


Effects of productive integration (*Dormitator latifrons* – *Oryza sativa*) on water quality: Evidence under tropical conditions

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ABSTRACT

The research on water quality and productive performance of an integrated chame-rice system (*Dormitator latifrons* – *Oryza sativa*) was carried out in Calceta, Manabí (Ecuador). It was implemented as a rectangular water-proofed pool (9 × 6 × 1 m; 54 m²), operated with 27 m³ of groundwater and automatic level control. The number of fry was 180 fry (55 g; 16.7 cm) and 273 seedlings (15 cm), with a fish:plant ratio 1:1.52. Water quality was evaluated for 20 weeks using a flag-type sampling design (five points: four corners and center), with biweekly measurements (morning/afternoon) for physicochemical variables using standardized techniques (potentiometry, oximetry, conductimetry, spectrophotometry and volumetry) and for total coliform determinations on a monthly basis using (Petrifilm; MPN/100 mL). A stable aquatic environment compatible with integrated culture was evidenced: slightly alkaline pH (7.82–8.15), temperature (27.65–28.56 °C), dissolved oxygen (7.40–8.81 mg/L), conductivity (1.51–1.55 mS/cm), TDS (803.72–817 mg/L), moderate salinity (972–997 ppm), and turbidity (18.57–21.88 NTU). In contrast, total coliforms showed heterogeneity (21 to >2400 MPN/100 mL). At the production level, survival reached 76.11% (mortality 23.89% concentrated in the first week), with an increase in average weight from 52.53 g to 294.35 g (final biomass 40.33 kg). Rice reached 128.3 cm and produced 4.05 kg, with a vegetable-animal ratio of 0.10. On the other hand, the sludge generated showed high nutrient concentration (NO₃⁻ 390–2170 mg/kg; NO₂⁻ 290–1610 mg/kg; PO₄³⁻ 25,000–50,000 mg/kg). The MANOVA analysis confirmed a dominant temporal control (Month order, p<0.001) and absence of global spatial differences (Point, p=0.313), indicating that the monthly variation determines water quality. Demonstrating that the integrated system showed physicochemical stability during the production cycle and a zootechnical-agricultural performance, this performance evidences an effective use of nutrients within the system, the variability of coliforms and the high load of N and P in sludge indicate that the sediment acts as a biogeochemical reservoir and potential secondary source. therefore, sustainability depends on incorporating solids management and sanitary surveillance as structural components of the model.

Keywords: production system, *Dormitator latifrons*, *Oryza sativa*, water quality, aquaculture sludge.

INTRODUCTION

Population growth and food demand have intensified pressure on water resources, especially in tropical regions where agri-food production depends on shallow water sheets, irrigation, and groundwater sources (UNESCO, 2024). On a global scale, agriculture accounts for approximately 70% of freshwater withdrawals, so

improving water productivity (more production per unit of water) has become a central axis of sustainability and food security (FAO, 2023).

Conventional agriculture and aquaculture have been characterized by high water consumption and the generation of nutrient-rich effluents, which increases pressure on receiving water bodies (Atique et al., 2022). In particular, the discharge of high loads of nutrients and organic

matter alters the physicochemical and biological processes of the system, favoring conditions that increase the risk of eutrophication, stimulate microbial proliferation that degrade water quality (Liu et al., 2024).

Integrated production models emerge as a viable alternative to improve water efficiency and promote internal nutrient recycling (Lindholm-Lehto, 2023). In this context, integrated rice-aquatic organism systems have established themselves as an agro-aquaculture model capable of taking advantage of ecological synergies: the aquatic component can contribute to nutrient cycling and biological control, while rice modifies the microhabitat (shade, shelter, water structure) and favors ecosystem services capable of reducing environmental pressures (e.g., less dependence on inputs) and improving the efficiency of the use of resources, although their performance depends on management and the local context (Costa-Pierce, 1987; Love et al., 2015).

On the tropical Pacific coast, the chame *Dormitator latifrons* is a species of productive interest because of its ecological plasticity, its ability to tolerate environmental fluctuations (including variations in salinity and relatively low oxygen conditions), and its potential for extensive or low-renewal systems (Chang, 1984). In addition, recent evaluations in integrated systems (e.g., small-scale aquaponics) confirm that chame performance is highly dependent on water management and quality, reinforcing the relevance

of studying its behavior in agro-aquaculture arrangements (Martins et al., 2010). Growth and physiological performance are closely linked to planting density and water quality, highlighting the importance of continuous monitoring of environmental parameters (Badillo-Zapata et al., 2022), which favors ecological stability and increases resource use efficiency compared to separate production systems (Maucieri et al., 2018; Somerville et al., 2014).

The physicochemical and biological parameters of the water are key factors that determine the stability of integrated systems and the health of cultured organisms, alterations in these parameters can affect the metabolic processes of fish, the availability of nutrients for plants and the efficiency of biogeochemical cycles, especially those related to nitrogen and phosphorus (Lindholm-Lehto, 2023; Boyd and Tucker, 2012)

In these systems, sludge rich in organic matter and nutrients is generated, which stands out for its high potential for agricultural use, provided that a physicochemical and microbiological characterization is carried out to guarantee its stability and environmental safety. The reuse of these by-products is aligned with the principles of circular economy and sustainability, by transforming waste into useful inputs for agricultural production. (Martins and Hapa, 2020; De Silva and Soto, 2009). In this sense, the present study aims to evaluate in an integrated chame-rice production system (*Dormitator latifrons* – *Oryza*

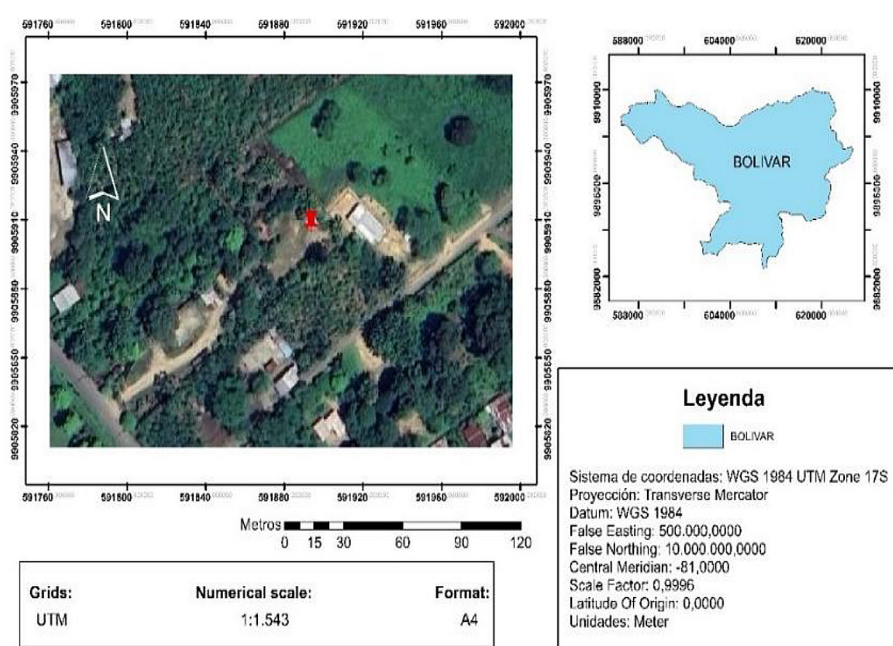


Figure 1. Location of study place

sativa) the effect on the physicochemical and biological parameters of the water, as well as the characterization of the generated sludge to establish its potential for use.

MATERIALS AND METHODS

The research was carried out on an agro-productive farm located in the community “El Corozo” site “El Limón” of the City of Calceta, Canton Bolívar, province of Manabí (Figure 1).

Type of research

The research is applied with a quantitative approach and an analytical descriptive scope, which characterizes the physicochemical and microbiological dynamics of water in an integrated chame-rice system (*Dormitator latifrons* – *Oryza sativa*).

Design of the chame-rice system (*Dormitator latifrons* – *Oryza sativa*)

A rectangular pool-type system was built (Figure 2). The construction of a pool-lagoon type system is aligned with recommended practices for full-life cycle fish breeding ponds, in aquaculture where the depth must be less than approximately ≤ 1.5 in small and medium-sized ponds used for extensive and semi-intensive culture of freshwater species, it also facilitates the penetration of light, gas exchange and water quality management, providing favorable conditions for the growth and survival of cultivated organisms demonstrating ecological stability and integration with agricultural components (Shah et al., 2022).

