Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Health and production assessment of rainbow trout and socioeconomic factors of producers in authorized production centers in apurímac: analysis of key factors and mortality

Avaliação sanitária e produtiva da truta-arco-íris e fatores socioeconômicos dos produtores em centros de produção autorizados em apurímac: análise de fatores-chave e mortalidade

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Submission: December 27st, 2024 | Acceptance: March 15th, 2025

ABSTRACT

The research evaluates the sanitary and productive factors in rainbow trout farming centers in Apurímac, Peru, identifying challenges related to infrastructure, sanitary management, and productive practices that affect the sector's sustainability. The centers use systems such as concrete ponds and floating cages but show inconsistencies in monitoring critical parameters, such as pH (70%) and stocking density (76.7%), while disinfection practices (93.3%), pest control (46.7%), and dead animal disposal lack standardization, increasing sanitary risks. Regarding feeding, 96.7% of producers use commercial balanced feeds, although deficiencies persist in feed conversion ratio calculation (80%), impacting efficiency. Mortality rates, higher in early stages and during the rainy season, reach up to 40% in fry and 20% in juveniles, associated with water quality, fry origin, and environmental management. Through statistical analyses, the study highlights the importance of implementing standardized sanitary protocols and strengthening technical training for producers to reduce mortality and optimize production. Additionally, improving infrastructure, as 30% of centers use materials like adobe, and environmental management is recommended to mitigate risks associated with diseases and climatic fluctuations. The study underscores the need for integrated policies that promote sustainable practices, reduce environmental impact, and enhance sector competitiveness, ensuring its contribution to food security and economic development in vulnerable rural communities. These findings provide a foundation for implementing strategies to increase productive efficiency and guarantee more equitable and sustainable aquaculture development in the region.

KEYWORDS: Sustainability. Biosecurity. Feeding. Mortality. Infrastructure.

RESUMO

A pesquisa avalia os fatores sanitários e produtivos em centros de criação de truta arco-íris em Apurímac, Peru, identificando desafios relacionados à infraestrutura, manejo sanitário e práticas produtivas que afetam a sustentabilidade do setor. Os centros utilizam sistemas como tanques de concreto e gaiolas flutuantes, mas apresentam inconsistências no monitoramento de parâmetros críticos, como o pH (70%) e a densidade de cultivo (76,7%), enquanto as práticas de desinfecção (93,3%), controle de pragas (46,7%) e descarte de animais mortos carecem de padronização, aumentando os riscos sanitários. Em relação à alimentação, 96,7% utilizam rações balanceadas comerciais, embora persistam deficiências no cálculo da conversão alimentar (80%), afetando a eficiência. As taxas de mortalidade, mais altas nas fases iniciais e durante o período de chuvas, atingem até 40% em alevinos e 20% em juvenis, estando associadas à qualidade da água, à origem dos alevinos e ao manejo ambiental. Por meio de análises estatísticas, destaca-se a relevância de implementar protocolos sanitários padronizados e fortalecer a capacitação técnica dos produtores para reduzir a mortalidade e otimizar a produção. Além disso, recomenda-se a melhoria da infraestrutura, considerando que 30% utilizam materiais como adobe, e do manejo ambiental para mitigar os riscos associados a doenças e flutuações climáticas. O estudo ressalta a necessidade de políticas integradas que promovam práticas sustentáveis, reduzam o impacto ambiental e fortaleçam a competitividade do setor, garantindo sua contribuição para a segurança alimentar e o desenvolvimento econômico em comunidades rurais vulneráveis. Esses achados fornecem uma base para implementar estratégias que aumentem a eficiência produtiva e garantam um desenvolvimento aquícola mais equitativo e sustentável na região.

PALAVRAS-CHAVE: Sustentabilidade. Biosegurança. Alimentação. Mortalidade. Infraestrutura.

INTRODUCTION

In Peru, continental aquaculture represents 80% of the fish destined for consumption, with rainbow trout (*Oncorhynchus mykiss*) being the primary cultivated resource (PRODUCE 2023). This activity is concentrated in the high Andean regions, where environmental conditions and the availability of lentic water bodies favor its development. Trout is not only a key source of protein for rural communities, but it also helps combat chronic malnutrition, which affects 31.2% of the population in these impoverished areas (FLOREZ & ROLDÁN 2021).

However, the growth of trout production in the Apurímac region has been uneven, and fish farms face significant sanitary and structural challenges. A study in the province of Abancay evaluated 35 fish farms, revealing that despite 80% using river water, the vast majority do not perform basic monitoring such as water quality (82.9%) or trout density (54.3%). Additionally, 91.4% of the fish farms report higher mortality during the rainy season, suggesting a lack of control over critical sanitary factors. Water quality, particularly pH, was found to be linked to factors such as cleaning methods and the shape of the ponds, indicating the importance of monitoring these parameters to improve fish health and reduce mortality (COAQUIRA 2019).

Furthermore, a cluster study in the same province found that the profitability of fish farms is directly related to the producers experience, the water source, and the market they have access to. The research identified four groups of producers: from small fish farmers to extensive systems for self-consumption. These results highlight the variability in knowledge levels and technical management among fish farmers, which impacts the efficiency and economic sustainability of production (ANCCO et al. 2023).

