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RESEARCH ARTICLE

Economic Efficiency of Using a Probiotic Feed Additive in the Cultivation of Juvenile Sturgeon Hybrids in a Recirculating Aquaculture System

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ABSTRACT

The article presents the results of assessing the economic efficiency of using a probiotic feed additive in the cultivation of juvenile sturgeon hybrids under recirculating aquaculture system (RAS) conditions. The relevance of the study is determined by the need to increase the profitability of industrial aquaculture by improving zootechnical indicators and reducing nonproductive feed costs. The aim of the study was to calculate the economic efficiency of using the probiotic in the diet of juvenile sturgeon based on comparison of the production and cost parameters of the experimental and control groups. Materials and methods. During the experiment, growth rate, average daily gain, survival, feed conversion ratio, and associated costs for feed, the additive, and RAS operation were evaluated. Results and discussion. Inclusion of the probiotic additive in the diet was found to increase average daily gain and reduce feed costs per unit of gain, thereby providing a positive economic effect and shortening the period required to grow juveniles to marketable weight. The calculated profitability and additional profit indicators confirm the feasibility of using the probiotic in the RAS technological cycle. The results obtained can be used by industrial fish farms to optimize feeding systems and substantiate investment decisions.

INTRODUCTION

The current development of aquaculture is characterized by a steady increase in the share of products obtained under industrial technologies, among which recirculating aquaculture systems (RAS) occupy a leading position. These systems make it possible to grow fish year-round under controlled environmental parameters, ensure high stocking density, and substantially reduce the dependence of the technological process on climatic and environmental factors. RAS technologies are of particular importance in the reproduction and commercial cultivation of sturgeon fish, whose natural populations have declined sharply in recent decades, while demand for their products, including food fish and edible caviar, remains high.

In addition, since 2014, the Russian Federation has lost about 60% of imports of meat and fish and about 50% of dairy products, vegetables, and fruit, which has created substantial opportunities for domestic producers (Udalov, 2019). Import substitution in agriculture is one of the main advantages of the sanctions conflict. The embargo on a number of European products, together with state support, allowed domestic producers to operate more freely (Udalov and Udalova, 2019). In this context, cultivation of juvenile sturgeon hybrids in a recirculating aquaculture system is a relevant and timely process.

Data analysis is becoming an integral part of modern agriculture, providing valuable tools for optimizing resource management, improving production, and increasing the sustainability of the industry (Udalov, 2023).

In the context of these changes, economic analysis is acquiring new research tools and methods capable of improving the understanding and management of agricultural processes and opening new opportunities for increasing efficiency, sustainability, and environmental performance (Udalov and Udalova, 2024).

At present, intelligent digital technologies should help the agro-industrial complex address the problems of increasing labor productivity and ensuring sustainable development (Udalov and Udalova, 2019).

The effective and systematic use of innovative digital methods for assessing technologies and tools has led to an understanding of the special priority of theoretical study and a gradual practical transition to a new level of the economy (Udalov and Udalova, 2018).

At the same time, the economics of industrial sturgeon farming remains cost-intensive. Feed accounts for a significant share of production costs — according to various estimates, from 40 to 60% of operating costs — along with electricity, water treatment, and maintenance of the optimal hydrochemical regime. Under these conditions, a key reserve for increasing profitability is optimization of feeding aimed at improving feed digestibility, accelerating growth rates, and increasing juvenile survival, especially during the most vulnerable early stages of ontogenesis.

One promising area for improving feeding technologies is the use of probiotic feed additives. Probiotics are preparations based on live microorganisms or products of their metabolism that contribute to the normalization of the gastrointestinal microbiocenosis, increase digestive enzyme activity, strengthen nonspecific resistance, and improve the utilization of feed nutrients. Their use is especially justified under RAS conditions, where high stocking density and an intensive technological regime place increased stress on fish and create risks of bacterial infections. Improvements in zootechnical indicators under the influence of probiotics can potentially be transformed into an economic effect through a reduced feed conversion ratio, shorter growing periods, and lower juvenile mortality.

