the most favorable numerical results, with an absolute weight gain of 61 g, relative weight gain of 17.9 %, feed conversion ratio of 1.69 kg/kg, and 100 % survival; however, between-group differences were not statistically significant. BioFeed-P-enriched extruded feed showed promising nutritional and biological performance in rainbow trout, supporting further evaluation as a domestic alternative to imported aquafeeds.

**Keywords:** Aquafeed, BioFeed-P, Extrusion, Growth, Phytobiotic, Rainbow trout.

## INTRODUCTION

The fish industry plays an important role in food security, economic growth and employment worldwide (Onomu et al. 2024). According to FAO (2024), fisheries and aquaculture support hundreds of millions of people along the entire value chain. Cage aquaculture is currently regarded as one of the most promising and economically efficient methods of commercial fish production, contributing to increased availability of fish products and supporting public health and economic development (Sangirova et al. 2020).

In Kazakhstan, the fisheries sector has been identified as a strategic area of agricultural development. The Programme for the Development of the Fisheries Sector until 2030 aims to increase fish production, domestic consumption, and export potential. Commercial aquaculture production has steadily increased from 13,287 tonnes in 2022 to 18,208 tonnes in 2024. Despite this growth, the industry remains highly dependent on imported feeds and other technological inputs. Therefore, the development of nutritionally balanced domestic fish feeds is considered one of the key factors for sustainable aquaculture expansion (Official Information Resource of the Prime Minister of the Republic of Kazakhstan 2023).

Extrusion is currently regarded as the leading technology for aquafeed production due to its ability to control pellet physical characteristics and improve feed quality through the combined effects of heat, moisture, pressure, and mechanical energy during processing (Cheng et al. 2024). The combined action of temperature and pressure promotes protein denaturation, starch dextrinization, and inactivation of antinutritional factors, resulting in improved nutrient digestibility and utilization compared with conventional feeds (Welker et al. 2018; Liu et al. 2021; Wan et al. 2022).

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At the same time, intensification of aquaculture increases the risk of water pollution and disease outbreaks, often leading to the use of antibiotics and chemotherapeutic agents. Residues of these compounds may accumulate in fish products and contribute to the development of antimicrobial resistance, which has become a major global concern (Zhou et al. 2021; Shao et al. 2021; Hua et al. 2022; Nik Mohamad Nek Rahimi et al., 2022; Li et al. 2023; Pennells et al. 2025). Consequently, the development of safe and sustainable alternatives to antibiotic-based feed additives is of increasing importance (Raza et al. 2022; Shao et al. 2024).

Among such alternatives, phytobiotics derived from medicinal plants have attracted considerable attention. These natural feed additives have been shown to improve growth performance, antioxidant status, immune responses, and resistance to environmental stressors and diseases in cultured fish (Hossain et al. 2023; Khanjani et al. 2024; Mansoori et al. 2024; Adilbekov et al. 2025).

The aim of the study was to develop a formulation and production technology for extruded feeds for rainbow trout enriched with the phytobiotic complex BioFeed-P, and to evaluate their fish-culture performance. This development is intended to address the shortage of nutritionally balanced domestically produced fish feeds in Kazakhstan. It was hypothesized that supplementation of rainbow trout diets with the phytobiotic complex BioFeed-P would improve growth performance, feed utilization efficiency, survival rate compared with fish receiving a diet without phytobiotic supplementation.

## MATERIALS AND METHODS

### Ethical approval

This study was approved by the Ethics Committee of the Faculty of Veterinary Medicine and Animal Husbandry Technology of S. Seifullin Kazakh Agrotechnical Research University (Approval Protocol No. 6, dated March 28, 2022).

### Study period and location

The overall study was conducted from June 2024 to November 2025 and included feed formulation, optimization of extrusion technology, laboratory analyses, and biological evaluation of the developed feeds. Feed formulation and nutritional evaluation of the diets were performed at the Feed Zootechnical Analysis Testing Laboratory. Optimization of extrusion technology with the addition of the phytobiotic was conducted at the production facility of «NFT-KATU» LLP (Astana, Kazakhstan). The quality characteristics of fish were assessed at the Food Safety Laboratory of S. Seifullin Kazakh Agrotechnical Research University. A 30-day biological feeding trial with rainbow trout was conducted from 1 November to 30 November 2025 at the aquaculture farm «BASTAU-ST19» LLP (Stepnogorsk, Akmola Region, Republic of Kazakhstan). The trial was designed to evaluate the effects of the developed experimental feeds on fish-culture and biological performance.

