











Biological behavior of tilapia (*Oreochromis niloticus*) and crayfish (*Procambarus veracruzanus*) in aquaponic

Comportamiento biológico de mojarra tilapia (*Oreochromis niloticus*) y camarón burrito (*Procambarus veracruzanus*) en acuaponía

De La Luz-Morales, G.¹ , Serna-Lagunes, R.^{1*} , Cebada-Merino, M.¹ ,
García-Martínez, M.A.¹ , Bañuelos-Hernández, K.P.¹ , Llarena-Hernández, R.C.¹ ,
Andrés-Meza, P.¹ , Zetina-Córdoba, P.² , Morales-Palacios, I.² , Del Rosario-Arellano, J.³ .

¹ Maestría en Horticultura Tropical. Facultad de Ciencias Biológicas y Agropecuarias, región Orizaba-Córdoba, Universidad Veracruzana. Josefa Ortiz de Domínguez s/n, Peñuela CP. 94945, Amatlán de Los Reyes, Veracruz.

² Programa de Ingeniería en Alimentos: Universidad Politécnica de Huatusco, Huatusco CP. 92100, Veracruz.

³ Universidad Interserrana del Estado de Puebla-Chilchotla. Av. Miguel Hidalgo s/n, CP. 7507. Chilchotla, Puebla.



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ABSTRACT

The food system presents numerous challenges, including population growth, environmental pollution, global warming, and soil degradation. Aquaponics is a sustainable system that can help address food security challenges. The objective of the study was to evaluate the biological behavior of tilapia (*Oreochromis niloticus*) and burrito shrimp (*Procambarus veracruzanus*) in an aquaponic system. An aquaponic system utilizing substrate beds was constructed. The system was matured by the proliferation of nitrifying bacteria. Readings of seven physicochemical parameters (ammonium, nitrites, nitrates, calcium, pH, temperature, and dissolved oxygen) were taken every 15 days for 5 months, with two replicates. The growth and development of tilapia and crayfish were evaluated by performing biometrics of total length and weight. These data were analyzed using box and whisker graphs, and a one-way analysis of variance (ANOVA) was applied to determine significant differences between the sampling months. Growth rates were estimated and evaluated using logarithmic curves and adjustment of the coefficient of determination (R^2). The developmental biology of fry demonstrated increases in weight and length, with a survival rate exceeding 50 %. Regarding crayfish, only the length increased, with a survival rate greater than 50 %. This aquaponic system is positioned as a technology transfer for the self-sufficiency in food production in the central region of Veracruz, Mexico.

KEY WORDS : Aquaponics, crayfish, development, food, growth, tilapia.

*Corresponding Author:

Ricardo Serna-Lagunes. Unidad de Manejo y Conservación de Recursos Genéticos. Facultad de Ciencias Biológicas y Agropecuarias, región Orizaba-Córdoba, Universidad Veracruzana. Calle Josefa Ortiz de Domínguez s/n, Col. Centro, Peñuela, C.P. 94945, Amatlán de Los Reyes, Veracruz, México. Teléfono: (271) 141 4702. E-mail: rserna@uv.mx

RESUMEN

El sistema alimentario presenta desafíos como el aumento demográfico, contaminación ambiental, calentamiento global y degradación de suelos. La acuaponía es un sistema sustentable que puede contribuir a solucionar los desafíos de seguridad alimentaria. El objetivo del estudio fue evaluar el comportamiento biológico de la mojarra tilapia (*Oreochromis niloticus*) y camarón burrito (*Procambarus veracruzanus*) en un sistema acuapónico. Se construyó un sistema acuapónico basado en camas de sustrato. Se maduró el sistema proliferando bacterias nitrificantes, se tomaron lecturas de siete parámetros fisicoquímicos (amonio, nitritos, nitratos, calcio, pH, temperatura y oxígeno disuelto) cada 15 días durante 5 meses, con dos réplicas de lectura. Se evaluó el crecimiento y desarrollo de tilapias y acociles realizando biometrías de longitud total y peso, estos fueron analizados con gráficos de cajas y bigotes y les fue aplicado un análisis de varianza (ANOVA) de una vía para determinar diferencias significativas entre los meses de muestreo. Se estimaron tasas de crecimiento, se evaluaron mediante curvas logarítmicas y ajuste del coeficiente de determinación (R^2). La biología del desarrollo de alevines de presentó aumentos en peso y longitud, con una sobrevivencia mayor al 50 %. Con respecto a los acociles, solo la longitud aumentó, con una sobrevivencia mayor al 50 %. Este sistema acuapónico se posiciona como una transferencia de tecnología para el autoconsumo alimentario en la región centro de Veracruz, México.