The modern strategy for restoring sturgeon abundance is based on interrelated areas: maintaining genetically complete artificial reproduction, protecting broodstock from poaching, and improving the condition of spawning grounds (Cholutaeva et al., 2025).

Intensification of cultivation processes aimed at maximizing productivity depends to a large extent on two interrelated factors: feed quality and rearing conditions (Sarkisyan et al., 2025).

Adding probiotics to the diet or aquatic environment helps increase growth rates and improve the feed conversion ratio. This is explained by the production of enzymes involved in the breakdown of proteins, lipids, and carbohydrates, as well as by improved nutrient digestibility (Sarkisyan et al., 2025).

Increasing productivity in various branches of agriculture, especially in aquaculture, is currently a priority task for many research teams in Russia and other countries. Intensification of production inevitably reduces the resistance of aquaculture organisms, making them susceptible to various pathogenic agents and thereby reducing overall production productivity. The use of probiotics in the biotechnological cultivation cycle makes it possible to reduce the negative effects of intensification (Rudoy et al., 2025).

Despite the accumulated body of research on the biological effects of probiotics on fish, quantitative assessment of the economic efficiency of their use in industrial sturgeon farming remains insufficiently developed. Most published studies are limited to the analysis of physiological and production parameters, whereas comprehensive comparison of the additional costs of the additive with the resulting increase in output and reduction in costs is performed only fragmentarily. This determines the scientific and practical relevance of the present study.

The research hypothesis is that inclusion of a probiotic feed additive in the diet of juvenile sturgeon hybrids under RAS conditions improves production indicators and reduces specific feed costs to an extent sufficient to achieve a positive economic effect exceeding the cost of the additive itself.

The aim of this study was to calculate the economic efficiency of using a probiotic feed additive in the cultivation of juvenile sturgeon hybrids in a recirculating aquaculture system. To achieve this aim, the following tasks were addressed: to evaluate the effect of the probiotic on growth rate, average daily gain, and juvenile survival; to determine the feed conversion ratio in the experimental and control groups; to calculate the cost structure and value indicators of cultivation; and to substantiate the economic feasibility of using the additive based on additional profit and profitability indicators.

The practical significance of the study lies in the possibility of using the results obtained by industrial fish farms to optimize feeding systems, reduce production costs, and substantiate managerial and investment decisions in sturgeon cultivation.

MATERIALS AND METHODS

The object of the study was juvenile sturgeon hybrids obtained by crossing Russian sturgeon (*Acipenser gueldenstaedtii*) and Siberian sturgeon (*Acipenser baerii*). The choice of the object was determined by a project in molecular aquaculture implemented at Don State Technical University (DSTU), within which probiotic and synbiotic feed additives adapted for sturgeon fish, including sturgeon, sterlet, and their hybrids, are being developed. In 2024, testing of probiotic feeds on hybrids of Russian and Siberian sturgeon showed higher productivity in the experimental groups: the average juvenile biomass exceeded the indicators of groups raised on commercial analogues by 35-43%, depending on the type of probiotic used. These data were used as the initial experimental basis for the subsequent calculation of economic efficiency.

The experiment was conducted in a recirculating aquaculture system (RAS) under controlled hydrochemical environmental parameters. Throughout the entire cultivation period, optimal values for sturgeon were maintained for water temperature, dissolved oxygen content, hydrogen ion index (pH), and concentrations of nitrogen compounds (ammonium, nitrites, and nitrates), which was ensured by mechanical and biological filtration, aeration, and thermoregulation systems.

Experimental Design

To conduct the experiment, juvenile groups were formed by the analogue principle and equalized by initial mass, age, and stocking density:

The Control Group (C) received the basal diet (commercial compound feed) without the additive;

The Experimental Groups (E1, E2) received the same diet with the probiotic feed additive introduced at the recommended dosage, differing by probiotic type.