One of the main sanitary challenges for trout producers in Apurímac is bacterial diseases, mainly those caused by Gram-negative bacteria, which have a high prevalence in intensive systems. These infections not only result in economic losses but also increase the dependence on the use of antimicrobials. In salmonid aquaculture, up to 20 times more antimicrobials are used than in human medicine, which poses serious environmental risks and requires the implementation of stricter control measures to comply with sanitary regulations (MILLANAO et al. 2011).

Aquaculture production in Apurímac reaches 323.7 tons per year (PRODUCE 2024); however, deficiencies in breeding techniques and sanitary control hinder productive efficiency and drive up costs. The high mortality rates, especially during the fingerling stage, increase operational expenses and weaken the sector's competitiveness, restricting access to quality trout products for vulnerable families (ZÁRATE et al. 2018).

The objective of this study is to analyze the sanitary indicators in the farming of rainbow trout in the authorized production centers of Apurímac, identifying the critical factors that influence fish mortality and evaluating the management practices implemented by the producers. Based on this analysis, the aim is to propose improvements that optimize productive efficiency and minimize the sanitary risks associated with intensive trout aquaculture in the region.

MATERIAL AND METHODS

Sampling strategy and sample size determination.

For this observational and descriptive cross-sectional study, a sampling strategy was adopted based on the review of the fish production centers benefiting from the National Program for Innovation in Fisheries and Aquaculture (PNIPA) in five provinces of the Apurímac department, Peru. The inclusion criteria considered fish farms in the Limited Resource Aquaculture (AREL) and Micro and Small Aquaculture Enterprises (AMYPE) categories, which operate under floating cage or pond systems and had projects executed between 2018 and 2021. Fish farms without aquaculture authorization issued by the Regional Directorate of Production Apurímac (DIREPRO) were excluded.

The sampling formula for proportions in known populations was used $(N * Z^2 * p * q)/(E^2 * (N-1) + Z^2 * p * q)$, where N= 37, p=0.5 (estimated proportion), Z=1.96 (95% confidence level), and E=0.08 (margin of error).

Although the initial goal was to survey all 37 centers, some declined to participate due to time limitations, a common circumstance in field studies. However, the obtained sample, which covers 81% of the population, is sufficiently representative and shows no significant bias, as the centers that did not participate do not differ in key characteristics. Therefore, the results are reliable and provide a valid insight into the sanitary situation of trout production in the region.Two types of surveys were developed, each specific to the production system (ponds and floating cages), focusing on the evaluation of sanitary indicators and potential risks.

Materials Used

Two types of questionnaires were used. In the production centers with floating cages, the questionnaire focused on both the infrastructure and the sanitary status of the trout, evaluating key aspects such as cage construction, durability, accessibility, production capacity, and maintenance measures. Water quality was also reviewed, considering dissolved oxygen concentration, temperature, and pH, as well as signs of diseases and biosecurity practices. In centers using ponds, a similar structure was followed, but adapted to the characteristics of these systems. Regarding infrastructure, pond construction, maintenance, and production capacity in terms of trout density were analyzed. Water parameters, such as temperature and oxygen, were also evaluated, along with disease management, waste, and biosecurity. In both cases, nutritional management was assessed, addressing types of food, feeding frequency, and their impact on fish health. These questionnaires achieved a reliability of 72.3% and 71.5%, respectively, according to the Cronbach's Alpha test, and were validated by a panel of aquaculture experts, ensuring the relevance and accuracy of the collected data.

Data Collection

Visits were made to 30 rainbow trout production centers, where direct information was collected through observation and interviews with the managers of each center. During the visits, relevant data on sanitary and productive conditions were recorded through on-site measurements, such as water quality (temperature, dissolved oxygen, and pH). Additionally, the interviews provided details on management practices, feeding, and disease control. All the information was systematized and stored in a database for subsequent statistical analysis.

Data processing and analysis

The collected data were entered and organized in a database using Excel 2021. Statistical analyses were conducted using the 'R' software, where descriptive analyses were performed to assess the main sanitary and management indicators in rainbow trout production centers. Subsequently, the Chi-square test was applied to examine associations between variables, considering fish mortality as the primary dependent variable. A p-value of < 0.05 was considered statistically significant.

RESULTS

Demographic characteristics of the aquaculture production centers benefiting from the PNIPA in Apurímac (2018 - 2021).

The results (table 1) show that the majority of aquaculture centers benefiting from the PNIPA come from the province of Abancay (36.7%), indicating a significant concentration in this area, possibly due to better environmental conditions and infrastructure. Chincheros (20%), Aymaraes (16.7%), and Andahuaylas (13.3%) also have notable representation, while Grau (10%) and Cotabambas (3.3%) have a smaller share in aquaculture production. Regarding the age of the producers, the majority group is between 31 and 40 years old (43.3%), followed by the 41 to 50-year-old group (30%), suggesting that aquaculture in Apurímac is in the hands of experienced individuals in their productive age. Only 6.7% of the producers are between 25 and 30 years old, reflecting a low participation of young people, which could pose a challenge for generational renewal in the sector. Regarding gender, 92.9% of the respondents are men, indicating a low female participation in trout production.