### Animals

Experimental studies to evaluate the efficacy of the developed feeds were conducted on one-year-old rainbow trout *(Oncorhynchus mykiss*) obtained from the aquaculture farm «BASTAU-ST19» LLP. Prior to the experiment, the fish were acclimatized to the rearing conditions for 14 days and fed a standard commercial diet. At the beginning of the trial, all fish were clinically healthy and showed no visible signs of disease or abnormal behaviour. Sex was not determined. Following acclimatization, the fish were allocated to four groups (one control and three experimental groups) using the principle of analogues, with 100 fish per group. Each group was maintained in a separate cage throughout the experimental period. In accordance with EU Regulation 2020/464 – Organic aquaculture standards, Annex II: Detailed rules for salmonids in fresh water, stocking density did not exceed 25 kg/m³. The initial mean body weight of fish in the groups ranged from 307 to 354 g.

### Experimental design

The control group received the imported commercial feed Aller Aqua (Christiansfeld, Denmark) without phytobiotic supplementation. The experimental groups received the developed extruded feed supplemented with BioFeed-P at inclusion levels of 0.03 % (Group 1), 0.06 % (Group 2) and 0.1 % (Group 3). Each experimental diet was represented by a single cage containing 100 fish. Therefore, the results should be interpreted as production-scale observations, and further studies with replicated cages are required to confirm the observed differences among dietary groups. The experimental fish were reared in cage lines mounted on floating frames and installed in a water body with flow-through water supply. The design of the experimental module, including a system of connecting walkways, provided the necessary technical access for regular feeding and monitoring of the fish. The hydrological regime was natural, with continuous water flow, which ensured optimal oxygen and temperature conditions. Fish in all groups were fed twice daily, in the morning and in the evening. The daily ration amounted to 2 % of body weight. Under farming conditions, dissolved oxygen concentration and water temperature were measured once a week during biometric sampling in order to adjust the daily ration for trout. Dissolved oxygen levels ranged from 11 to 12 mg/L, and water temperature ranged from 5.6 to 12 °C. A 30-day experiment was conducted on one-year-old rainbow trout to evaluate the fish-culture and biological performance of the developed feeds. A schematic representation of the experimental setup used to evaluate BioFeed-P-supplemented diets on rainbow trout growth performance is shown in Fig. 1.

### Feed formulation and production technology

During feed formulation, ingredients were selected on the basis of their nutritional value to meet the dietary requirements of rainbow trout for major nutrients, including protein, fat, vitamins, macroelements, and microelements. The nutritional value of each ingredient was taken into account proportionally. BioFeed-P was used as a plant-derived bioactive additive. Its composition includes fatty acids (55 %) – stearic, oleic, palmitic, and others; flavonoids (6.78 %) – pinostrobin, pinocembrin, and chrysin; organic acids (2.5 %) – glycolic, malic, and citric; phenolic acids (2 %) – populin and salicin; carbohydrates (1.9 %) – glucose, fructose, and ribose; essential oils (1 %); vitamins A, C, P and B12;