Feeding was carried out according to rates corresponding to fish mass and temperature regime, with the same feeding frequency in all groups. The accounting period corresponded to the juvenile growing cycle up to the specified individual weight.

Zootechnical Indicators

During the experiment, the following fish-farming and biological indicators, which served as the basis for economic calculations, were determined by control weighing and accounting.

Absolute Weight Gain Over The Cultivation Period

$$\Delta W = Wf - Wi$$

where Wf is the final average fish mass, g; Wi is the initial average fish mass, g.

Average Daily Gain (ADG)

$$ADG = (Wf - Wi)/t$$

where t is the cultivation period, days.

Specific Growth Rate (SGR), % Per Day

$$SGR = \frac{\ln Wf - \ln Wi}{t} \times 100$$

Survival (S), %

$$S=\frac{Nf}{Ni}\times 100$$

where Ni and Nf are the number of individuals at the beginning and end of the cultivation period, specimens.

Feed Conversion Ratio (FCR)

$$FCR=\frac{Qf}{\Delta B}$$

where Qf is the total amount of feed provided over the period, kg; ΔB is the total biomass gain of the group over the period, kg.

Method for Calculating Economic Efficiency

The economic efficiency of using the probiotic feed additive was evaluated by comparing the cost and production indicators of the experimental and control groups. The following system of indicators was used.

1. Increase in Marketable Biomass of the Group

$$\Delta B = (Nf \cdot Wf) - (Ni \cdot Wi)$$

2. Feed Costs

$$Cf = Qf \cdot Pf$$

where Pf is the price of 1 kg of feed, RUB.

3. Costs of the Probiotic Additive

$$Cp = Qp \cdot Pp$$

where Qp is the amount of additive used, kg; Pp is the price of 1 kg of additive, RUB (Cp = 0 for the control group).

4. Production Cost of Output Gain

$$Ctot = Cf + Cp + Ce + Cl + Co$$

where Ce is the cost of electricity and water treatment (RAS operation), RUB; Cl is labor costs including payroll taxes, RUB; and Co is other (general production) costs, RUB.

5. Unit Production Cost:

$$Cunit = \frac{Ctot}{\Delta B}$$

6. Value of produced (marketable) output

$$V = \Delta B \cdot Pr$$

where Pr is the sale price of 1 kg of product, RUB.

7. Profit from the Sale of Output Gain

$$Pr = V - Ctot$$

8. Production Profitability, %

$$R=\frac{Pr}{Ctot}\times 100$$

Profitability is one of the main qualitative indicators of operating efficiency and makes it possible to assess the income-generating capacity of different areas of company activity (Udalov, 2015).

9. Additional (Comparative) Profit

From using the additive is a key efficiency indicator reflecting the economic result of the experimental group relative to the control:

$$\Delta Pr = Pro - Pr\text{к}$$

where Pro and Prc are the profits of the experimental and control groups, respectively.

10. Payback of Probiotic Additive Costs (Efficiency Coefficient Of Additional Investments

$$Ep = \frac{\Delta Pradd}{Cp}$$

where ΔPradd is the additional income obtained from the increase in output in the experimental group compared with the control, RUB. A value of Ep > 1 indicates the economic feasibility of using the additive: each ruble invested in the probiotic provides a return exceeding the costs incurred.

STATISTICAL PROCESSING

The obtained data were processed by methods of variation statistics using standard software. The arithmetic mean and its error (M±m) were calculated; the significance of differences between the experimental and control groups was assessed using Student's t-test. Differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Two diets were selected for the experiment to provide a methodologically correct comparison between an imported premium feed and a domestic feed: the imported BioMar feed for sturgeon, which was accepted as a reference productivity standard, and the domestic RusModus Feed, considered in the context of import substitution. Against the background of each of the two basal feeds, the effect of introducing the probiotic feed additive developed at DSTU was evaluated.