Table 1. Distribution of aquaculture production centers benefiting from the PNIPA by province, age group, and gender (n=30).

Dimension	Strata	Frequency (%)
Province	Abancay	11 (36.7%)
	Andahuaylas	4 (13.3%)
	Aymaraes	5 (16.7%)
	Chincheros	6 (20.0%)
	Cotabambas	1 (3.3%)
	Grau	3 (10.0%)
Age group	People aged 25-30 years	2 (6.7%)
	People aged 31-40 years	13 (43.3%)
	People aged 41-50 years	9 (30.0%)
	People older than 51 years	6 (20.0%)
Gender	Male	28 (92.9%)
	Female	2 (7.1%)

Characteristics of the water resource and production systems in aquaculture centers benefiting from the PNIPA.

In Table 2, we can observe the analysis of the data regarding the type of water resource used in the aquaculture centers benefiting from the PNIPA. It reveals that the majority of the facilities use water from lagoons (36.7%), followed by rivers (33.3%) and springs (30%), reflecting diversity in water sources. Regarding the origin of the water resource, 68.4% comes from primary sources, while 31.6% shares water from other users within 5 km. Concerning shared water use, 72.7% of the centers are the only ones in their area, while 27.3% share the resource with up to three additional centers. In terms of the frequency of mesh replacement in floating cages, 54.6% do it biweekly, reflecting relatively consistent management, while 27.3% do it by campaign. The majority of floating cages used are commercial modules (81.8%), indicating a preference for more standardized technologies. Regarding the material of the production ponds, concrete predominates (47.4%), followed by combinations of masonry and earth, which shows variety in the infrastructure used in the region's aquaculture.

Table 2. Distribution of water resource types, origin, shared use, and characteristics of the rainbow trout production systems benefiting from PNIPA in Ponds (P) and Floating Cages (FC).

Dimension	Type	Frequency (%)
Water resource (n=30)	Lagoon	11 (36.7%)
	Rivers	10 (33.3%)
	Spring	9 (30.0%)
(E) Source of water resource (n=19)	First use	13 (68.4%)
	Shared use within 5 km	6 (31.6%)
(JF) Shares water resource (n=11)	No	8 (78.7%)
	With 1 production center	1 (9.1%)
	With 2 production centers	1 (9.1%)
	With 3 production centers	1 (9.1%)
(JF) Mesh replacement frequency (n=11)	Biweekly	6 (54.6%)
	Monthly	2 (18.2%)
	Per campaign	3 (27.3%)
(JF) Type of floating cages (n=11)	Commercial modules	9 (81.8%)
	Artisan	2 (18.2%)
(E) Pond material type (n=19)	Concrete	9 (47.4%)
	Concrete, Masonry	3 (15.8%)
	Concrete, Soil	2 (10.5%)
	Masonry	2 (10.5%)
	Concrete, Geomembrane	1 (5.3%)
	Concrete, Soil, Masonry	1 (5.3%)
	Geomembrane	1 (5.3%)

Analysis of Operational Characteristics and Training in Aquaculture Centers Beneficiaries of the PNIPA in Apurímac.

The analysis of Table 3 reveals that most of the aquaculture centers benefiting from the PNIPA in Apurímac have been involved in the activity for three to five years (36.7%), while only 6.7% have more than 10 years of experience. Regarding economic dependence, 60% of respondents combine trout farming with other activities, while

40% rely exclusively on trout farming. Additionally, the majority of centers (73.3%) are small-scale operations (AREL), producing less than 3.5 metric tons (MT), and the main activity is fattening (63.3%). Regarding the time dedicated to aquaculture, 50% dedicate two to four hours per day, and only 6.7% work more than 7 hours. Additionally, 53.3% do not have non-family workers, and those who do employ workers (46.7%) mostly employ between one and three people (63.3%). A concerning aspect is that 96.7% of centers do not have SANIPES sanitary authorization, which could impact the quality and safety of production. Most of the fingerlings come from local sources (36.7%), while only 10% produce them in-house. Most respondents receive monthly training (53.3%), although 10% have only annual training. Finally, only 3.3% have a specialized professional, and 26.7% follow a set of Good Aquaculture Practices (BPA), while 10% implement a more comprehensive set of health and protocol plans.

Table 3. Characteristics of Aquaculture Activity in PNIPA Beneficiary Centers in Apurímac.