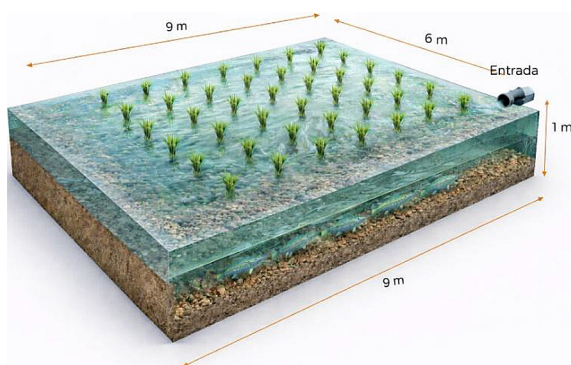


Figure 2. Dimensions of the chame-rice production system (*Dormitator latifrons* – *Oryza sativa*)

Waterproofing of the pool

The delimitation and excavation of the pool was carried out using a hydraulic backhoe to remove the soil and form the rectangular structure, later a polyethylene geomembrane was installed as an impermeable barrier to minimize losses due to infiltration, depending on the edaphic characteristics of the site, in addition, a layer of compacted clay of 0.05 m (5 cm) was placed on the geomembrane. Aimed at reinforcing waterproofing, mechanically protecting the polymeric material and favoring the sealing of microdiscontinuities, increasing the stability of the bottom, this practice is considered a key technical component in the construction of aquaculture ponds (Boyd, 1995).

Implementation of rows for the transplantation of rice seedlings (*Oryza sativa*)

Vertical rows were formed, with a height of 0.35 meters above the base of the system, this type of elevation facilitates the control of the water level and reduces the waterlogging of seedlings (FAO, 2003). The separation between rows of 0.15 meters complies with what was established by Uphoff et al., 2011 where stocking distances with this dimension promote uniform growth, especially in integrated systems where hydraulic management is shared with aquaculture components.

Hydraulic components

The system was supplied by an automated filling mechanism, using a 1 Hp centrifugal pump connected to a groundwater source, to reach an operating volume of 27 m³. The supply was made through a discharge pipe of 1 inch in diameter, which allowed a regulated flow and a controlled contribution of the water resource during the operation of the system (Mercado Bautista et al., 2023).

The water level was monitored by an automatic float-type sensor (generic, switchable horizontal, 110–220 V, IP68), configured to activate the pumping system when the level dropped, mainly due to losses associated with evaporation under local climatic conditions. The implementation of this type of automatic control is recommended in aquaculture and integrated systems, as it allows maintaining stable hydraulic conditions, optimizing the use of water resources, and reducing stress on cultured organisms (FAO, 2017).

Obtaining and handling of specimens (*Dormitator latifrons*) and seedlings of rice (*Oryza sativa*)

Specimens of chame (*Dormitator latifrons*) were acquired in a fish farming area located in Chone-San Antonio, Ecuador, introducing a total of 180 individuals in the juvenile stage, with an average weight of 55 g and an average length of 0.167 m, fry with these biometric characteristics are suitable for integrated systems, as they favor adaptation to the culture environment and reduce initial mortality (Vega et al., 2016). The rice seedlings were obtained by germination in trays, where sp rice seeds were sown and maintained for a period of 21 days until conditions for transplantation were reached, when planting the seedlings presented an average height of 0.15 m and an approximate root length of 0.12 m, incorporating a total of 273 seedlings into the system by the transplant method, recommended technique to ensure uniform establishment and reduce initial crop stress (FAO, 2003).

Mortality rate

The mortality rate of the chames (*Dormitator latifrons*) It was determined to evaluate the response of the organisms to the conditions of the chame – rice system and to the management applied, the number of dead individuals was recorded and related to the initial number of planted organisms, expressed as a percentage, was carried out using the Equation (1) (Núñez, 2025):

$$Survival (\%) = \frac{Nm}{Ni} \times 100 \quad (1)$$

where: Nm – number of individuals killed,
 Ni – initial number of individuals.

Establishment of the dose and type of feeding

The feeding rate was determined from the total biomass of the system, calculated as the product between the number of individuals and the average individual weight ($B = N \times P$). From this estimated biomass, the daily feed ration (R) was obtained by applying a specific feed percentage for each stage of the crop, according to the expression: $R = B \times (\%A / 100)$ (Lovell, 1998).

Establishment of monitoring points

A flag-type sampling design was used to characterize the water quality of the integrated chame-rice system (Figure 3), which consists of taking samples at four points corresponding to the corners of the pond and one point in the central area. This type of sampling identifies the spatial variability of physicochemical parameters in shallow water bodies, where differences associated with hydraulic circulation, edge effects and biological distribution of aquatic organisms may occur (Wetzel and Likens, 2000). The combination of peripheral and central point's allows a representative sample of the system to be obtained, reducing biases derived from spot sampling and improving the reliability of analytical results. This approach is widely recommended for aquaculture ponds and small-scale experimental systems, due to its balance between technical representativeness and operational efficiency (ISO, 2019).



Figure 3. Sampling points in the chame – rice system (*Dormitator latifrons* – *Oryza sativa*)

Frequency of monitoring

The biweekly frequency for physicochemical parameters in the morning and afternoon during the production cycle (20 weeks) identifies critical conditions associated with the minimum daily values of dissolved oxygen and temperature, considered determinants in aquaculture systems (Badiola et al., 2012).

Total coliform analyses monthly allow efficient periodic monitoring of production systems (Niemelä et al., 2003).

The physicochemical parameters were performed using the standard methods for examination water and wastewater methodology (Table 1).

The monitoring of the physicochemical and biological indicators was carried out following internationally recognized standardized methods – Standard Methods for the Examination of Water and Wastewater, validated spectrophotometric procedures for nutrients and nitrogenous compounds, standardized methodologies for turbidity (ISO 7027) and validated commercial procedures for coliform counting (Petrifilm). The selection of techniques (potentiometry for pH; sensors/oximeters for dissolved oxygen; conductimetry for conductivity and total dissolved solids; spectrophotometry for nitrites, phosphates, ammonium and color; and volumetry for chlorides, alkalinity and hardness) responds to criteria of accuracy, reproducibility and widespread use in aquaculture and water monitoring (APHA et al., 2017; ISO, 2016; Lindholm-Lehto, 2023). For microbiological determination, the Petrifilm technique was used,

validated and standardized for coliform counts in environmental matrices (3M, 2018).

Biometrics of chame (*Dormitator latifrons*) and rice seedlings (*Oryza sativa*)

The biometrics of the chames (*Dormitator latifrons*) were performed by measuring the total length with a flexible graduated tape measure for anthropometric use and the individual weight with a precision digital scale type gramera. The capture of the organisms was carried out after the controlled reduction of the pond water level by approximately 60%, which allowed direct handling, with minimal stress induction, guaranteeing the reliability of the final biometric records (Wedemeyer, 1996; Conte, 2004).

Biometric variables of length and weight is a standard practice in aquaculture studies that is a direct indicator of the growth, management efficiency and adaptation of organisms to the culture system. These parameters are widely used to analyze production performance and compare results between different systems and management conditions (Vega et al., 2016).

Physicochemical and biological characterization of the generated sludge to establish the potential for use

Sludge sampling was carried out using five monitoring points distributed under a flag-type design as a reference, which allows representative samples to be obtained in shallow water

Table 1. Physicochemical parameters

| Parameter | Unity | Method |
|-------------------------|------------|-------------------------------------|
| pH | - | Potentiometry |
| Temperature | °C | Sensors integrated in potentiometry |
| Electrical conductivity | mS/cm | Conductimetry |
| Total dissolved solids | mg/L | Conductimetry |
| Dissolved oxygen | mg/L | Oximetry |
| Turbidity | NTU | Spectrophotometry |
| Color | Pt-Co | Spectrophotometry |
| Nitrites | mg/L | Spectrophotometry |
| Phosphates | mg/L | Spectrophotometry |
| Ammonium | mg/L | Spectrophotometry |
| Chlorides | mg/L | Volumetry |
| Alkalinity | mg/L | Volumetry |
| Total hardness | mg/L | Volumetry |
| Total coliforms | MPN/100 ml | Petrifilm method |

bodies and aquaculture systems, where sludge accumulation can vary depending on hydraulic circulation, differential sedimentation and biological activity (Wetzel and Likens, 2000). The collected sludge was analyzed (Table 2) as it is a key indicator to determine the chemical stability, nutritional content and sanitary quality of the material. These parameters are widely used to evaluate the suitability of sludge from aquaculture and agro-aquaculture systems for agricultural reuse or environmentally safe management (USEPA, 2003).