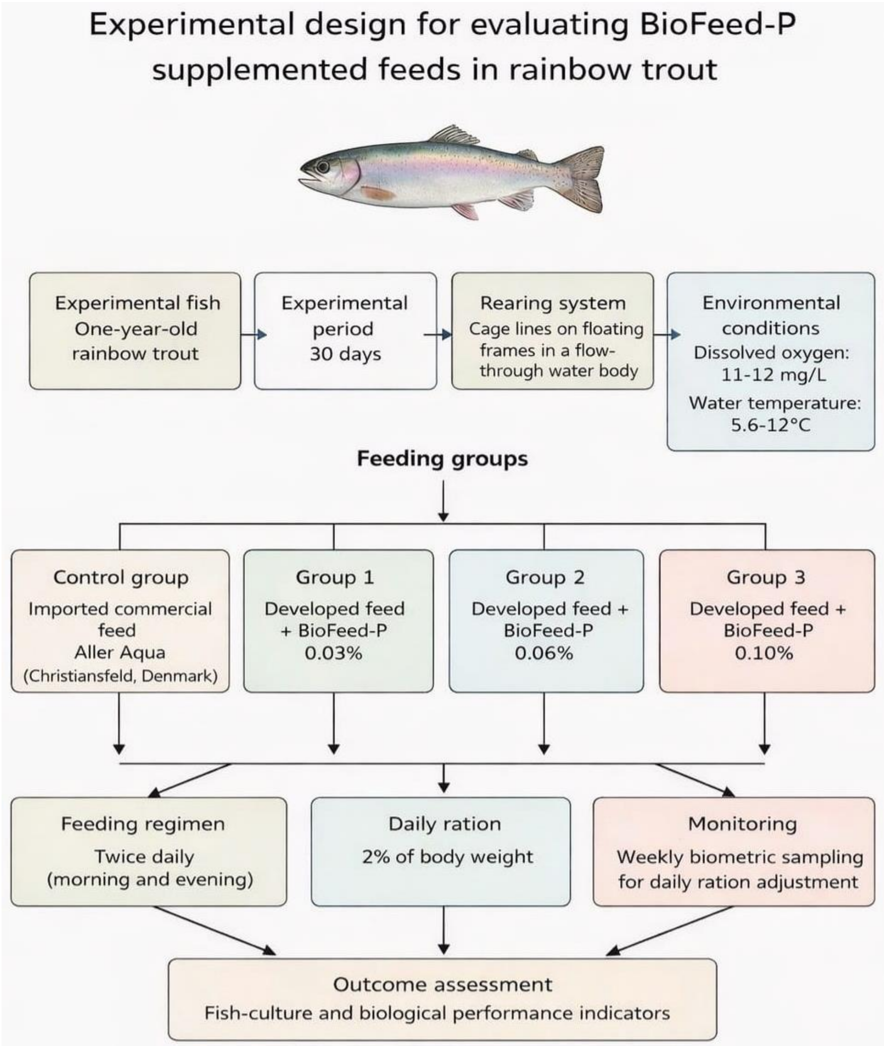


**Fig. 1:** Schematic representation of the experimental design used to evaluate the effects of BioFeed-P-supplemented feeds on the growth performance of rainbow trout.

trace elements (mg/kg) – iodine (1058), zinc (52), manganese (8.25), copper (6.17), and cobalt (0.015); amino acids – asparagine, alanine, valine and leucine; phenolic glycosides – populin and salicin; and other classes of compounds with high biological activity. In the biological trial, BioFeed-P was incorporated into the experimental diets at inclusion levels of 0.03 %, 0.06 %, and 0.1 %. Table 1 presents the representative formulation of the developed extruded feed used as the basis for the experimental diets.

**Table 1:** Ingredient composition and energy value of the compound feed for rainbow trout

| Ingredients | Content, wt. % | Content of metabolizable energy in feed, kcal |
|---|---|---|
| Blood meal | 24.0 | 1085.51 |
| Fish meal | 23.0 | 955.64 |
| Pea grain | 15.0 | 539.98 |
| Fish oil | 12.0 | 1105.14 |
| Rapeseed meal | 10.0 | 380.84 |
| Animal fat | 4.0 | 370.48 |
| Wheat grain | 2.0 | 66.04 |
| Barley grain | 2.0 | 65.18 |
| Maize grain | 2.0 | 67.30 |
| Sunflower seeds | 2.0 | 114.11 |
| Lysine | 2.0 | 56.50 |
| Methionine | 1.0 | 28.25 |
| Premix | 1.0 | 22.60 |
| BioFeed-P | 0.1 | 1.42 |
| Total | 100 | 4858.98 |

**Feed quality analysis**

The nutritional value of the extruded feed enriched with the phytobiotic was determined using a FOSS NIRS™ DS2500 analyzer (FOSS Analytical A/S, Hillerød, Denmark). Organoleptic and physicochemical properties were assessed in accordance with GOST 10385-2014 "Compound feeds for fish" (GOST 10385-2014 2014).