PALABRAS CLAVE: Acuaponía, acocil, alimentos, crecimiento, desarrollo, tilapia.

Introduction

Globally, faced with significant challenges such as human population growth, soil degradation, food insecurity, climate change, and environmental pollution, several developing countries are facing crises, as this impacts the social sector due to economic and food collapses (Goddek *et al.*, 2015). For example, in rural areas, small- and medium-scale aquaponics for self-consumption is an alternative to contribute to the goals of the 2030 Agenda (Flores-Aguilar *et al.*, 2024). Furthermore, when developing and implementing aquaponics projects, the pillars of sustainability in agriculture, aquaculture, and aquaculture production are considered (Schoor *et al.*, 2023).

The transfer and establishment of aquaponics in urban and rural farms promise to develop food that meets local human food needs (Muñoz-Euán *et al.*, 2024). In this sense, there is a desire to implement technologies such as aquaponics that address these problems in a sustainable manner (El-Essawy *et al.*, 2019). Aquaponics is viewed as a sustainable technology that offers

an option to address the afore mentioned problems, to eradicate excessive water consumption in food production, avoid the production of polluting waste, reduce the excessive use of energy and fossil fuels, and serve as an alternative for producing highly nutritious and safe foods without the use of chemicals or environmental damage (Sawkar *et al.*, 2020).

Human population growth is driving a significant demand for both animal- and plant-based foods. Given the challenges facing conventional food production systems to meet this demand, limitations such as declining arable land, limited freshwater supplies, and soil degradation are pressing concerns. These challenges require sustainable technologies such as aquaponics to address food sector deficits for subsistence consumption (FAO *et al.*, 2020). Although aquaponics is still in its early stages of development, it can effectively contribute to addressing food security challenges (Campos-Pulido *et al.*, 2015).

The species used in an aquaponic system are determined according to the type of production required and the project's purpose (whether experimental, commercial, or subsistence). However, in general, five species of fish are preferred for primary food production in aquaponic systems (Table 1) (Palm *et al.*, 2018). To choose an aquaculture species for an aquaponic system, the type of production, the ease of acquiring the species, fish density, the rate or speed of growth and development, and factors of the water column such as its temperature, pH, nitrates, oxygen and other physicochemical parameters, as well as the interaction of the species in the aquaponic system, and growth rates and times are taken into account (Colorado & Ospina, 2019).

Table 1. Main aquaculture species in aquaponics (Somerville, 2014).

Culture specie	Temperature °C	Nitrate mg/l	Nitrite mg/l	Dissolved Oxygen mg/l	Protein %	Period of growth
Eurasian carp (<i>Cyprinus carpio</i>)	25-30°C	<1	<1	>4	30-38	600 gr in 10 months
Nile Tilapia (<i>Oreochromis niloticus</i>)	27-30	<2	<1	>4	28-32	600 gr in 7 months
Channel Catfish (<i>Ictalurus punctatus</i>)	25-30	<1	<1	>3	25-36	400 gr in 8 months
Rainbow trout (<i>Oncorhynchus mikyss</i>)	14-16	<0.5	<0.3	>6	42	1 kg in 15 months
Mujol and Mujil Lisa (<i>Muguil cephalus</i>)	20-27	<1	<1	>4	30-34	750 gr in 10 months

The Nile tilapia *O. niloticus* is important for production and consumption in tropical and subtropical regions. It adapts to lentic environments, including ponds, lagoons, reservoirs, and aquaponic systems (Kaneshima *et al.*, 2022), and develops at temperatures ranging from 21 to 32 °C (Ani *et al.*, 2022; Ramos *et al.*, 2022). The nutritional contribution of this species to the human diet consists of fatty acids, proteins, vitamins B, D, and E, phosphorus, and calcium. Therefore,

its cultivation represents a high profitability. However, its biological behavior in recirculating and aquaponic systems needs to be evaluated based on regional climatic conditions (El-Kady *et al.*, 2022), as this generates information and knowledge about its adaptability, profitability, and metabolism (Zappernick *et al.*, 2022).