Statistical analysis

MANOVA (Multivariate Analysis of Variance) was used using IBM SPSS (v25), which is part of the general multivariate linear model, and allows to contrast whether the mean vectors of a set of response variables differ between levels of a factor (e.g., Point) and/or in the presence of a covariate (e.g., Mes_orden). Pillai (Pillai's trace) was used as one of the deviations from assumptions (e.g., imperfect multivariate normality, moderate heterogeneity) of primary inference (Finch and French, 2013).

RESULTS

Implementation of the chame – rice system (*Dormitator latifrons* – *Oryza sativa*)

The pool for the small-scale integrated chame-rice system has the following dimensions (9 × 6 × 1 m) and an area of 54 m² to use a volume of water of 27 m³ whose dimensions favor the growth of rice as well as the mobility of the chame (*Dormitator latifrons*). The number of fingerlings with 180 individuals of chame and 273 seedlings of rice allowed a balanced relationship between fish and plant orienting it to the fattening and growth phase, where this relationship facilitates the use of

nutrients generated by the fish, therefore, the use of commercial concentrated feed allows a uniform nutritional contribution for the fish. The seeding ratio was 1:1.5.

The initial biometrics were performed on a total of 180 chame individuals, to characterize the morphometric status of the population at the beginning of production. The organisms had an initial average weight of 55 g and an average total length of 16.70 cm, indicating a relatively homogeneous population in terms of size. The mortality rate was 23.89% and the survival rate was 76.1% (Table 3, Figures 4, 5).



Figure 4. Row construction



Figure 5. Sowing rice (*Oryza Sativa*)

Table 2. Physicochemical parameters of sludge

| Parameter | Unity | Method |
|-------------------------|------------|-------------------|
| pH | - | Potentiometry |
| Electrical conductivity | mS/cm | Conductimetry |
| Nitrites | mg/L | Spectrophotometry |
| Nitrates | mg/L | Spectrophotometry |
| Phosphates | mg/L | Spectrophotometry |
| Total coliforms | MPN/100 mL | Petrifilm method |
| Organic matter | kg/mg | Ignition |

Establishment of the dose and type of feeding

The daily ration was established as a percentage of the live biomass, employing a rate of 4% during the initial phase and 7% in the final phase of culture, a common approach in semi-intensive systems, where feeding rates are adjusted according to fish size, water temperature and natural feed availability, allowing growth to be optimized and waste minimized (El-Sayed, 2006; De Silva and Anderson, 1995) (Table 4).

Chame-rice ratio (*Dormitator latifrons* – *Oryza sativa*)

A chame: rice ratio of 180:273 was established, equivalent to 1:1.52 (or 60:91), which represents

Table 3. Technical data sheet of the chame-rice system (*Dormitator latifrons* – *Oryza sativa*)

| | |
|------------------------|------------------------------|
| Dimensions | 9 × 6 × 1 m |
| Area | 54 m ² |
| Volume | 13.5 m ³ |
| Water source | Well (groundwater) |
| Water volume | 27 m ³ |
| Production phase | Commercial concentrated feed |
| Production destination | Fattening – growth |

Table 4. Percentage of feed dose

| Description | Value |
|--------------------------|--------------------|
| Food: Feedpac protein | 28% |
| Number of chames | 180 |
| Average weight per chame | 55.39 g |
| Dosage | R= 400 g R = 4% |

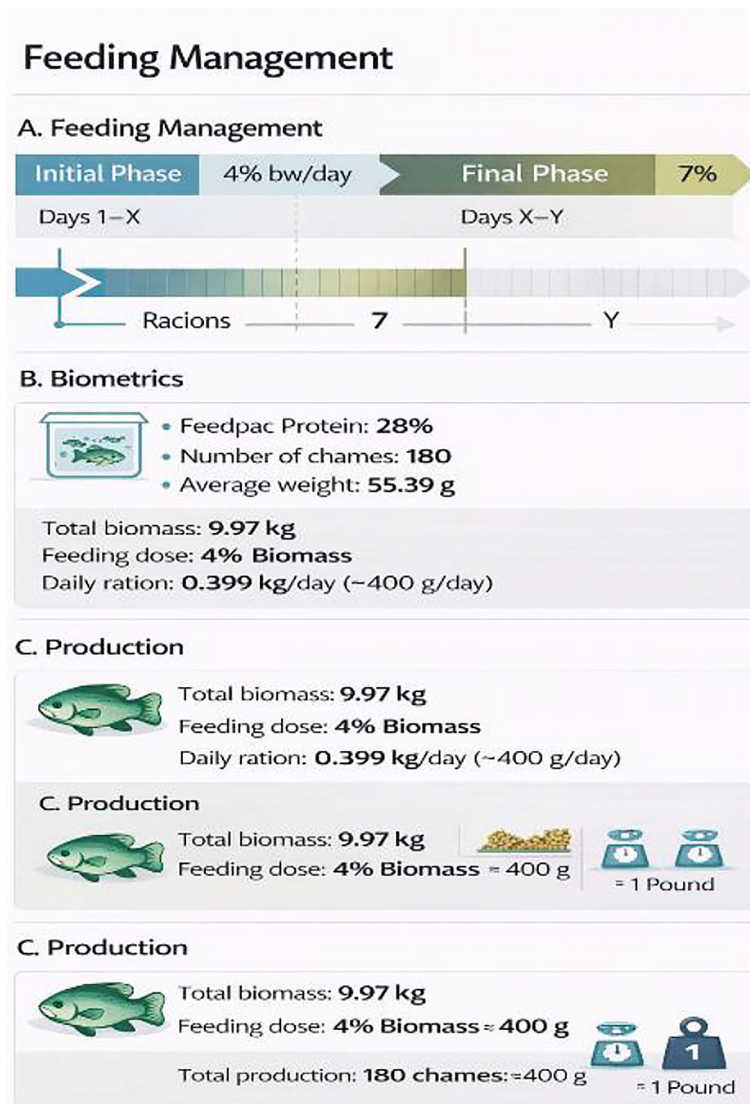


Figure 6. Feeding of chames (*Dormitator latifrons*)

a higher proportion of the vegetable component compared to aquaculture, this favors the development of phytoplankton, periphyton and macroinvertebrates, which can constitute a natural source of food for fish, contributing to the saving of external inputs such as balanced feed; in turn, the fish provides nutrients through excreta that increase organic matter and enrich the water, substrate and rice cultivation (Halwart and Gupta, 2004).

Evolution of physical, chemical and microbiological parameters

pH (hydrogen potential)

Figure 7 shows the variation in pH at five points of the chame–rice system, with values that remained in a slightly alkaline range (7.82–8.15). The pH in the afternoon was higher than in the morning (morning 7.80 < 8.1 afternoon), with increases of 0.21–0.22 units, in addition to increases in points 2 and 3, while the lowest were observed in points 4 and 5. The spatial differences are moderate, indicating a relatively homogeneous pH distribution, the observed range reflecting suitable conditions for the development of *Dormitator latifrons*.

TDS (total dissolved solids)

There is no diurnal/evening variation in total dissolved solids (TDS) at the five points of the chame–rice system, but there is a downward trend with values between 803.72 and 817 mg/L, shown in Figure 8. A stabilization is observed at point 5, with moderate and uniform variations between points, the values indicate a stable salt concentration compatible with integrated extensive aquaculture systems.

Temperature (°C)

Figure 9 shows the distribution of water temperature for the five sampling points, showing a consistent behavior between points, afternoon temperatures were higher (28.37–28.56 °C) compared to morning temperatures (27.65–27.86 °C), stable heat exchange conditions and favorable environmental control are demonstrated, maintaining values within adequate ranges for the physiological development of chame (*Dormitator latifrons*) in integrated systems.

Dissolved oxygen

Figure 10 shows the dynamics of dissolved oxygen (DO), the afternoon records showed higher concentrations (8.46–8.81 mg/l) in contrast to the morning (7.40–7.80 mg/l), indicating an increase in photosynthetic activity during the hours of greatest solar radiation. A moderate variation was observed between points 2 and 5 and a slight decrease in point 4, with no evidence of low oxygen conditions. These DO values remained within optimal ranges for *Dormitator latifrons chames*.