**Biological performance assessment**

During the experimental trials, the following parameters were assessed: absolute weight gain, average daily weight gain, relative weight gain, feed conversion per 1 kg of weight gain, as well as the physiological condition and survival rate of the fish. Fish growth was assessed according to the methods of Yu. A. Privezentsev, which involve the systematic determination of linear and weight parameters, as well as the calculation of absolute and average daily weight gain, characterizing the growth and development rates of fish (Privezentsev 1982) (Fig. 2). Throughout the experiment, weekly biometric sampling was performed in each cage. During each sampling event, 30 fish were randomly selected from each cage and measured for the main biological parameters, including body weight (M) and total length (L). Fish condition was evaluated using Fulton's condition factor (Kf), calculated according to the following formula:

$$Kf = 100 \times M / L^3$$ (Fulton 1904).

Consumption of the extruded feed by the fish was recorded throughout the experimental period, and the amount of feed applied per unit of weight gain was also determined. The functional loading method was used to assess fish survival, taking into account their adaptive responses under the experimental conditions.


**Fig. 2:** Assessment of rainbow trout growth performance during the experiment: (A) total length measurement; (B) body weight measurement.

**Statistical analysis**

Statistical analysis of the data was performed using StataNow/BE 18.5 software. All data are presented as mean ± standard deviation (SD). Normality of data distribution was assessed using the Shapiro-Wilk test. Because body weight at the beginning and end of the experiment was determined from sampled fish within each group rather than from unequivocally identified repeated measurements of the same individuals, these observations were treated as independent samples. Accordingly, within-group comparisons between initial and final body weight were performed using Welch's two-sample t-test. Differences among the four groups at the beginning and at the end of the experiment were explored separately using one-way analysis of variance (ANOVA). The Kruskal-Wallis test was used as a non-parametric sensitivity analysis when distributional assumptions were not fully met. Differences were considered statistically significant at $P < 0.05$. Because each feeding group was represented by a single cage, between-group statistical comparisons should be interpreted with caution and regarded as exploratory rather than confirmatory.

## RESULTS

**Feed formulation and nutritional value**

During the development of the production extruded feed formulations, ingredients were selected on the basis of scientifically established nutritional requirements of rainbow trout for the principal nutrients, including crude protein, lipids, vitamins, and macro- and microelements. Based on the analysis of the chemical composition of the raw ingredients and the calculation of their energy value, the component structure was optimized and a feed formulation was developed for further optimization of the extrusion process (Table 1).

The feed ingredients were selected to provide rainbow trout with all essential nutrients. Animal-derived ingredients used in the formulation included fish meal, blood meal, fish oil, and animal fat, whereas plant-derived ingredients included rapeseed meal, cereal grains (wheat, barley and maize), pea grain, and sunflower seeds. To optimize the amino acid profile, synthetic amino acids (L-lysine and DL-methionine) were incorporated into the formulation. To enhance the biological value and overall efficacy of the feed, the diet was supplemented with a premix containing vitamins and trace elements, as well as the phytobiotic complex BioFeed-P, which was tested at different inclusion levels in the biological trial.

According to the laboratory analysis, the developed extruded feed contained 43.56 % crude protein, 17.56 % crude fat, 23.71 % carbohydrates and 2.19 % crude fibre on a dry matter basis (Table 2). The moisture content was 8.21 %, indicating good storage stability. The metabolizable energy of the diet reached 4858.98 kcal/kg. The obtained composition was comparable to that of the imported commercial feed used as a reference.

Extrusion parameters and physicochemical properties of the feed.

The prepared raw material mixture was subjected to extrusion at 100-120°C (optimal value: 100.3°C) and pressure up to 50 atm. Texture formation was achieved by forcing the melt through a die with a 3 mm opening. The linear dimensions of the target product (pellet length ≤ 1 cm) were controlled by adjusting the cutter knife rotation speed. The technological cycle included a stage of vacuum coating (impregnation) with lipid components. This process was carried out under negative pressure of -5 atm (according to the pressure gauge) for 5 min, ensuring deep penetration of the lipid fraction into the porous pellet structure.

The final dehydration stage (drying) was carried out at 100 °C for 15-20 min, which made it possible to achieve the required moisture content and microbiological stability of the finished product.