While the study and use of freshwater crustaceans or crayfish in aquaponic systems are scarce, only the shrimp *Litopenaeus vannamei* and the Malaysian prawn (*Macrobrachium rosenbergii*) have been studied more for experimentation and commercialization purposes in aquaponics (Gámez, 2018), since they adapt easily, and according to León (2013), *L. vannamei* reaches 8.7 to 19 g per individual, with a yield of 1.3 to 13.4 ton ha⁻¹ and survival rate of 58-98 %. Gámez (2018) reports a survival rate of 40-56 %, a growth rate of 0.73 g / week, and a final weight of 15.61 %, while Ronzón-Ortega *et al.* (2012) reported weights of 8.10 to 9.20 g for the Malayan king prawn (*M. rosenbergii*) and a survival rate of 77–93 %.

Aquaponic systems achieve higher yields compared to conventional aquaculture production systems. For example, in an aquaponic system, white shrimp (*L. vannamei*) achieved a 95 % survival rate, which is reflected in higher yield and productivity (Schardong *et al.*, 2020), compared to extensive cultures in terms of survival and yield: 50 %; semi-intensive and intensive: 75 %; and hyper-intensive: 80–85 % (Lara-Espinoza *et al.*, 2015; Puentes *et al.*, 2023). With the Malayan king prawn (*M. rosenbergii*), survival rates of 77 % have been reported at stocking densities of 16 organisms per m² (Ronzón-Ortega *et al.*, 2012); these conditions can be extrapolated to native burrito shrimp, or crayfish species such as *Procambarus veracruzanus* (Crustacea, Cambaridae), whose wild populations are at risk due to habitat pollution in central Veracruz. Therefore, aquaponics is a conservation and management strategy for these species through production (Lorán-Núñez & Valdéz-Guzmán, 2009).

Crayfish farming represents a viable option in aquaponic systems, due to its bioecology, which is linked to larval development, good adaptation, growth, and year-round reproduction (Arredondo-Figueroa *et al.*, 2011). It can be produced in recirculating systems to evaluate their growth and development (Hernández-Vergara *et al.*, 2018). Therefore, the objective of this study was to evaluate the biological behavior (growth and survival) of tilapia (*Oreochromis niloticus*) and burrito shrimp (*Procambarus veracruzanus*) in an aquaponic system.

Material and Methods

This study was conducted in an urban area of the municipality of Córdoba, Veracruz, Mexico, situated at an elevation of 860 meters above sea level. It borders the municipality of Ixhuatlán del Café to the north, Coetzala to the south, Amatlán de los Reyes to the east, Fortín to the west, and Atoyac to the northeast (Figure 1).