Salinity

Figure 11 shows salinity along the five sampling points of the chame–rice system. The values varied between 972.34 and 996.78 ppm, evidencing a moderate concentration with no differences between the sampling periods, indicating a stable saline condition during the evaluated cycle. Point 5 presented the maximum value, while point 4 registered the lowest concentration, suggesting possible local effects associated with dilution,

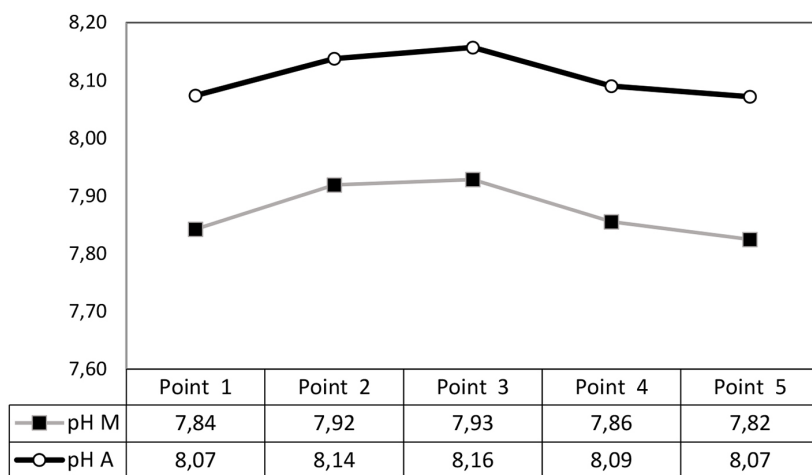


Figure 7. pH behavior morning vs afternoon

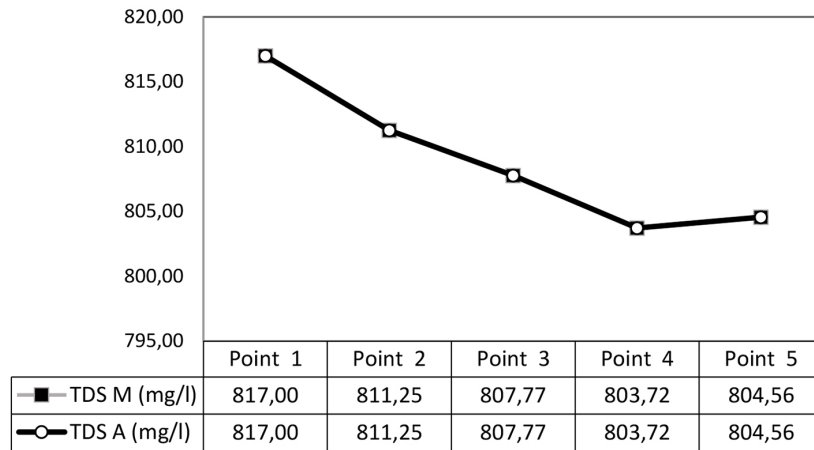


Figure 8. Behavior of the TDS morning vs afternoon

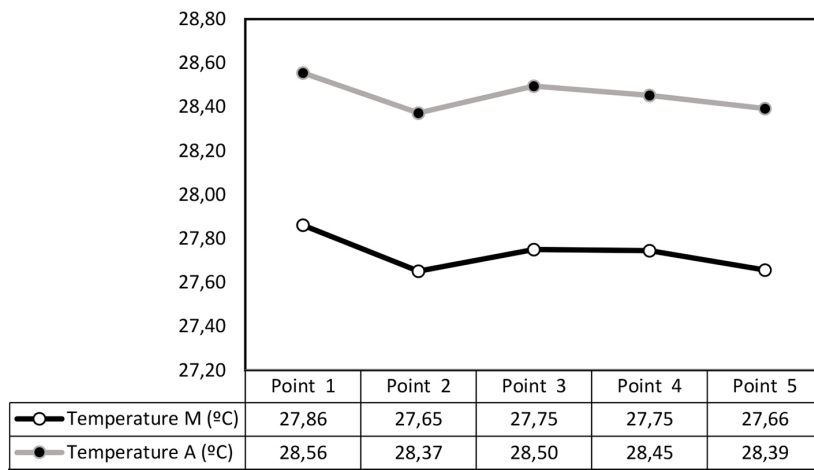


Figure 9. Morning vs afternoon temperature behavior

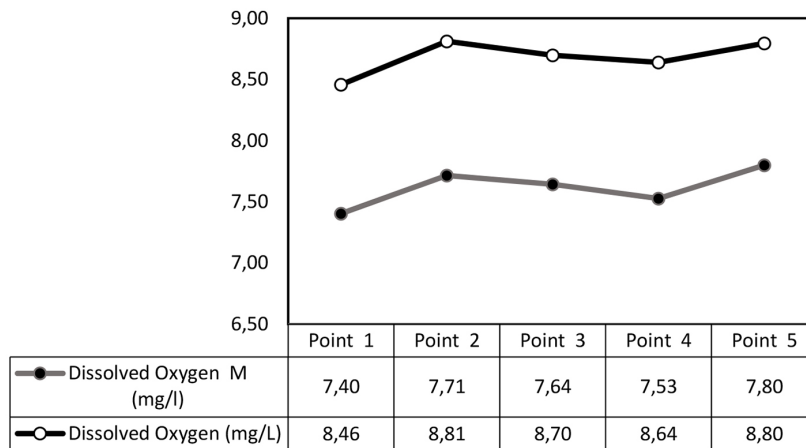


Figure 10. Dissolved oxygen behavior (mg/L) morning vs afternoon

water exchange or micro-dynamics of the system. Overall, salinity remained within ranges compatible and stable with the physiological tolerance of *Dormitator latifrons*.

Conductivity

Figure 12 shows that the electrical conductivity of the water presented a homogeneous spatial

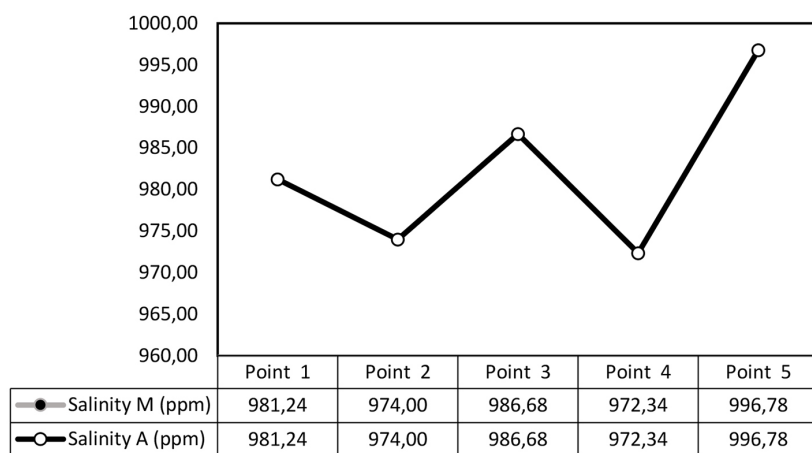


Figure 11. Behavior of the salinity (PPM) of the pool in the morning vs afternoon

distribution at the five points of the chame-rice system, with values between 1.51 and 1.55 mS/cm. A slight increase is recorded at point 5, possibly associated with local accumulation of salts, the general stability between day and afternoon indicates an adequate control of the ion balance, compatible with the physiology of the chame and the sustainability of the integrated system.

Turbidity

Figure 13 shows that the turbidity of the water presented moderate variations between 18.57 and 21.88 NTU at the five points of the chame-rice system, with an increase to point 3 and a slight decrease towards points 4 and 5, the concentration of suspended particles in the central area of the system is high, associated with sediment re-suspension and biological activity; however, the values remained stable and within ranges compatible with extensive aquaculture systems.

Chlorides

Figure 14 shows that the concentration of chlorides showed spatial variations (103–116 mg/L) at the sampling points, with an increase from point 1 to points 2 and 3, a slight decrease at point 4 and a more marked increase at point 5. This behavior reflects a heterogeneous distribution of the chloride ion, the values remained within normal ranges for freshwater aquaculture systems, with no changes in the day and evening schedules.

Alkalinity

Figure 15 shows a progressive increase in total alkalinity without variations between monitoring schedules, with values between 588 and 970 mg/L as CaCO₃ from point 1 to point 5, the regulatory capacity at the end points of the system, favoring pH stability in the face of biogeochemical processes.