Analysis of the quality characteristics of the developed feed showed the following organoleptic properties: the pellets had a regular cylindrical shape (6-9 mm in length), a uniform dark-brown colour, and a characteristic odour without foreign impurities. The physicochemical characteristics of the pellets were as follows: friability – 2 %, moisture content – 8 % and water stability – 3 h. It was established that, under optimal storage conditions (+5 to +15°C, relative air humidity not exceeding 65 %), the feed had a shelf life of at least 6 months.

A comparative analysis of the chemical composition of the developed feed and its imported analogue was also performed (Table 2).

The developed extrusion technology and feed formulation served as the basis for a patent application entitled "Method for Producing Extruded Feed for Rainbow Trout" (Application No. 2025/1131.1, filed on 17 November 2025).

**Amino acid and vitamin profile**

The analysis of vitamin and amino acid composition yielded the results shown in Table 3. Analysis of the amino acid composition demonstrated a marked advantage of the developed extruded feed enriched with the phytobiotic BioFeed-P over the foreign analogue. The most pronounced differences were observed in the contents of

**Table 2:** Chemical composition of the developed extruded feed enriched with the phytobiotic BioFeed-P

| Physicochemical parameters: | Developed extruded feed | Reference feed from a foreign manufacturer |
|---|---|---|
| Protein content, % | 41.28 ± 0.04 | 39.38 ± 0.04 |
| Protein content on a dry matter basis, % | 43.56 ± 0.06 | 42.66 ± 0.06 |
| Fat content, % | 14.62 ± 0.12 | 14.23 ± 0.22 |
| Fat content on a dry matter basis, % | 17.56 ± 0.02 | 16.29 ± 0.04 |
| Carbohydrate content, % | 23.71 ± 0.03 | 24.35 ± 0.16 |
| Moisture content, % | 8.21 ± 0.32 | 9.13 ± 0.20 |
| Ash content, % | 9.57 ± 0.04 | 9.67 ± 0.04 |
| Crude fibre content, % | 2.19 ± 0.02 | 2.43 ± 0.02 |

**Table 3:** Amino acid and vitamin composition of the extruded feed enriched with the phytobiotic BioFeed-P

| Nutrients | Developed extruded feed | Reference feed from a foreign manufacturer |
|---|---|---|
| | Amino acids, % | |
| Arginine | 3.438 ± 1.375 | 1.401 ± 0.560 |
| Lysine | 2.188 ± 0.744 | 2.031 ± 0.690 |
| Tyrosine | 1.354 ± 0.406 | 1.050 ± 0.315 |
| Phenylalanine | 2.292 ± 0.688 | 1.541 ± 0.462 |
| Histidine | 1.354 ± 0.677 | 0.483 ± 0.242 |
| Leucine + Isoleucine | 2.709 ± 0.704 | 1.891 ± 0.492 |
| Methionine | 0.948 ± 0.322 | 0.224 ± 0.076 |
| Valine | 2.709 ± 1.083 | 2.241 ± 0.896 |
| Proline | 3.334 ± 0.867 | 2.311 ± 0.601 |
| Threonine | 1.875 ± 0.750 | 1.261 ± 0.504 |
| Serine | 2.292 ± 0.596 | 1.401 ± 0.364 |
| Alanine | 1.771 ± 0.460 | 1.611 ± 0.419 |
| Glycine | 2.396 ± 0.815 | 1.681 ± 0.571 |
| Vitamins, mg/100 g | | |
| - β-tocopherol | 16.07 ± 0.10 | 15.23 ± 0.26 |
| - B1 (thiamine) | 0.53 ± 0.10 | 0.41 ± 0.082 |
| - B2 (riboflavin) | 1.28 ± 0.54 | 0.64 ± 0.26 |
| - B6 (pyridoxine) | 2.35 ± 0.47 | 2.64 ± 0.53 |
| - B3 (niacin) | 1.15 ± 0.23 | 0.39 ± 0.08 |
| - B5 (pantothenic acid) | 1.26 ± 0.05 | 2.05 ± 0.37 |

Note: Values are presented as mean ± SD of three analytical replicates (n = 3). Statistical comparisons between the developed extruded feed and the reference feed were not performed because the analyses were intended to characterize the nutritional and physicochemical properties of the feeds rather than to test differences between experimental diets.

arginine, histidine, phenylalanine, and proline. In particular, the arginine concentration in the experimental feed reached 3.438 ± 1.375 %, which was 2.4-fold higher than that in the analogue (1.401 ± 0.560 %). Histidine content exceeded that of the control feed by 2.8-fold, whereas phenylalanine and proline levels were 1.4-fold higher. The high biological value of the formulation was further confirmed by the increased contents of critically important limiting amino acids, including lysine, methionine, and threonine, relative to the control sample.