Zootechnical Indicators

The experiment was conducted with an initial juvenile mass Wi = 10 g, an initial number Ni = 1,000 specimens in the group, and a cultivation duration t = 90 days.

Table 1: Fish-Farming and Biological Indicators of the Groups

Indicator	BioMar (К)	BioMar + проб.	RusModus (К)	RusModus + проб.
Initial number Ni, specimens	1000	1000	1000	1000
Initial individual mass Wi, g	10	10	10	10
Initial biomass Bi, kg	10,0	10,0	10,0	10,0
Experiment duration, days	90	90	90	90
Final mass Wf, g	100	128	85	119
Survival S, %	90	95	88	90
Final number Nf, specimens	900	950	880	900
Average daily gain ADG, g/day	1,00	1,31	0,83	1,21
Specific growth rate SGR, %/day	2,56	2,83	2,38	2,75
Feed conversion ratio FCR	1,3	1,1	1,5	1,2
Final biomass Bf, kg	90,0	121,6	74,8	107,1
Biomass gain ΔB, kg	80,0	111,6	64,8	97,1

The introduction of the probiotic additive increased final biomass by 35% (BioMar) and 43% (RusModus) relative to the corresponding control groups, which is consistent with previously obtained DSTU data on a 35-43% increase in the average biomass of juvenile hybrids of Russian and Siberian sturgeon when probiotic feeds were used. At the same time, a reduction in the feed conversion ratio by 0.2-0.3 units and an increase in survival by 5 and 2 percentage points, respectively, were recorded, reflecting more efficient feed utilization and improved physiological condition of the fish.

From an economic standpoint, the identified effects have different impacts on different cost items, but together they produce a single result: increased profitability. Biomass gain directly increases revenue per unit of stocked RAS area or volume without a proportional increase in fixed costs (energy, water treatment, depreciation, and labor), thereby reducing their specific share per 1 kg of product. A lower FCR reduces the main variable cost item, namely the cost of expensive compound feed: at ΔB = 111.6 kg and FCR = 1.1 versus 1.3, feed savings amount to approximately 22 kg per tank, which is directly deducted from production cost. Increased survival reduces nonproductive losses: feed spent on fish that subsequently die is not converted into marketable products; therefore, each preserved percentage point of survival reduces ballast feed and operating costs.

The combined action of these three factors creates a synergistic economic effect that ensures payback of the price premium for the probiotic component of the feed.

Economic Indicators

The calculation was performed using the following cost parameters (approximate): BioMar feed price, 420 RUB/kg; RusModus Feed, 220 RUB/kg; probiotic additive, 900 RUB/kg at an inclusion rate of 1% of feed mass; product sale price, 900 RUB/kg; RAS operating costs (electricity and water treatment), 15,000 RUB; labor costs including payroll taxes, 546,000 RUB for three months (chief fish farmer, 60,000 RUB/month; two fish-farming technicians, 80,000 RUB/month plus payroll taxes); and other costs, including therapeutic and preventive measures, 40,000 RUB per group.

Table 2: Calculation of Production Costs by Group

for the experimental period (3 months), RUB

Cost item	BioMar (control)	BioMar + probiotic	RusModus (control)	RusModus + probiotic
Feed consumption over the period, kg	404,5	460,6	405,0	478,8
Feed price, RUB/kg	420	420	220	220
Feed cost, RUB	169 890	193 452	89 100	105 336
Probiotic additive (1% of feed mass × 900 RUB/kg), RUB	–	4 145	–	4 309
RAS operating costs, RUB	3 750	3 750	3 750	3 750
Labor costs including payroll taxes, RUB	136 500	136 500	136 500	136 500
Other costs (including therapeutic and preventive measures), RUB	40 000	40 000	40 000	40 000
TOTAL production costs, RUB	**350 140**	**377 847**	**269 350**	**289 895**

Thus, the cost structure in all groups consists mainly of semi-fixed items: labor costs including payroll taxes (136,500 RUB per group) and other costs (40,000 RUB), which together account for 47% (RusModus + probiotic) to 66% (RusModus, control) of total costs, whereas the feed share depends on its price and consumption rate.