Variable	Strata	Frequency (%)
Time Developing Aquaculture Activity (n=30)	1-3 years	9 (30.0%)
	3-5 years	11 (36.7%)
	5-10 years	8 (26.7%)
	More than 10 years	2 (6.7%)
Economic Dependency (n=30)	Trout farming and other activities	18 (60.0%)
	Exclusively trout farming	12 (40.0%)
Production Level (n=30)	AREL (<= 3.5 TM)	22 (73.3%)
	AMYPE (>3.5 - 150 TM)	8 (26.7%)
Production Type (n=30)	Fattening	19 (63.3%)
	Hatchery	11 (36.7%)
Hours Per Day Dedicated to Aquaculture Activity (n=30)	2-4 hours	15 (50.0%)
	4-6 hours	13 (43.0%)
	More than 7 hours	2 (6.7%)
Has Non-Family Workers (n=30)	No	16 (53.3%)
	Yes	14 (46.7%)
Number of Employees (n=30)	1-3	19 (63.3%)
	3-5	2 (6.7%)
	More than 10	2 (6.7%)
	Did not respond	7 (23.3%)
Has SANIPES Health Certification (n=30)	No	29 (96.7%)
	Yes	1 (3.3%)
Source of Fry (n=30)	Local	11 (36.7%)
	Provincial	8 (26.7%)
	Regional	8 (26.7%)
	Own production	3 (3.3%)
Frequency of Technical Training (n=30)	Annual	3 (3.3%)
	Semi-annual	8 (26.7%)
	Monthly	16 (53.3%)
	Weekly and monthly	1 (3.3%)
	Bi-weekly	1 (3.3%)

Characteristics of Aquaculture Production in PNIPA Beneficiary Centers

The analysis of Table 4 reveals that the majority of PNIPA beneficiary aquaculture centers in Apurímac carry out two campaigns per year, representing 70% of the sample, indicating high production activity in these centers. Additionally, the average market weight of the trout is concentrated at 250 grams, with 70% of respondents achieving this category, suggesting a preference or established market standard. Regarding the duration of the campaigns, most (40%) last six months, while 36.67% extend to seven months, indicating that producers are optimizing their farming cycles to maximize production. Overall, these results show a structured and efficient approach in the aquaculture operations of the region.

Table 4. Analysis of production cycles, market weight, and trout production duration in aquaculture centers (n=30).

Variable	Strata	Frequency (%)
Number of campaigns per year	1 campaign	5 (16.7%)
	2 campaign	21 (70.0%)
	3 campaign	3 (10.0%)
	More than 3 campaigns	1 (3.3%)
Average commercial weight of trout	250g (4 per kilo)	21 (70.0%)
	200g (5 per kilo)	9 (30.0%)
Average number of months per campaign	5	3 (10.0%)
	6	12 (40.0%)
	7	11 (36.7%)
	8	3 (10.0%)
	9	1 (3.3%)

Evaluation of monitoring practices of environmental parameters, selection, disinfection, pest control, and disposal of dead animals in Aquaculture Centers in Apurímac.

The analysis of management practices in the aquaculture centers benefiting from the PNIPA shows good practices in monitoring water quality parameters, with 100% measuring temperature and 83.3% measuring dissolved oxygen. However, only 70% monitor pH, which could indicate areas for improvement. The stocking density is controlled by 76.7% of the centers, while 23.3% do not, which could impact the health and performance of the fish. Regarding selection, most centers perform it every 30 days. Disinfection practices are common (93.3%), but the frequency varies, with disinfection mainly occurring by campaign. Pest control is less frequent, with 53.3% of centers not performing it. Finally, the disposal of dead animals is mostly carried out in septic pits, although a small percentage do not take any action, which could pose a health risk (Table 5).

Characteristics of the type of feed, storage, and feeding frequency in different fish production stages

In the aquaculture centers benefiting from PNIPA, almost all producers (96.7%) use commercial balanced feed for feeding their fish, while only 3.3% supplement with homemade feed, reflecting a strong dependence on commercial feed. Most store the feed in facilities made of durable materials (56.7%), although a significant percentage (30%) stores it in adobe warehouses, which could affect the feed quality due to less protection from environmental factors. Regarding feed management, 90% calculate biomass to adjust feeding, and 80% calculate the feed conversion ratio, demonstrating a technical approach to feeding. Regarding daily rations, most producers provide three to four feedings per day for both fry and juveniles, indicating proper management at these stages. However, for the finishing phase, the majority provide two to three feedings per day, adjusting to the fish's needs in this final growth phase (table 6).

Table 5. Sanitary management and monitoring practices in aquaculture centers benefiting from PNIPA.

Variable	Strata	Frequency (%)
Measure dissolved oxygen (n=30)	Yes	25 (83.3%)
Measure pH (n=30)	Yes	21 (70.0%)
Measure temperature (n=30)	Yes	30 (100.0%)
Measure stocking density (n=30)	Yes	23 (76.7%)
Frequency of selection (days) (n=30)	15	7 (23.3%)
	20	2 (6.7%)
	30	18 (60.0%)
	90	2 (6.7%
	Does not perform	1 (3.3%)
Disinfection performed (n=30)	Yes	28 (93.3%)
Frequency of disinfection (n=30)	Weekly	1 (3.3%)
	Bi-weekly	5 (16.7%)
	Monthly	8 (26.7%)
	Quarterly	3 (10.0%)
	By campaign	11 (36.7%)
	No specification	1 (3.3%)
	No response	1 (3.3%)
Pest control frequency (n=30)	Weekly	2 (6.7%)
	Bi-weekly	1 (3.3%)
	Monthly	2 (6.7%)
	Quarterly	5 (16.7%)
	Semi-annually	3 (10.0%)
	Annually	1 (3.3%)
	Does not perform	16 (53.3%)
Disposal of dead animals (n=30)	Septic pit	18 (60.0%)
	Trash can	5 (16.7%)
	Burial	2 (6.7%)
	Ensiling	1 (3.3%)
	"No mortality"	1 (3.3%)
	Does not perform any action	2 (6.7%)
	No response	1 (3.3%)

Table 6. Feed management and storage in PNIPA beneficiary aquaculture centers.