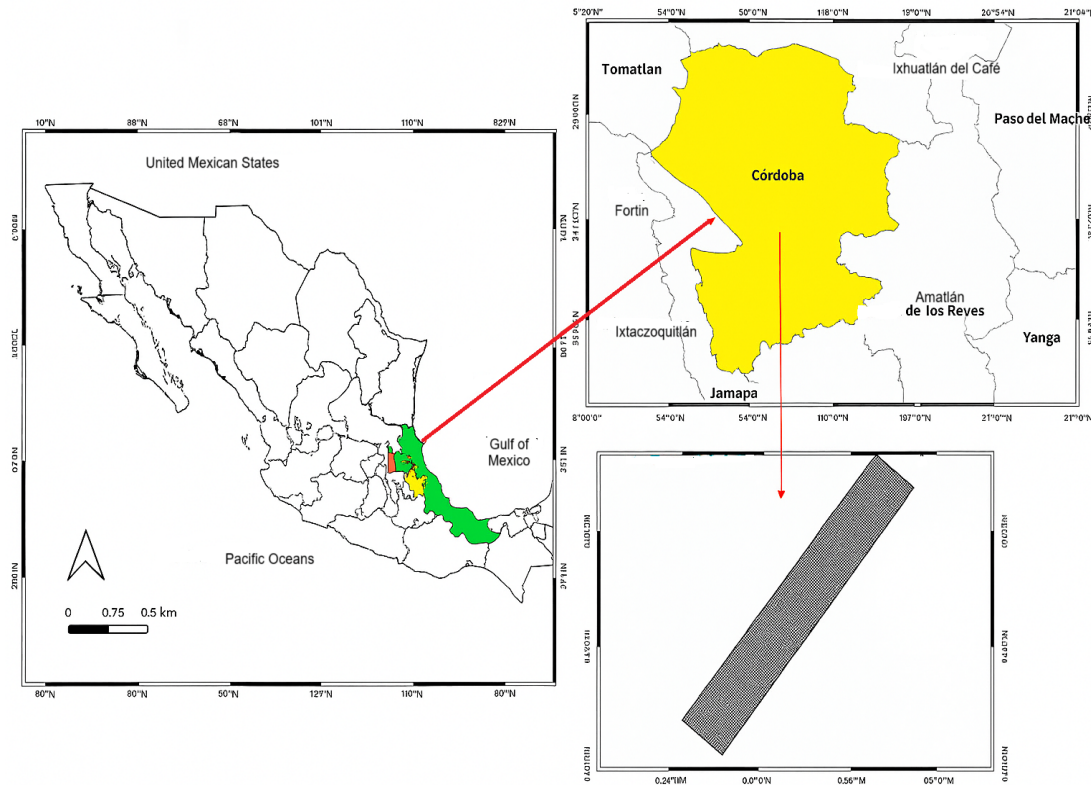


Figure 1. Geographic location of the experimental area.

Source: QGIS v. 3.28.

The municipality of Córdoba has a temperate-humid climate, with an average temperature of 19.9°C, ranging from 12°C to 32°C, rarely falling below 8°C or exceeding 36°C; the average annual rainfall is 1,800 mm (Figure 2).

Design, construction, acclimatization and variables of the aquaponic system.

An aquaponic system was constructed using substrate beds (media beds) within a 1000 L drum. This was cut to a capacity of 700 L. The cut part of the drum (300 L) was filled with red tezontle (granulometry of 3-5 cm) and placed on top, serving as a bed for planting chayote and quelite plants. To pump water from the drum to the growing bed, a submersible pump with a flow rate of 2000 L/h was used to maintain water balance in the growing bed. A bell-type siphon was installed in the aquaponic system to maintain the water level by draining excess water; this allows water to flood the growing bed, so that it automatically drains excess water when it reaches the level of the siphon (Figure 3).

Acclimatization involved balancing the chlorine (Cl) content of the aquaponic system water using a Pool Style colorimetric kit until it reached a concentration between 0.2 and 0.5 ppm. This process took 4 weeks to achieve the proliferation of nitrifying bacteria colonies responsible for converting ammonium to nitrates, which was accomplished by adding fish food as an ammonium source (Goddek *et al.*, 2019). pH, ammonium, nitrite, and nitrate levels were assessed weekly using the API Water Test Kit Freshwater® colorimetric kit. When necessary, the water was titrated with potassium chromate (K_2CrO_4) and silver nitrate ($AgNO_3$) until balanced values of ammonium, nitrite, and nitrate were observed, along with a pH of approximately 7 (Table 2).