The vitamin contents did not differ substantially overall; however, the developed feed also showed some favorable differences compared with the reference feed in this respect. The level of β-tocopherol in the developed feed was 16.07 ± 0.10 mg, slightly exceeding that of the analogue, in which the content was 15.23 ± 0.26 mg. Although the absolute difference was small, the low standard deviation indicates a consistently higher content of this antioxidant component in the developed feed.

Analysis of water-soluble vitamins showed that, compared with the analogue, the developed feed had a substantial advantage in the content of thiamine (B1), which was higher by 22 %, riboflavin (B2), which was 2-fold higher, and niacin (B3), which was 3-fold higher. At the same time, the contents of pyridoxine (B6) and pantothenic acid (B5) were lower than those in the analogue by 11 % and 65 %, respectively.

Thus, the developed extruded feed containing the phytobiotic complex BioFeed-P showed several favorable compositional differences compared with the imported reference feed. Higher levels of several essential amino acids were observed, particularly arginine (2.4-fold higher) and histidine (2.8-fold higher), as well as lysine, methionine, and threonine, indicating the favorable nutritional quality of the protein fraction. A higher content of β-tocopherol (16.07 mg vs. 15.23 mg) was also recorded, suggesting enhanced antioxidant potential of the feed, along with advantages in vitamins B3, B2 and B1.

**Fish growth performance and feed conversion**

The effects of extruded feeds supplemented with different concentrations of the phytobiotic complex BioFeed-P on the growth performance of rainbow trout are presented in Table 4 and Fig. 3. Experimental Group 1 received 0.03 % BioFeed-P, Experimental Group 2 received 0.06 %, and Experimental Group 3 received 0.1 %, whereas the control group received the imported commercial diet Aller Aqua without phytobiotic supplementation. At the end of the experimental period, body weight was significantly higher than the initial value in all groups ($P < 0.001$). The highest absolute weight gain was recorded in Experimental Groups 2 and 3, reaching approximately 61 g in both groups, followed by the control group (approximately 57 g) and Experimental Group 1 (51 g). Relative weight gain showed a similar trend and was highest in Experimental Group 3 (17.9 %), followed by Experimental Group 2 (17.2 %), Experimental Group 1 (16.6 %), and the control group (16.1 %).

**Table 4:** Fish-culture and biological performance indicators of rainbow trout

| Parameter | Study groups | | | |
|---|---|---|---|---|
| | Experimental Group 1 | Experimental Group 2 | Experimental Group 3 | Control Group |
| Average initial weight, g | 307 ± 35.3 | 354.6 ± 33.4 | 341 ± 33.2 | 353 ± 58.0 |
| Average final weight, g | 358 ± 20.8* | 415.2 ± 44.0* | 402 ± 5.0* | 410.2 ± 13.3* |
| Absolute weight gain, g | 51 | 61 | 61 | 57 |
| Average daily weight gain, g | 1.8 | 2.2 | 2.2 | 2.0 |
| Relative weight gain, % | 16.6 | 17.2 | 17.9 | 16.1 |
| Feed conversion ratio, kg/kg | 1.77 | 1.73 | 1.69 | 1.80 |
| Survival rate, % | 100 | 100 | 100 | 100 |

Note: Values are presented as mean ± SD. Asterisks indicate a statistically significant increase in body weight from the initial to the final measurement within the same group ($P < 0.001$). No statistically significant differences were observed among the experimental dietary groups ($P > 0.05$). Because each treatment was represented by a single cage, between-group comparisons should be interpreted with caution.