Variable	Strata	Frequency (%)
Type of feed supplied to the fish (n=30)	Balanced	29 (96.7%)
	Balanced with homemade feed	1 (3.3%)
Feed storage location (n=30)	Noble material warehouse	17 (56.7)
	Adobe warehouse	9 (30.0%)
	Geomembrane material warehouse	1 (3.3%)
	Wood warehouse	1 (3.3%)
	House	2 (6.7%)
Calculates biomass for feeding (n=30)	Yes	27 (90.0%)
	No	3 (10.0%)
Calculates feed conversion ratio (n=30)	Yes	24 (80.0%)
	No	6 (20.0%)
Daily feed rations: Fry (n=28)	1-2	3 (10.7%)
	2-3	2 (7.1%)
	3-4	12 (42.9%)
	> 4	11 (39.3%)
Daily feed rations: Juveniles (n=29)	1-2	3 (10.3%)
	2-3	15 (51.7%)
	3-4	11 (37.9%)
Daily feed rations: Finished (n=29)	1-2	10 (34.5%)
	2-3	17 (58.6%)
	3 – 4	1 (3.5%)
	> 4	1 (3.5%)

Mortality rates in fry, juveniles, and fish in the finishing stage during rainy and dry periods in PNIPA beneficiary aquaculture centers.

Table 7 shows a general trend of low mortality rates (1-5%) across different production stages during both rainy and dry periods. However, during the rainy season, it is observed that fry and juveniles experience a slight increase in mortality compared to the finishing stage, which may suggest greater susceptibility during these early phases. During the dry periods, mortality remains mostly low, but there is greater variability in mortality rates, especially in juveniles, indicating potential challenges in managing extreme environmental conditions, such as water scarcity or high temperatures. These fluctuations could be related to the handling capacity and the available water resource conditions at each aquaculture center.

Table 7. Mortality in different fish development stages during rainy and dry periods.

Variable	Strata	Frequency (%)
Type of feed supplied to the fish (n=30)	Balanced	29 (96.7%)
	Balanced with homemade feed	1 (3.3%)
Feed storage location (n=30)	Noble material warehouse	17 (56.7)
	Adobe warehouse	9 (30.0%)
	Geomembrane material warehouse	1 (3.3%)
	Wood warehouse	1 (3.3%)
	House	2 (6.7%)
Calculates biomass for feeding (n=30)	Yes	27 (90.0%)
	No	3 (10.0%)
Calculates feed conversion ratio (n=30)	Yes	24 (80.0%)
	No	6 (20.0%)
Daily feed rations: Fry (n=28)	1-2	3 (10.7%)
	2-3	2 (7.1%)
	3-4	12 (42.9%)
	> 4	11 (39.3%)
Daily feed rations: Juveniles (n=29)	1-2	3 (10.3%)
	2-3	15 (51.7%)
	3-4	11 (37.9%)
Daily feed rations: Finished (n=29)	1-2	10 (34.5%)
	2-3	17 (58.6%)
	3 – 4	1 (3.5%)
	> 4	1 (3.5%)

Evaluation of sanitary services and disease management in Aquaculture Production Centers beneficiaries of the PNIPA.

Table 8 reveals that 70% of aquaculture centers receive sanitary advice from public or private institutions, while 30% operate without this type of technical support, which may limit their capacity to manage disease outbreaks effectively. Sixty percent of the centers reported the presence of diseases, with fungal infections, particularly saprolegniosis, being the most common at 50%. In 36.7% of the cases, no specific diagnosis was made, and only 3.3% relied on laboratory analysis, indicating limited diagnostic capacity and a strong dependence on empirical or informal methods. Although 96.2% of the affected centers reported having implemented treatments, the responsibility for these actions varied among veterinarians (37.5%), producers (29.2%)

and different types of engineers, suggesting a lack of standardization in therapeutic protocols.

Table 8. Sanitary evaluation and disease management in rainbow trout production centers beneficiaries of the PNIPA.