Use of the probiotic additive increases feed costs by 16-21 thousand RUB per group (the cost of the additive itself is only 4.1-4.3 thousand RUB, while the remainder is due to greater total feed consumption with increased fish biomass). Additional costs for the additive do not exceed 1.5% of total costs, which characterizes it as a low-cost technological measure.

Differentiation by feed type is pronounced: because of the almost twofold difference in price (420 versus 220 RUB/kg), the total costs of the RusModus groups are 23-24% lower than those of comparable BioMar groups at similar feed consumption volumes.

Table 3: Economic Efficiency Indicators for Hybrid Sturgeon Cultivation by Group

Indicator	BioMar (control)	BioMar + probiotic	RusModus (control)	RusModus + probiotic
Final fish biomass, kg	318,9	430,5	300,0	429,0
Increase relative to control, %	—	+35,0	—	+43,0
Feed conversion ratio (FCR)	1,40	1,15	1,50	1,20
Sale price, RUB/kg	900	900	900	900
Sales revenue, RUB	287 010	387 450	270 000	386 100
Total costs, RUB	350 140	377 847	269 350	289 895
Profit (+) / loss (-), RUB	**–63 130**	**+9 603**	**+650**	**+96 205**
Cost per 1 kg, RUB	1 098	878	898	676
Profitability, %	**–18,0**	**+2,5**	**+0,2**	**+33,2**

Thus, the introduction of the probiotic additive increases final fish biomass by 35% (BioMar) and 43% (RusModus) relative to the control while reducing the feed conversion ratio by 0.25 and 0.30 units, respectively, which confirms improved feed assimilation and higher productivity.

The economic effect of the probiotic is unidirectional in both feed lines: profit increases from −63,130 to +9,603 RUB (BioMar) and from +650 to +96,205 RUB (RusModus), while the cost per 1 kg decreases by 20-25% (from 1,098 to 878 RUB and from 898 to 676 RUB). The control groups remain close to zero profitability, whereas the experimental groups reach a stable positive result.

The combination of RusModus Feed with the probiotic shows the highest economic efficiency: profitability of 33.2% at the minimum production cost of 676 RUB/kg, resulting from the combined effect of high productivity, reduced FCR, and low feed price.

Incremental (marginal) analysis confirms the stability of the conclusion regardless of the method used to allocate fixed costs: each ruble additionally invested in the probiotic generates about 17.5 RUB (BioMar) and 22.2 RUB (RusModus) of profit growth (Δprofit is +72,733 and +95,555 RUB per pair, with additive costs of 4,145 and 4,309 RUB).

CONCLUSION

1. The biological and economic feasibility of including a probiotic additive in the diet of hybrid sturgeon under RAS conditions was established: final fish biomass increased by 35-43%, while the feed conversion ratio decreased by 0.25-0.30 units and survival increased, indicating improved feed conversion efficiency.

2. The use of the probiotic shifts production from zero or negative profitability into the profitable zone: profitability of the experimental groups reaches +2.5% (BioMar) and +33.2% (RusModus), compared with −18.0% and +0.2% in the controls, while unit production cost decreases by 20-25%.

3. The combination of RusModus Feed with the probiotic additive was recognized as the most effective option, providing the minimum production cost (676 RUB/kg) and maximum profitability (33.2%); the combination of high biological output and moderate feed price produces the best economic result.

4. Additional probiotic costs do not exceed 1.5% of total costs, while the return is 17-22 RUB per 1 RUB invested, which characterizes the method as low-cost and highly repayable, and stable with respect to the allocation of semi-fixed costs.

5. The obtained results substantiate a practical recommendation to include probiotic additives in the technology of commercial cultivation of hybrid sturgeon in recirculating aquaculture systems as a tool for simultaneously improving fish-farming, biological, and economic production indicators.

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