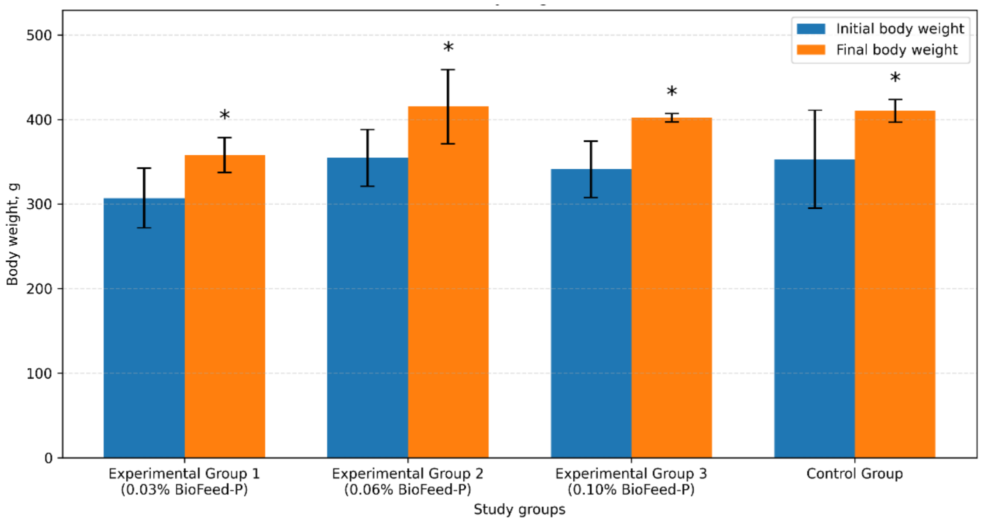


**Fig. 3:** Initial and final body weight of rainbow trout in the control group and experimental groups fed extruded diets supplemented with 0.03 %, 0.06 %, and 0.1 % BioFeed-P. Values are presented as mean body weight (g). Values are presented as mean ± SD. Asterisks indicate significant differences between initial and final body weight within the same group ($P < 0.001$). Between-group comparisons showed no significant differences among the experimental diets ($P > 0.05$).

Feed utilization efficiency was numerically most favorable in Experimental Group 3, which showed the lowest feed conversion ratio (1.69 kg/kg), compared with 1.73 kg/kg in Experimental Group 2, 1.77 kg/kg in Experimental Group 1, and 1.80 kg/kg in the control group. Survival rate was 100 % in all groups throughout the study. In addition, fish from all groups maintained normal physiological status, as indicated by regular opercular movements, a glossy body surface, intact scales tightly attached to the body, and bright red gills. Although body weight differed among groups at the beginning of the experiment, no statistically significant differences were detected among the experimental diets for the evaluated growth performance indicators. Nevertheless, the data indicate a favorable numerical trend in growth performance with BioFeed-P supplementation, especially at the 0.1 % inclusion level.

## DISCUSSION

The developed extruded feed supplemented with the phytobiotic complex BioFeed-P demonstrated nutritional characteristics consistent with the dietary requirements of rainbow trout (*Oncorhynchus mykiss*). The crude protein, lipid, metabolizable energy, amino acid, and vitamin contents were within the ranges reported for high-quality commercial trout feeds and current nutritional recommendations for salmonids (Drew et al. 2007; National Research Council 2011; de Oliveira-Júnior et al. 2021; Palma et al. 2021).

The applied feed-processing technology, including extrusion, vacuum coating, and final drying, was consistent with modern aquafeed manufacturing practices and ensured the production of pellets with suitable physical stability and nutritional quality (Rokey et al. 2000; Gatlin et al. 2007; Hardy 2010; Sørensen 2012; FAO 2018; Lee et al. 2020).

Compared with the reference imported feed, the developed formulation was characterized by higher levels of several nutritionally important amino acids, including arginine, histidine, lysine, methionine, and threonine. These amino acids play essential roles in growth, protein synthesis, nutrient utilization, and physiological regulation in rainbow trout and may contribute to improved productive performance under intensive aquaculture conditions (Ketola 1983; Walton et al. 1986; Ahmed et al. 2022; Zhang et al. 2024). The developed feed also contained higher concentrations of β-tocopherol and several B-group vitamins, which play important roles in antioxidant defense, cellular metabolism, and enzymatic processes in fish (Hu et al. 2025). These compositional characteristics may provide additional physiological benefits and support fish adaptation to farming conditions. Overall, the nutritional profile of the developed feed suggests that it may serve as a promising domestic alternative to imported trout feeds while providing a suitable basis for evaluating the biological effects of BioFeed-P supplementation.