Variable	Strata	Freq.	Percentage (%)
Sanitary advice by public and/or private institutions (n=30)	Yes	21	70
	No	9	30
Presence of disease (n=30)	Yes	18	60
	No	12	40
Disease diagnosis (n=30)	Public institutions	6	20
	Field test	5	16.7
	Producers/friends	4	13.3
	Field test and Producers/friends	2	6.7
	Laboratory	1	3.3
	No significant disease suspicion events	1	3.3
Type of disease identified (n=22)	Not performed	11	36.7
	Fungi (saprolegniosis)	11	50
	Red mouth (*Yersinia ruckeri*)	2	9.1
	Furunculosis (*Aeromona salmonicida*)	1	4.6
	Fry disease (*Flavobacterium psychrophilum*)	3	13.6
	Furunculosis and Fungi (*saprolegniosis*)	1	4.6
	Red mouth, Furunculosis, and Fungi	1	4.6
	Red mouth and Fungi	1	4.6
	Red mouth, Furunculosis, Fungi, and Fry disease	1	4.6
Perform treatments (n=26)	Yes	25	96.2
	No	1	3.9
Responsible for treatment (n=24)	Veterinarian	9	37.5
	Producers	7	29.2
	Fisheries engineer	3	12.5
	Owner and Veterinarian	1	4.2
	Aquaculture engineer	1	4.2
	Fisheries engineer and Producers	1	4.2
	Veterinarian and Producers	1	4.2

Analysis of key factors in production and mortality in aquaculture centers: a statistical approach.

The analysis of Table 9 shows that factors such as the type of production, time spent in aquaculture activities, and economic dependency are significantly associated with production levels, suggesting that these aspects directly influence the performance of the centers. Regarding mortality, variables like fry origin, dissolved oxygen measurement, pH, stocking density, disinfection practices, disease presence, biomass calculation, and feed conversion ratio are significantly associated with higher fish survival, highlighting the importance of controlling these parameters in aquaculture management. However, other factors such as the number of annual campaigns, cleaning practices, and climate type do not show a statistically significant influence, indicating that their impact on mortality is minimal or indirect.

Table 9. Relationship between production and mortality factors in aquaculture centers.

Variables	Factors	Chi-Square (p-Value)
Production	Type of production	0.0354
	Time spent in aquaculture activity	0.0248
	Economic dependency	0.0016
	Employs workers outside the family unit	0.7852
Mortalidade	Origin of fry	0.0126
	Number of campaigns per year	0.1684
	Average duration of campaigns (in months)	0.0590
	Measures dissolved oxygen	0.0023
	Measures pH	0.00003
	Measures stocking density	0.0017
	Performs cleaning	0.7151
	Performs disinfection	0.0017
	Presence of diseases	0.0035
	Calculates biomass for feeding	0.000000202
	Calculates feed conversion ratio	0.00000002408
	Diagnoses diseases	0.5392
	Administers treatments	0.8684
	Climate type	0.7999

DISCUSSION

Between 2018 and 2021, PNIPA supported aquaculture centers in Apurímac, focusing on rainbow trout production. The demographic characteristics of producers, such as age, educational level, and experience, influenced the adoption of innovations and productive efficiency. These variables are key to evaluating the impact of the program's interventions.

The demographic results of the aquaculture production centers supported by PNIPA in Apurímac highlight important trends in the geographic distribution, age, and gender of producers. The higher concentration of centers in Abancay (36.7%) could be influenced by factors such as access to infrastructure and water resources, aligning with observations by ANCCO et al. (2023) regarding the importance of environmental factors in aquaculture development. In contrast, the low representation in Cotabambas (3.3%) suggests logistical barriers similar to those identified by ZÁRATE et al. (2018). The predominance of the 31–40 age group (43.3%) indicates a mature and experienced producer population, critical for the sector's sustainability, as noted by COAQUIRA (2019). However, the low participation of younger individuals highlights a significant challenge for generational succession. The limited involvement of younger people in aquaculture could hinder the long-term development of the sector, as it may lead to an aging workforce with fewer skills transfer opportunities. This challenge requires urgent attention to ensure the next generation's engagement through targeted policies, training, and access to funding opportunities.

Moreover, the significant gender disparity, with 92.9% male participation, underscores the underrepresentation of women in aquaculture, reflecting patterns similar to those documented by CARDENAS (2024) This disparity suggests that gender roles may limit women's involvement in the industry, which is consistent with findings by BENET (2019) and ARENAS & PINEDA (2024), who argue that aquaculture remains a male-dominated field in many regions. To overcome these barriers, it is essential to implement inclusive policies that provide women with access to training, financial resources, and leadership roles within the sector. Empowering women through education and policy reform could be transformative for aquaculture, fostering a more equitable and diverse industry. These results underscore the urgency of addressing geographic, gender, and generational disparities to promote a more inclusive, sustainable, and equitable development of aquaculture in the region (BRUGERE et al. 2023).

In aquaculture centers in Apurímac, environmental monitoring and management practices demonstrate a high commitment to managing critical parameters for aquaculture production but also highlight areas for improvement. Most centers monitor essential parameters such as temperature (100%) and dissolved oxygen (83.3%), reflecting awareness of their importance for trout health, aligning with studies like CARDENAS (2024), which emphasizes the influence of these variables on growth and survival rates. However, pH measurement and stocking density monitoring are less consistent (70.0% and 76.7%, respectively), potentially indicating a lack of standardization in monitoring protocols a weakness also noted by CARDOZO et al. (2024) in rural aquaculture systems. Regarding selection and disinfection, there is a trend of performing these practices at regular intervals, with most centers conducting selection every 30 days (60.0%) and disinfection primarily per campaign (36.7%), consistent with recommended sanitary control practices to minimize diseases, as indicated by AHMAD et al. (2021).