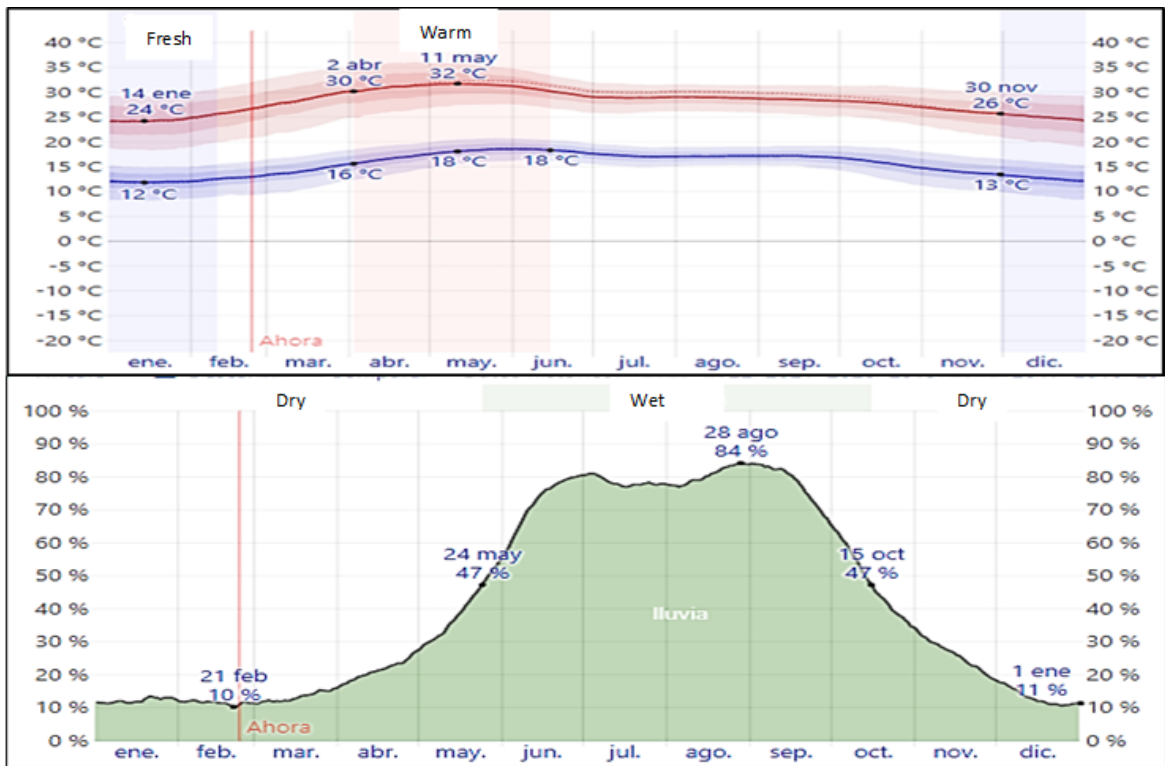


Figure 2. Meteogram of Córdoba during the study period.

Source: <https://es.weatherspark.com>



Figure 3. Aquaponic system design to evaluate the growth of tilapia and acociles.

Table 2. Values of the physicochemical parameters of the water of the aquaponic system.

Physicochemical parameters	Average	Standard Deviation	Standard Error	Coefficient of Variation	Minimum	Maximum
Temperature (°C)	23.39	2.74	0.42	11.69	18.5	29.1
pH (units)	7.57	0.09	0.01	1.14	7.2	7.6
Ammonia (ppm)	0.36	0.23	0.03	62.95	0.25	1
Nitrite (ppm)	0.38	0.52	0.08	137.23	0	2
Nitrate (ppm)	31.51	23.92	3.65	75.9	5	80
Calcium (ppm)	622.72	608.94	92.86	97.79	16	2500
Dissolved Oxygen (mg L ⁻¹)	4.94	1.51	0.23	30.6	2.2	10

After acclimating the aquaponic system, readings of seven physicochemical parameters were taken every 15 days for a period of five months, with two replicate readings taken during the period from December 2023 to April 2024. In total, 43 readings of temperature (°C) and dissolved oxygen (DO; mg L⁻¹) were measured with a LAQUAtwin® electronic detector; nitrogen (N; mg L⁻¹), ammonium (NH₄⁺; mg L⁻¹), nitrites (NO₂⁻; mg L⁻¹), nitrates (NO₃⁻; mg L⁻¹), and pH were measured using a commercial colorimetry kit API Water Test Kit Freshwater®.

Characteristics and evaluation of the species managed in the study.

The developmental biology of 30 Nile tilapia (*O. niloticus*) fingerlings of the Super Macho breed was evaluated. These fingerlings were 3.5 cm long and weighed 1.5 g on average at the start of the experiment. This breed was chosen because it is important in terms of production and consumption, since it adapts to lentic environments, ponds, lagoons, reservoirs, and aquaponics (Kaneshima *et al.*, 2022), being the most used species due to its adaptability, profitability, and optimal metabolism (Zappernick *et al.*, 2022).

The second aquaculture species evaluated was 15 specimens of the crayfish *Procambarus veracruzanus*, which were collected in streams located in the municipality of Córdoba, Veracruz, with sizes between 4 and 6 cm. Within the state of Veracruz, the crayfish *P. veracruzanus*, commonly known as burrito shrimp, has been studied little. Consumption is regional among indigenous communities, who, during the rainy seasons (June-September), collect them for self-consumption (Saha *et al.*, 2016). The crayfish inhabits freshwater ecosystems with slow currents such as rivers, streams, and floodable areas. They are omnivorous, resemble small lobsters, have a body covered by a strong calcified integument (exoskeleton), and adapt to temperatures between 20-28 °C. Regarding the cultivation of crayfish, it presents a feasible manipulation in relation to other species, this is due to its bioecology linked to its larval development, good adaptation, development and reproduction all year round (Arredondo-Figueroa *et al.*, 2011); it is a species that is beginning to be produced in recirculation systems to evaluate its growth and development (Hernández-Vergara *et al.*, 2018).

Evaluation of the biological development of species in aquaponics

Biometry surveys began in December 2023 and ended in April 2024, spanning 5 months of experimentation, equivalent to approximately 22 weeks. To evaluate the growth and development of the Nile tilapia and crayfish, biometry measurements of total length (TL) and weight (g) of the Nile tilapia and crayfish were taken every 15 days. These were analyzed with box-and-whisker plots and one-way analysis of variance (ANOVA) and Tukey's *post hoc* tests were applied to determine significant differences between sampling months, with an alpha of 0.05 (Zar, 2010).