The results of the experiment indicate that the use of feeds enriched with BioFeed-P was associated with favorable numerical trends in the growth performance of rainbow trout (*Oncorhynchus mykiss*). In all experimental groups, fish weight gain was numerically higher than in the control group, which received the imported commercial feed Aller Aqua without phytobiotic supplementation. The highest relative weight gain was observed in the third experimental group (0.1 % phytobiotic inclusion), exceeding the corresponding values in the second (0.06 %), first (0.03 %), and control groups by 0.7 %, 1.3 %, and 1.8 %, respectively.

The growth-promoting effect may be explained by the composition of the phytobiotic, which includes a vitamin-mineral complex. According to international studies, adequate dietary supplementation of vitamins and trace elements contributes to improved growth performance, feed utilization, immune function, and stress resistance in fish through the regulation of enzymatic, hormonal, and metabolic processes (Rokey et al. 2000; Abdul Kari 2025; Mmanda 2025). At the same time, the use of functional additives, including phytobiotics, may support fish productivity, improve nutrient utilization, and enhance the energy efficiency of diets (Brezas and Hardy 2020).

The dynamics of weekly weight gain confirm that the experimental groups exhibited more intensive growth than the control from the very first weeks of the trial. At the same time, assessment of the physiological condition of the fish showed the preservation of all signs of normal viability, including regular opercular movements, glossy and undamaged scales, bright red gills, and scales tightly attached to the body. Survival was 100 % in all groups, indicating the safety of feeds containing the phytobiotic.

Taken together, the experimental data suggest that feeds enriched with BioFeed-P, particularly at an inclusion level of 0.1 %, may provide favorable growth and feed conversion outcomes in rainbow trout. However, several limitations should be considered when interpreting these findings. The feeding trial lasted only 30 days, and each dietary groups was represented by a single cage containing 100 fish. In addition, slight differences in initial fish body weight among groups and the absence of a domestic feed control without BioFeed-P should be considered when interpreting the results. The study focused primarily on growth performance and feed utilization and did not include assessments of immune status, digestive enzyme activity, intestinal health, or flesh quality. Therefore, because between-group differences were not statistically significant, these findings should be interpreted as promising numerical trends that warrant further investigation under expanded experimental conditions with replicated cages and additional physiological and product-quality assessments.

## Conclusion

In the present study, an extruded feed for rainbow trout supplemented with the phytobiotic complex BioFeed-P was developed and evaluated in terms of nutritional value and biological efficacy. The developed feed was comparable with the imported analogue in overall nutritional value and showed favorable differences in several individual compositional parameters. The inclusion of BioFeed-P was associated with favorable numerical improvements in growth performance and feed conversion, with the most pronounced trend observed at an inclusion level of 0.1 %. However, differences among groups were not statistically significant. The obtained results support the feasibility of further evaluation of the developed formulation as a domestically produced feed for rainbow trout culture. The development of such feeds may contribute to import substitution in the aquaculture sector of the Republic of Kazakhstan by expanding the range of domestically produced feeds and reducing dependence on foreign supplies. In addition, the use of balanced extruded feeds may be regarded as one of the factors contributing to food security, as well as to the quality and veterinary-sanitary safety of fish products.

## DECLARATIONS

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**Conflict of Interest:** The authors declare that they have no conflict of interest.

**Data Availability:** Data available upon request from the corresponding author.

**Ethics Statement:** All experimental procedures involving fish were conducted in accordance with the institutional guidelines for the care and use of animals in research. The study was approved by the Ethics Committee of the Faculty of Veterinary Medicine and Animal Husbandry Technology of S. Seifullin Kazakh Agrotechnical Research University (Approval Protocol No. 6, dated March 28, 2022).

**Author’s Contribution:** GA, BY, and ZA conceived and designed the study. GA, LS, KZh, KZ, and MY conducted the experiments and collected the data. BY, GA, and LS analyzed and interpreted the data. ZA and BY supervised the study. GA and BY drafted the manuscript. LS, KZh, KZ, MY, and ZA revised the manuscript critically for important intellectual content. All authors read and approved the final manuscript.

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