Nevertheless, only 53.3% carry out pest control, posing a significant risk to crop biosecurity, as warned by OSBORN & HENRY (2019) in similar contexts. Regarding the disposal of dead animals, 60.0% use septic pits, an appropriate practice for organic waste management. However, the 16.7% that use trash bins and the 6.7% that take no action raise concerns about environmental impact and potential infectious outbreaks (CARDENAS 2024). These findings underscore the need for stricter and more uniform policies in the region to ensure effective environmental and sanitary management in aquaculture, thereby promoting the sector's sustainability (GARLOCK et al. 2024).

The predominant use of commercial feed in aquaculture centers in Apurímac (96.7%) reflects widespread adoption of nutritional practices that optimize rainbow trout growth, aligning with findings by KASIRI et al. (2012) on the importance of commercial feed for productive efficiency. Only one center combines commercial feed with homemade formulations, suggesting a preference for the reliability and nutritional composition of commercial products, as also observed by ZHENG et al. (2023) in similar aquaculture systems.

The storage of feed, predominantly in warehouses made of durable materials (56.7%), indicates a concern for maintaining quality and minimizing contamination. However, the continued use of adobe warehouses (30.0%) and other less secure materials may compromise feed quality, a risk highlighted by HAGAN et al. (2013) and O’MEARA et al. (2020). Additionally, most centers (90.0%) calculate biomass to adjust feeding, reflecting efforts to optimize feed efficiency and reduce costs, aligning with recommendations by CALLET et al. (2017) and MELÉNDEZ (2024). However, only

80.0% calculate the feed conversion ratio, which may indicate a lack of precision in some centers for assessing growth efficiency relative to feed consumption, a weakness also observed by MELÉNDEZ (2024). In terms of feeding frequency, fry are predominantly fed three to four times daily (42.9%), meeting the energy requirements of early growth stages. Feeding frequency tends to decrease during juvenile and finishing stages, focusing on feed efficiency (CARDENAS 2024). This approach aligns with previous studies emphasizing the importance of adjusting feeding frequency to the metabolic needs and developmental stage of fish (CARDINALETTI et al. 2022), These findings highlight variability in feeding practices and the opportunity to standardize criteria to enhance aquaculture productivity in the region (ANCCO et al. 2023).

The mortality rates observed in aquaculture centers in Apurímac exhibit significant variability across different production stages (fry, juveniles, and finishing-stage fish) and climatic periods, reflecting the environment's influence on fish health. During rainy periods, fry mortality is primarily concentrated in low ranges (1–5%, 51.7%) and moderate ranges (5–10%, 31.0%), suggesting adequate management in terms of water quality and environmental conditions. This aligns with COAQUIRA (2019), who noted that proper water management can mitigate the impact of rainfall on the mortality of young fish. For juveniles, mortality remains mostly low (1–5%, 58.6%) during rainy periods, reflecting a less vulnerable phase of trout development. In finishing-stage fish, mortality is even lower (1–5%, 78.6%), likely due to their better adaptation to environmental conditions, as mentioned by (ZÁRATE et al. 2018). However, mortality rates during the dry season reveal a more concerning pattern for fry and juveniles, with increased mortality at higher ranges, particularly for fry (20–40%, 10.7%) and juveniles (10–20%, 13.8%). This suggests that low water availability and high temperatures adversely affect fish survival in these stages.

These findings align with (CRICHIGNO et al. 2021), who reported that dry seasons can induce thermal stress and deteriorate water quality, increasing fish vulnerability. For finishing-stage fish, mortality rates during the dry season (1–5%, 67.9%) remain relatively low, which can be attributed to the greater resilience of adult fish to environmental variations, as observed by (DEL VILLAR-GUERRA et al. 2019)). However, the persistence of mortality rates above 5% in all stages during the dry season underscores the need to improve management strategies. Measures such as better control of water temperature and enhanced water quality management during periods of scarcity are crucial to mitigate the impact of climatic fluctuations on aquaculture production (FIORDELMONDO et al. 2020).

The evaluation of health services and disease management in aquaculture centers benefiting from PNIPA in Apurímac reveals a predominantly organized approach regarding health advice and disease management. Seventy percent of centers receive health advice from public or private institutions, reflecting efforts to enhance health and disease management in productive units. Regarding disease occurrence, 60% of centers report disease events, emphasizing the need for proper diagnoses and treatments.

The most common diagnostic methods include public institutions (20%) and field tests (16.7%), followed by diagnoses performed by producers or through collaboration among peers (13.3%). This indicates a more informal approach in some centers and reliance on social networks for veterinary care. Among reported diseases, fungal infections (saprolegniosis) are the most prevalent, affecting 50% of centers with reported diseases, followed by red mouth disease (*Yersinia ruckeri*) and fry disease (*Flavobacterium psychrophilum*). Although most diseases (96.2%) are treated, the responsibility for treatment primarily falls on veterinarians (37.5%).