Using biometric data, growth rates were estimated for mojarra and crayfish individuals using the following formula: $TC = (L_f - L_i) / \text{Number of months evaluated}$, where: TC = Growth rate, L_i = Initial length, L_f = Final length (Rahman *et al.*, 2022). TCs were evaluated using logarithmic curves and adjusted for the coefficient of determination (R^2). The regression equation was also estimated for both Nile tilapia and crayfish (Zar, 2010). Logarithmic trend curves are used in biological studies of captive animals for management, utilization, and production purposes, as they enable the identification of how temperature, feeding, humidity, and management factors impact the growth rate of species (Serna-Lagunes *et al.*, 2010).

The percentage (%) of survival was calculated with the following formula designed for this study: $TS = (O_{vf} \times 100) / O_{vi}$, where: TS = Survival rate, O_{vi} = Initially living organisms, O_{vf} = Finally living organisms.

Results and Discussion

According to the results of the analysis of variance, significant differences were found due to the increase in weight and length of tilapia, while for crayfish, only the length showed a significant increase (Table 3).

Table 3. Results of ANOVA applied to the weight and length of mojarra and crayfish in aquaponics.

		Source of Variation	Sum of Squared	Degree freedom	Means Squared	F	<i>p-value</i>
Nile tilapia	Weight	Model	2259.77	5	451.95	115.8	< 0.0001
		Months	2259.77	5	451.95	115.8	< 0.0001
		Error	447.7	114	3.93		
		Total	2707.47	119			
	Length	Model	438.95	5	87.79	145.94	< 0.0001
		Months	438.95	5	87.79	145.94	< 0.0001
		Error	68.58	114	0.6		
		Total	507.52	119			
Crayfish	Weight	Model	8.05	3	2.68	2.25	< 0.0926
		Months	8.05	3	2.68	2.25	< 0.0926
		Error	66.80	56	1.19		
		Total	74.85	59			
	Length	Model	4.40	3	1.47	3.61	< 0.0186
		Months	4.40	3	1.47	3.61	< 0.0186
		Error	22.73	56	0.41		
		Total	27.13	59			

The mean tests indicated that significant differences were found during the months of study, finding an increase in the last period or month of the experiment (Figure 4).