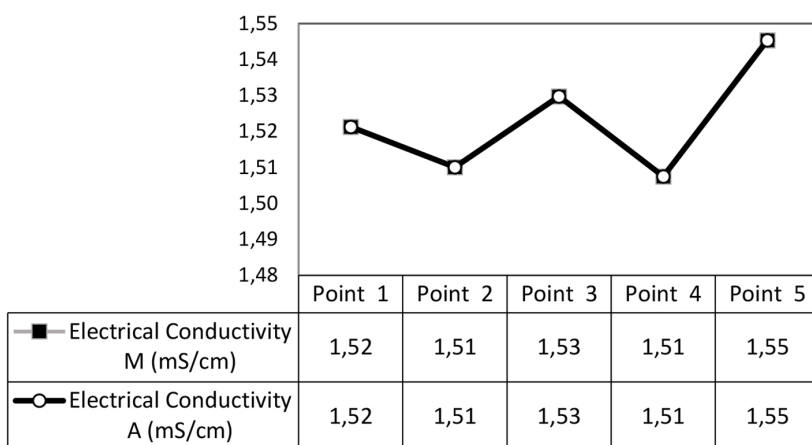


Figure 12. Average conductivity (mS/cm) in the system

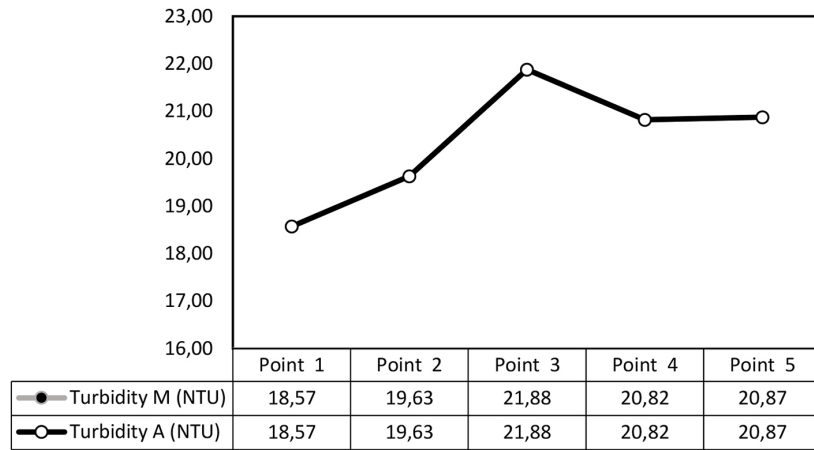


Figure 13. Average turbidity behavior (NTU) of the system

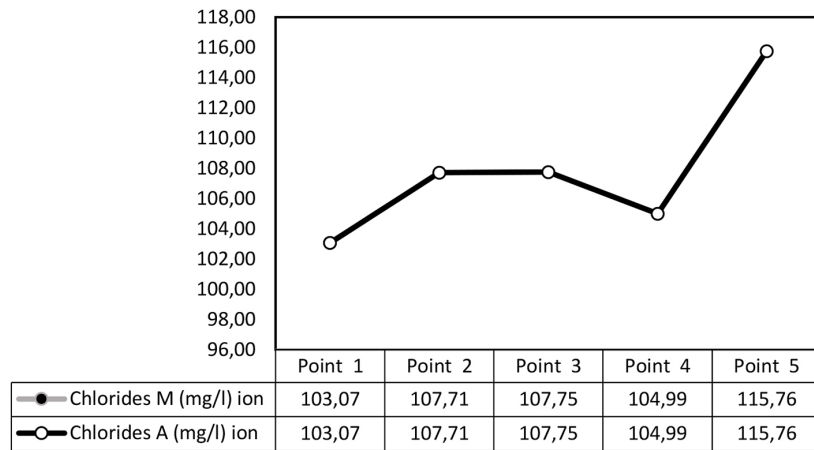


Figure 14. Chloride behavior (mg/L) in the morning vs afternoon system

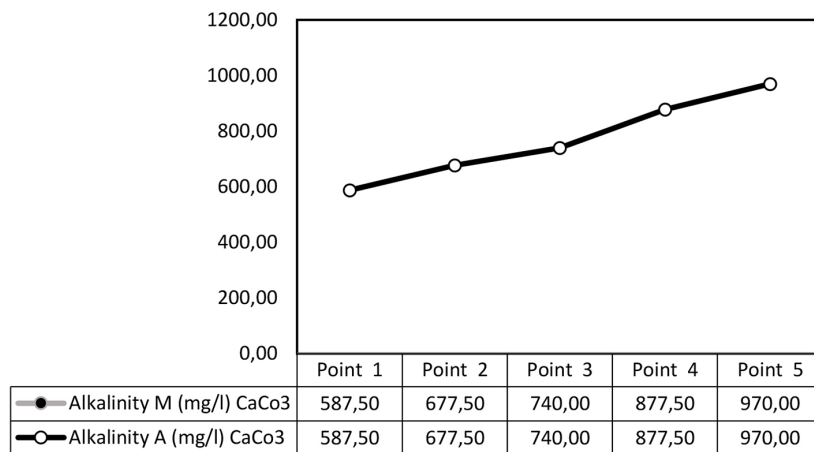


Figure 15. Behavior of CaCO₃ alkalinity (mg/L) in the morning vs. afternoon

Color

In Figure 16, no changes in the color of the water in the system are observed between the

daytime schedule, but there are variations in the different points, thus having an initial increase in the apparent color of the water (Pt/Co) from point 1 to point 2, followed by slight fluctuations

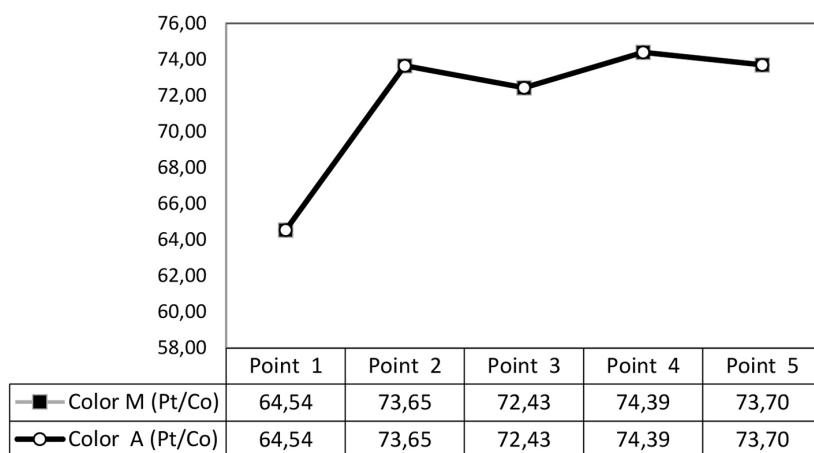


Figure 16. Color behavior in the system (Pt/Co) morning vs afternoon

between points 3 and 5, keeping the values within a narrow range. This behavior shows apparent color stability and controlled conditions of the chame-rice system, compatible with groundwater production environments, without indications of severe eutrophication or significant visual deterioration.

Nitrites

Figure 17 shows that nitrite (NO₂⁻) concentrations remained low and relatively stable at the five sampling points, with slightly higher values in the morning compared to the afternoon. The spatial variation shows homogeneous conditions of the system and absence of accumulation of intermediate nitrogen compounds, maintaining the levels within safe ranges for aquatic organisms in the chame-rice system.

Phosphate

In Figure 18, phosphate (PO₄) concentrations were higher in the morning (1.98–2.50 mg/L) compared to the afternoon (1.57–1.84 mg/L), with the maximum value at point 5 during the morning and the minimum at point 3. The spatial and temporal distribution reflects a heterogeneous dynamic of phosphorus in the system, with variations between points and times.

Ammonium

Figure 19 shows that ammonium (NH₄⁺) concentrations were similar between morning and afternoon at all sampling points, with values ranging from 1.11 to 1.44 mg/L. The spatial variation was slight and consistent throughout the system, with no marked differences between points, no indications of localized accumulation or alterations associated with point organic loads.