Producers also play a significant role (29.2%), highlighting the critical contribution of veterinary professionals in fish health management while showcasing active producer participation in disease control and treatment. This scenario reflects a predominantly informal health management structure, characterized by a high level of collaboration among various actors. Such collaboration could be a key factor in improving disease management and control in aquaculture across the region.

The analysis of key factors in production and mortality in aquaculture centers, using the Chi-squared test, reveals statistically significant relationships between several factors and production, as well as between some of these factors and mortality in the aquaculture centers. Regarding production, factors such as the type of production ($p = 0.0354$), the time spent developing aquaculture activity ($p = 0.0248$), and economic dependence ($p = 0.0016$) show significant relationships, suggesting that these variables have a considerable impact on aquaculture production.

On the other hand, the presence of non-family workers does not show a significant association with production ($p = 0.7852$). In terms of mortality, factors like the origin of the fry ($p = 0.0126$) and environmental parameters such as dissolved oxygen ($p = 0.0023$), pH ($p = 0.00003$), and stocking density ($p = 0.0017$) present significant relationships, indicating that proper control of these factors can have an impact on mortality rates. There is also a significant association between mortality and disinfection ($p = 0.0017$), suggesting that good disinfection practices can reduce mortality in the centers. However, other variables such as the number of campaigns per year ($p = 0.1684$), the average duration of the campaign ($p = 0.0590$), cleaning ($p = 0.7151$), and diagnosis and treatment of diseases ($p = 0.5392$ and $p = 0.8684$, respectively) do not show a statistically significant relationship with mortality.

Finally, the calculation of biomass for feeding ($p = 0.000000202$) and the calculation of the feed conversion ratio ($p = 0.00000002408$) have extremely low p-values, suggesting that these factors are fundamental in proper feed management, which in turn can influence mortality rates. However, the type of climate ($p = 0.7999$) is not significantly associated with mortality in aquaculture centers.

CONCLUSION

The sanitary characteristics of rainbow trout farming in production centers in the department of Apurímac reveal that, although appropriate practices for health management and cultivation condition control have been implemented, there are still certain variabilities in areas such as infrastructure, disease management, and monitoring of critical water quality parameters. While most centers carry out preventive health measures and disease control, areas for improvement were identified, such as the standardization of sanitary procedures and the strengthening of producer training. These aspects are essential to ensure the sustainability and optimization of aquaculture production in the region, as improvements in these areas would help reduce sanitary risks and increase productive efficiency, allowing for more stable and competitive aquaculture development in Apurímac.

In the farming conditions of floating cages and ponds, it is observed that pond cultivation systems constructed with durable materials, such as concrete, offer better maintenance and sanitary control conditions compared to those built with simpler materials, such as adobe or geomembranes. This highlights the importance of improving the infrastructure of aquaculture centers, as a greater investment in these resources could lead to improved fish health conditions and increased productivity.

In the sanitary management of floating cages and ponds, most of the centers implement preventive measures such as cleaning, disinfection, and disease treatment. However, a lack of uniformity in procedures and intervention frequency was identified. The reliance on producers and field diagnoses limits the implementation of more specialized treatments. It is recommended to strengthen training and promote a more structured and systematic approach to aquaculture health management to reduce disease incidence and improve the efficiency of applied treatments.

NOTES

AUTHOR CONTRIBUTIONS

Ivar Zárate, Cristian Zoilo Sánchez, and Paul Anthony Cayllahua contributed to the conceptualization, methodology, and formal analysis of the study. Keyro Alberto Meléndez and Cristian Zoilo Sánchez were responsible for software development and validation. Investigation, resource management, and data curation were carried out by Ivar Zárate, Keyro Alberto Meléndez, and Cristian Zoilo Sánchez. The original draft was prepared by Ivar Zárate, Keyro Alberto Meléndez, and Cristian Zoilo Sánchez, while Keyro Alberto Meléndez and Paul Anthony Cayllahua contributed to the review and editing. Visualization and supervision were managed by Keyro Alberto Meléndez. Project administration was led by Ivar Zárate and Cristian Zoilo Sánchez, with funding acquisition by Ivar Zárate. All authors have read and approved the final version of the manuscript.

FUNDING

This research was supported by a master’s scholarship in Aquatic Health granted to Ivar Zárate by the National Council for Science, Technology and Technological Innovation – CONCYTEC (Peru), through the “Master’s Scholarship Program in Aquatic Health”.

INSTITUTIONAL REVIEW BOARD STATEMENT

Ethical review and approval were not required for this study, as it did not involve experiments with humans or animals.

INFORMED CONSENT STATEMENT

Participants were informed about the voluntary nature of the study prior to survey administration. No personal or identifiable information was collected, so written informed consent was not required. Anonymity and confidentiality of responses were ensured.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

ACKNOWLEDGEMENTS

The authors thank the rainbow trout producers of Apurímac for their collaboration during fieldwork. We also express our gratitude to the National Council for Science, Technology and Technological Innovation – CONCYTEC for granting the scholarship that enabled the development of this research.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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