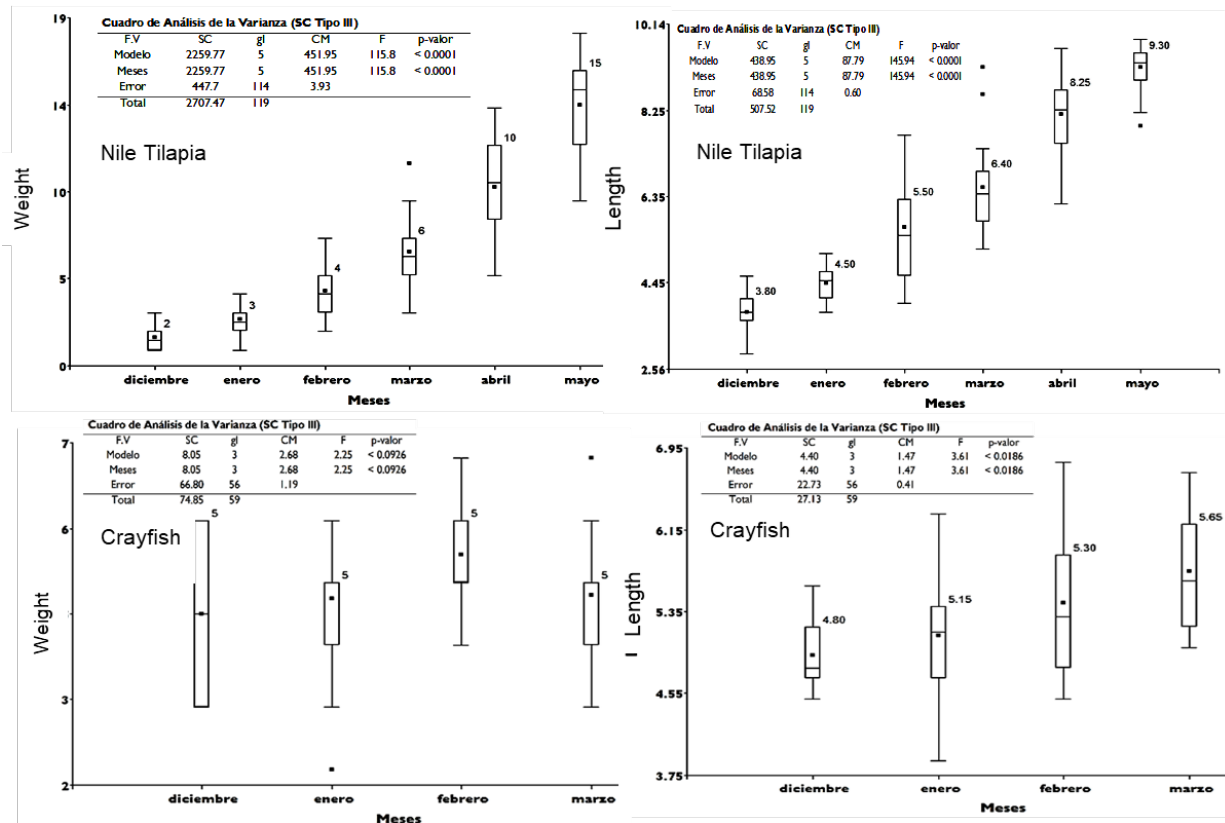


Figure 4. Variation in weight and length of *O. niloticus* and *P. veracruzanus* in aquaponics.

The growth rates for *O. niloticus* and *P. veracruzanus* were fitted to logarithmic trend curves, with a coefficient of determination $R^2 = 0.90$ and 0.83 , respectively (Figure 5), indicating animal growth that is characterized by rapid growth at the beginning, and the asymptote occurs at the end of the experiment.