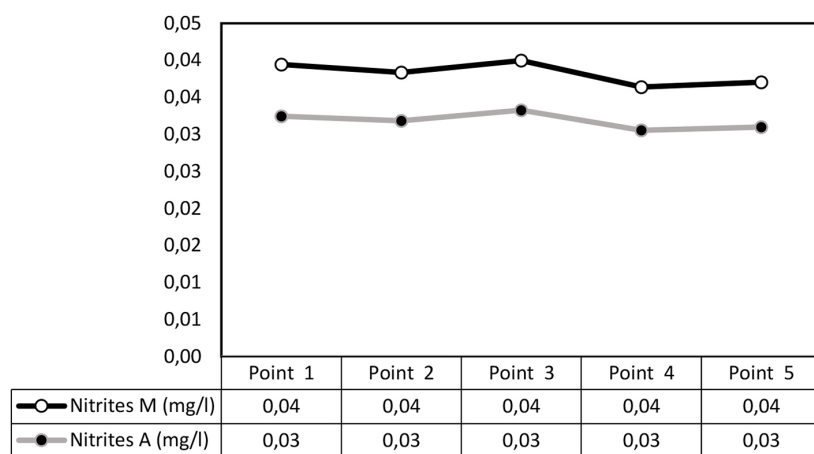


Figure 17. Nitrite behavior (mg/L) morning vs afternoon

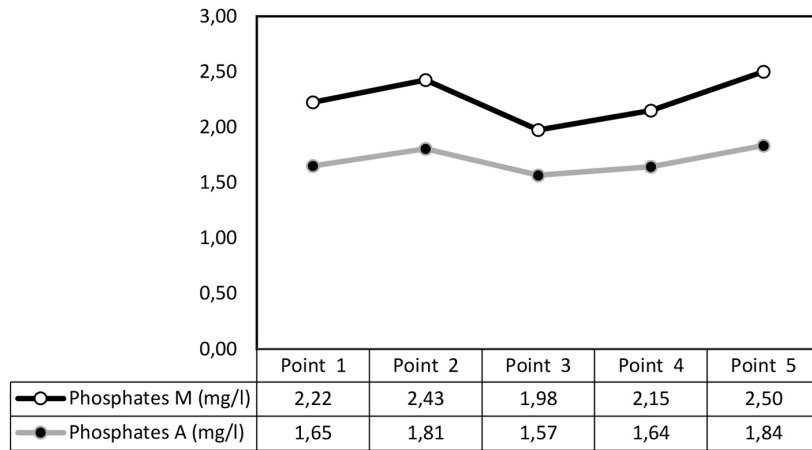


Figure 18. Phosphate behavior (mg/L) in the morning vs. afternoon

Total hardness

Figure 20 shows the behavior of the total hardness expressed as CaCO₃, showing a moderate spatial variation between the monitoring points, with values between 362.63 and 401.13 mg/L. The highest value was recorded at point 3, while point 4 presented the lowest hardness, the records between the morning and the afternoon confirm the temporal stability of this parameter.

Total coliforms

Figure 21 shows the concentrations of total coliforms, showing spatial and temporal variability, with values ranging from 21 to 2400 MPN/100 mL. During the monitoring period, months (August, October and December) were observed with generalized increases at several sampling points, as well as months in which high concentrations occurred in a timely manner,

evidencing a heterogeneous distribution of total coliforms within the pool.

Production of plant and animal biomass

At the end of the experimental period in the chame-rice system pool, a total of 137 chame individuals were recorded, from an initial stocking of 180 organisms. During the first week of culture, a cumulative mortality of 43 individuals was observed. The final biometry performed on the 137 surviving organisms showed an average weight of 294.35 g and an average total length of 26.39 cm (Figure 22). 273 rice seedlings were planted, with an initial average height of 15 cm, at the end of the production cycle, the plants reached an average height of 128.3 cm. The total harvest obtained was 8.92 lb (4.05 kg), equivalent to an average yield of 0.0148 kg per plant, reflecting

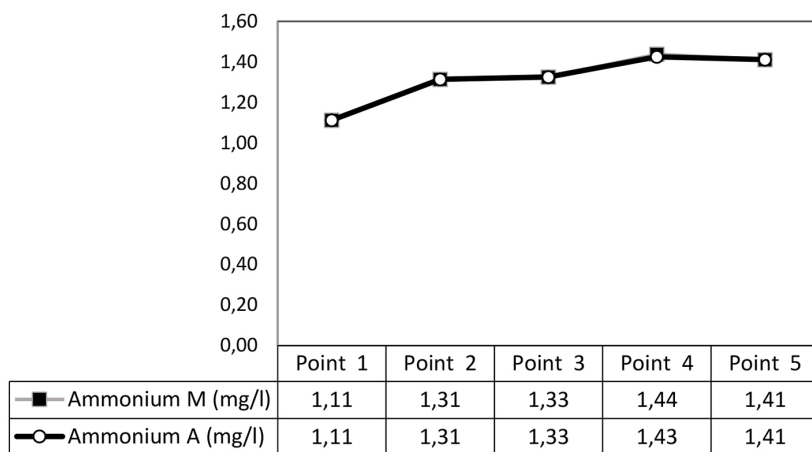


Figure 19. Ammonium behavior (mg/L) in the morning vs afternoon

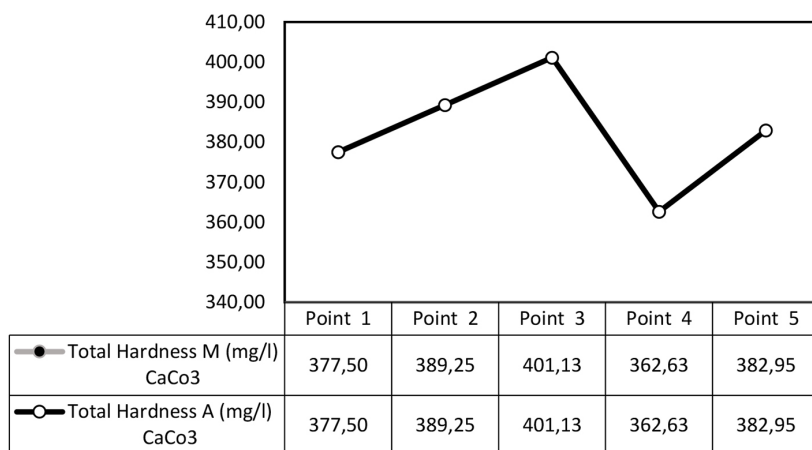


Figure 20. Behavior of total hardness (mg/L) CaCO₃ morning vs afternoon

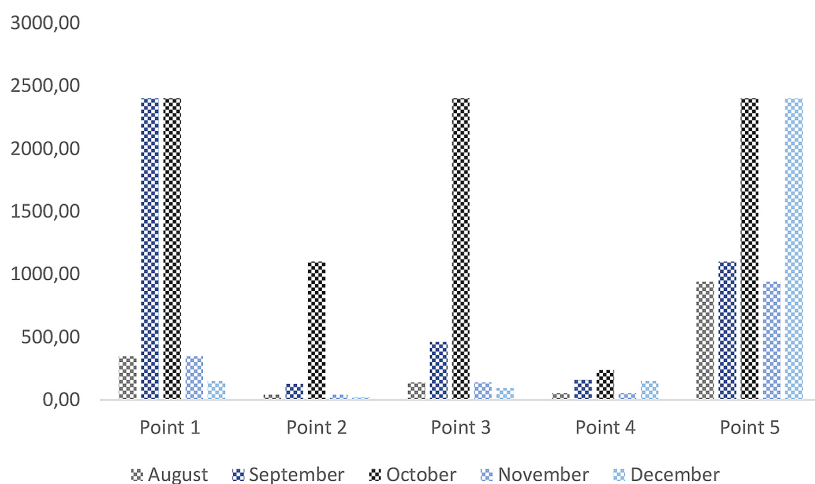


Figure 21. Behavior of total coliforms (MPN/100 mL)

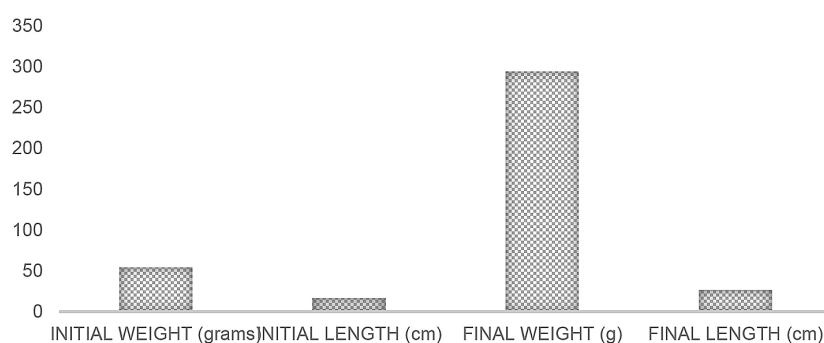


Figure 22. Average of the initial vs. final biometrics of the chame (*Dormitator latifrons*)

the productive performance under the management conditions implemented.