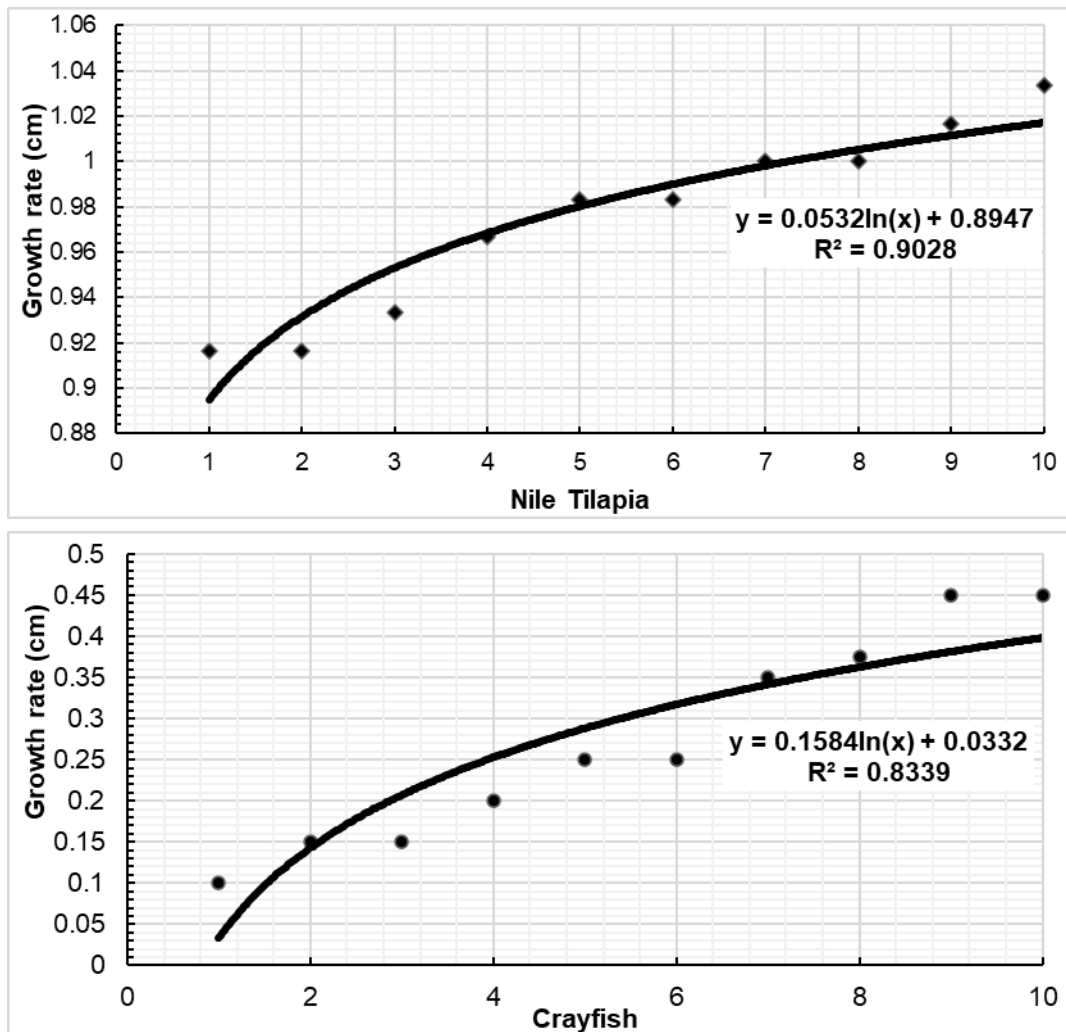


Figure 5. Curves and growth rates of *O. niloticus* (top) and *P. veracruzanus* (bottom).

The survival rate for *O. niloticus* was 60 %, with 18 out of 30 organisms introduced into the aquaponic system surviving. The survival rate for *P. veracruzanus* reached 80 %, with 12 individuals surviving out of 15 organisms introduced into the aquaponic system (Table 4).

Table 4. Survival parameters of tilapia and crayfish fry in aquaponics

Survival parameters	Living organisms finally	Initially living organisms	Survival rate (%)
Nile tilapia	18	30	60
Crayfish	12	15	80

O. niloticus fingerlings adapted to the conditions of the aquaponic system, as their growth, development, and survival rates were adequate, showing an increase in length, weight, and survival. However, in other culture densities and more controlled conditions, performance and survival can be improved, as Barbosa *et al.* (2022) obtained an 81 % survival rate and tilapia weighing 0.567 kg in an aquaponic system with floating rafts and substrate beds.

When we compared our results with those of Ani *et al.* (2022), who compared two tilapia culture stocking densities to evaluate their growth rates, obtaining an adequate performance, since the stocked fingerlings (150 fish/m³) increased their growth rate from 17.9 ± 1.7 g to 42.6 ± 3.1 g, while with 300 fish/m³ they increased their growth rate from 18.2 ± 2.2 g to 32.0 ± 3.8 g. However, it should be noted that the aquaponic system used in this study was 1 m³ with a stocking density of 30 fingerlings, so the density may play a significant role in the variation in growth rates. Regarding the effect of physicochemical parameters of water flow, such as pH, ammonium, nitrites, and nitrates, on the fry, these were maintained within standard parameters, such as pH 7.6, which helps the fry and any aquaculture species maintain a good metabolism. This is related to what was reported by Gebauer *et al.* (2021), who indicated that the survival and development of fish is influenced by a pH of 7.5 to 8, since daily food intake depends on this, which can be adequately metabolized.

Regarding *P. veracruzanus* crayfish, there is little information on their biology in aquaponics. However, in this study, they had an adequate adaptation, as the weight remained constant in all specimens, while the length increased during the experiment. To increase survival, the number of shelters for protection and shelter should be increased. The association with tilapia may have influenced reduced feeding, thereby maintaining a constant weight. According to Hernández-Vergara *et al.* (2018), they experimented with a recirculation system with the polyculture of *P. acanthophorus* crayfish population with Nile tilapia *O. niloticus*, and determined that, unlike the crayfish, the Nile tilapia showed similar survival and growth in all treatments.

Conclusions

The developmental biology of *O. niloticus* Nile tilapia fingerlings showed increases in weight and length, with survival rates greater than 50 %. Regarding the crayfish, only length increased during the experiment, with survival rates greater than 50%. Mortality rates were attributed to

territorial behavior, stress factors related to adaptation conditions in the aquaponic system, and the lack of refuge that serves as shelter and protection for fish and crayfish.

Author contributions

Work conceptualization , GLM, RSL, and MCM; Methodology development, GLM, RSL, and MCM; Software management, GLM, RSL, and MCM; Experimental validation, MAGM, EPP, KPBH, and PZC; Results analysis, GLM, RSL, MCM, MAGM, EPP, KPBH, PAM, RCLH, and JLRA; Data management, manuscript writing and preparation, GLM, RSL, MCM, MAGM, EPP, KPBH, IMP, RCLH, and JLRA; Writing, review, and editing, GLM, RSL, MCM, MAGM, EPP, KPBH, PAM, PZC, IMP, RCLH, and JLRA; Project manager, GLM, RSL, and MCM; Funding acquisition, GLM, RSL, MCM, MAGM, EPP, KPBH, and PZC.

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Ethical declarations

This study does not require ethical approval.

Informed consent statement

Not applicable.

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Conflict of interest

The authors declare no conflict of interest.

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