The absolute gain was 241.82 g and 10.56 cm, equivalent to 460.38% in weight and 66.67% in length. Survival was 76.11% and mortality was 23.89%, concentrated in the first week, suggesting

a critical period associated with the initial adaptation phase. The total biomass went from 9.45 kg to 40.33 kg, with a net increase of 30.87 kg and a total percentage gain of 326.51%, indicating that the productive performance was dominated by the increase in body mass of the survivors.

Table 5. Summary of MANOVA (Pillai Trace)

| Effect | Pillai trace | F (approx.) | GL (hypothesis) | GL (error) | p |
|-----------|--------------|-------------|-----------------|------------|--------|
| Point | 2.755 | 1.192 | 52 | 28 | 0.313 |
| Mes_orden | 3.902 | 21.340 | 52 | 28 | <0.001 |

In the vegetable component, rice increased its average height from 15.0 cm to 128.3 cm, with an absolute increase of 113.3 cm and a percentage gain of 755.33%. The total harvest was 4.05 kg from 273 seedlings, with an average yield of 0.0148 kg·plant⁻¹ (14.8 g·plant⁻¹).

Multivariate analysis (MANOVA)

The multivariate analysis of variance (MANOVA) (Table 5) showed that the temporal trend (Mes_orden) had a significant multivariate effect on the physicochemical variables, showing that the system does not behave constantly during the period evaluated, modifying its profile month by month (Pillai trace: $V = 3.902$; $F(52, 28) = 21,340$; $p < 0.001$). In contrast, no consistent multivariate differences were detected between the sampling points ($V = 2.755$; $F(52, 28) = 1.192$; $p = 0.313$). These results suggest that the variability of the system is mainly controlled by temporal processes, while, at the spatial scale, the behavior is relatively homogeneous, without persistent patterns of multivariate separation between points.

Physicochemical and microbiological composition of sludge

Table 6 illustrates the physicochemical and microbiological composition of sludge at five points (P1–P5) at the end of the production cycle, neutral to slightly alkaline pH (7.86–8.60), with the highest value in P1 (8.60) and the lowest in P5 (7.86), with relatively stable conditions in

acidity/alkalinity. The conductivity varies markedly (0.21–0.87 mS/cm), indicating differences in the ionic charge of the mud, with greater mineralization in P1 (0.87) and P3 (0.73), and lower in P4 (0.24) and P5 (0.21). Nitrates (390–2170 mg/kg) and nitrites (290–1610 mg/kg) have a high variability: P2 and P1 concentrate the maximums of both nitrates (2170 and 2040 mg/kg) and nitrites (1610 and 1510 mg/kg), while P5 registers the minimums (390 and 290 mg/kg), with differentiated contributions of nitrogenous compounds and/or different dynamics of transformation and retention of nitrogen between points. In contrast, phosphates remain very high at all sites (25,000–50,000 mg/kg), reaching 50,000 mg/kg in P2, P4 and P5, evidencing a persistent and cumulative phosphorus load in the sludge. From the microbiological component, total coliforms show changes of (3–2400 MPN/100 mL): P3 stands out as a clear source of contamination (2400), followed by P4 (120) and P5 (64), while P1 (3) and P2 (32). Finally, organic matter is higher in P4 (129.03) and P3 (118.94) and lower in P5 (76.51), which, together with the maximum of coliforms in P3, suggests that in this sector there is greater accumulation of organic material and conditions that favor the persistence or incorporation of microbiological contamination, while P1–P2 are characterized more by high nitrogen load and P5 by relatively low nitrogen values. conductivity and organic matter, although with phosphates it remains constant.

Table 6. Behavior of the physicochemical and microbiological composition of the sludge

| Parameters | Point 1 | Point 2 | Point 3 | Point 4 | Point 5 |
|------------------------------|---------|---------|---------|---------|---------|
| pH | 8.60 | 8.42 | 8.11 | 8.32 | 7.86 |
| Conductivity (mS/cm) | 0.87 | 0.55 | 0.73 | 0.24 | 0.21 |
| Nitrates (mg/kg) | 2040 | 2170 | 810 | 1620 | 390 |
| Nitrites (mg/kg) | 1510 | 1610 | 600 | 1200 | 290 |
| Phosphates (mg/kg) | 25000 | 50000 | 25000 | 50000 | 50000 |
| Organic matter (kg/mg) | 85.71 | 88.93 | 118.94 | 129.03 | 76.51 |
| Total Coliforms (MPN/100 mL) | 3 | 32 | 2400 | 120 | 64 |

DISCUSSION

The physicochemical dynamics of the chame-rice system evidenced an environmentally stable and productively viable functioning under semi-intensive conditions, however, it responded to a typical behavior of shallow water bodies where the evening increases in pH and dissolved oxygen with respect to the morning values reflect the assimilation of CO₂ during the day and the consequent displacement of the carbonate-bicarbonate balance, a phenomenon widely described in productive aquatic ecosystems (Wetzel, 2001).

In fish, handling during capture, biometrics, transfer and stocking rapidly triggers the physiological response to stress, raising cortisol levels and temporarily altering homeostasis, which can decrease the adaptability of organisms and increase their susceptibility to subsequent mortality (Martínez-Porchas et al., 2009; Ramsay et al., 2009). In *Dormitator latifrons*, it has also been shown that feed management directly influences survival, since high rations favor the accumulation of ammonia nitrogen and increase the risk of mortality, particularly in intensive systems without timely water exchange (Muñoz-Chumo et al., 2023). Added to this is the possible action of parasitic agents or opportunistic pathogens, since infestations by *Argulus* sp. have been reported in crops of this species with high prevalence and significant mortality, as well as significant reductions in the survival of larvae affected by tricodine (Vega-Vilasante et al., 2017; Reyes-Mero et al., 2024).

According to Wurts and Durborow (1992), pH values in the range 7.82–8.15 describe a slightly alkaline, and therefore chemically stable, condition for aquaculture production in extensive and semi-intensive schemes. Boyd and Lichtkoppler (1979) point out that morning ranges close to 6.5–9 are usually associated with better operating conditions in ponds, however, pH tends to increase towards the afternoon as a result of limnological processes.

In particular, this behaviour is due to the dynamics of dissolved inorganic carbon: during the photoperiod, photosynthesis consumes CO₂ (acidifying component), which shifts the CO₂–HCO₃⁻–CO₃²⁻ balance and favours an increase in pH; in the absence of light, respiration predominates, CO₂ accumulates, and pH drops (Boyd and Lichtkoppler, 1979). Accordingly, Tucker and D’Abramo (2008) describe that when photosynthesis exceeds respiration, CO₂ extraction from

water intensifies and pH rises, while when photosynthesis ceases, the CO₂ generated by respiration accumulates and pH decreases. In rice-fish systems, this oscillation can be accentuated by the higher photosynthetic biomass associated with rice cultivation and algae/periphyton in the water surface; in this context, the photosynthetic removal of CO₂ raises the pH and, in a coupled way, pH and dissolved oxygen tend to increase simultaneously during the day (Halwart and Gupta, 2004).

Similarly, Wurts and Durborow (1992) point out that, at the ecological scale, the spatial variation of pH can express micro-gradients internal to the system; in this sense, the pattern recorded in the chame arroz system (higher pH at points 2–3 and lower at 4–5) is consistent with local differences in productivity, therefore greater photosynthesis occurs in sectors with more light, lower turbidity or greater algae/peripheral biomass and, simultaneously, with contrasts in mixing and hydraulic exchange that regulate the accumulation or removal of CO₂ (Wurts and Durborow, 1992).

The mineralization of the water, expressed as total dissolved solids (TDS), remained at 804–817 mg/L, well below the reference threshold frequently used in pond aquaculture (<3.000 mg/L), this moderate mineralization is potentially favorable for osmoregulation and ionic stability of the medium (Sink and Chesser, 2023). On the other hand, *Dormitator latifrons*, being a euryhaline species, has a wide tolerance to salinity variations, which does not constitute a limitation for the performance of the species in populations of Ecuador (Chang, 1984). In agreement, Li et al. (2025) state that the processes of bioturbation, mineralization, and nutrient recycling depend directly on the management and load of the production system.

Regarding temperature, Halwart and Gupta (2004) point out that, when the system uses groundwater, the sheet of water can respond quickly to atmospheric forcing due to the accumulation of solar energy in a shallow body of water. In flooded rice paddies, the authors describe that the field functions as a greenhouse-like system (Halwart and Gupta, 2004), so that the diel amplitude is usually reduced, this behavior is consistent with the buffering effect of the rice canopy, so that crop shading and a relatively uniform water level simultaneously explain the morning–afternoon difference and thermal homogeneity (Halwart and Gupta, 2004). In addition, Vargas-Ceballos et al. (2024) points out that values (≈27.6–28.6 °C) are fully compatible with physiology in integrated systems.

FAO (2018) and Hem (1992) describe the relatively “conservative” nature of dissolved salts: at the intraday scale, their variation is usually dominated by the water balance (evaporation, rainfall, intake/exchange, and infiltration) rather than by metabolic processes operating on hourscales, a salinity close to ~1 ppt remains far from the reported tolerance extremes, therefore, the system provides a stable ionic environment, with a low probability that salinity itself explains biological variations (Chang, 1984). This stability also has a physiological basis: the fish must sustain the homeostasis of water and ions, mainly through the gill epithelium; when the osmotic gradient is modified, the demand for ion transport increases and, consequently, the energy cost of osmoregulation (Evans et al., 2005, p. 97).

Therefore, nitrogen dynamics, moderate ammonium concentrations, and low levels of nitrites in the water column indicate that the system maintained a functional balance between fish excretion, bacterial nitrification, and plant assimilation in productive ponds, this aerobic process is sensitive to oxygen, pH, and alkalinity (Prosser, 1989; Hargreaves, 1998). The conditions recorded (slightly alkaline pH and high alkalinity) favored the oxidation of ammonium to nitrate without critical accumulations of nitrite, a potentially toxic intermediate compound, in addition, the presence of rice as a plant component probably acted as a partial sink of inorganic nitrogen, incorporating it into aboveground and root biomass, which contributes to stabilize the concentration in water (Lu and Li, 2006; Xie et al., 2011). These mechanisms help the compatibility of *Dormitator latifrons* with integrated systems characterized by low water renewal, in which physicochemical stability and nutrient balance are determinants for productive performance (Vega-Villasante et al., 2016).

Total coliform concentrations showed high spatial and temporal variability in shallow systems with emergent vegetation, bacterial distribution usually responds to hydraulic microdynamics, accumulation of organic matter and root biofilms, and other increases could be associated with sediment resuspension or increased availability of organic substrate (Pachepsky and Shelton, 2011).

In rice-fish, Yu et al. (2018) describe relevant variations in physicochemical parameters and nutrients throughout the crop period and between system components, which are associated with sediment management and accumulation/resuspension. In a complementary way, Qin et al.

(2025) report multiple temporary campaigns in rice-fish and show that variables such as pH, dissolved oxygen, solids and inorganic forms of nitrogen/phosphorus fluctuate between samplings, reflecting operational and seasonal changes.

At the operational and productive level, feed based on percentage of biomass (4% in the initial phase and subsequent adjustment) remained within recommended ranges for growing tropical omnivorous fish (National Research Council (NRC), 2011; El-Sayed, 2006). The stability of ammonium and nitrites suggests that there was no organic overload, however factors such as stress due to transport, handling and acclimatization can induce physiological alterations that increase early mortality (Barton, 2002).

Halwart and Gupta (2004) shows that an average weight greater than 240 g indicates an adequate adaptation to the integrated system, there being a complementary contribution of natural resources generated within the system (perifiton, macroinvertebrates associated with roots and sediments), this synergy partially reduces dependence on external inputs (balanced feed) and improves ecological efficiency.

Likewise, rice yields were lower than those of conventional intensive agricultural systems (4–8 t/ha), which is attributed to several factors: absence of mineral fertilization, stocking density adjusted to the aquaculture component, competition for hydraulic space, and experimental nature of the system (Lu and Li, 2006).

The generated sludge has a low salt load (conductivity ~0.21–0.87 mS/cm) and a neutral–slightly alkaline pH (~7.86–8.60), which suggests a material that is low salinizing and chemically compatible with soils with good buffer capacity. In parallel, the high phosphate content (25,000–50,000 mg/kg) and the reported organic fraction are consistent with aquaculture sludge where P originates mainly in feces and uneaten feed, accumulating as mineral phosphates (e.g., calcium) and/or P associated with organic matter; therefore, the residue can be interpreted as a potential P-rich input for amendment/fertilization conditioned to prior stabilization and to define doses according to the receiving soil. (Pérez-San Martín et al., 2025; Prüter et al., 2020)

From the regulatory point of view in Ecuador, DIR-ARCA-RG-014-2025 establishes the need for comprehensive characterization for the use/management of sludge, incorporating physicochemical variables (pH, organic matter, N and P),

verification of contaminants/metals and microbiological component (including indicators such as fecal coliforms, Salmonella and enterococci) as conditioning factors for exploitation alternatives, agricultural use is not interpreted as “direct application”, but as a destination conditional on stabilization/sanitization (e.g., composting, drying, or other treatments), quality control of the final product, and then applying improvement measures before proposing its use as an amendment. (ARCA, 2025)

The presence of total coliforms (up to 2400 MPN/100 mL) as an international benchmark, the US EPA Biosolids Framework (40 CFR 503.32) defines pathogen reduction thresholds (e.g., Class A) based on fecal coliforms per g of total solids or Salmonella per 4 g (dry basis), in addition to treatment/verification approaches; therefore, there is a need for sanitization/stabilization and harmonized reporting with post-treatment verification to support agricultural use without sanitary ambiguities. (ARCA, 2025; U.S. EPA, 2026)

The high spatial and temporal variability of the total coliforms in the system suggests a microbiological dynamic controlled by the interaction between external inputs of organic matter, internal hydraulic heterogeneity and changing environmental conditions. In shallow ponds, the concentrations of indicator bacteria tend to fluctuate due to the influence of runoff, make-up water, the presence of fauna, and the accumulation of sediments and organic waste, which favor pollution pulses and an inhomogeneous distribution in the water column (Payment and Locas, 2011; WHO, 2017). Added to this is the effect of aquatic vegetation and sediments, which can act as bacterial reservoirs, as well as variations in temperature, radiation, and precipitation, which modulate their persistence and proliferation (Vymazal, 2014; Ahmed et al., 2018).

Therefore, to increase the productive efficiency and health safety of the system, it is essential to control the inlet water, improve hydraulic circulation, periodically remove sediments and reduce the organic load generated by uneaten food and excreta, factors that favor the proliferation of microorganisms and the deterioration of the sanitary conditions of the crop. Likewise, the implementation of biosecurity measures, such as the restriction of access to vector animals, proper food management and the systematic monitoring of physicochemical and microbiological parameters of the water, contributes to reducing health

risks and improving the productive stability of the system. (Boyd and Tucker, 2012; FAO, 2020).

This system is aligned with the principles of the Code of Conduct for Responsible Fisheries (FAO, 1995), by optimizing the use of water resources and minimizing external discharges. Likewise, the guidelines of the Aquatic Animal Health Code (WOAH, 2023) emphasize the importance of animal welfare and continuous sanitary monitoring, aspects that can be strengthened through improvements in acclimatization and biosecurity protocols.

CONCLUSIONS

The integrated chame-rice system (*Dormitator latifrons*–*Oryza sativa*) demonstrated technical-productive feasibility and physicochemical stability for 20 weeks, with compatible ranges for production (slightly alkaline pH; adequate temperature and dissolved oxygen; stable conductivity and TDS). The multivariate analysis confirmed that the dynamics of water quality were dominated by the temporal component: MANOVA (Pillai trace) identified a significant effect of Month-order ($p < 0.001$) and absence of spatial differences by Point ($p = 0.313$). Consequently, the monthly variation influences the quality of the water in the system, which highlights the importance of considering seasonal monitoring and operational management throughout the production cycle. The system evidenced a favorable productive performance, reflected in adequate survival, increase in plant and animal biomass, sludge indicates processes of loading and retention of nutrients contribute to the sustainability of the model, but incorporating systematic microbiological monitoring as axes of risk control and optimization of the operation of the system.

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