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Research Article

Growth of *Penaeus vannamei* shrimp in a recirculation system

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ABSTRACT. Shrimp can adapt to various types of farming systems, especially in ample salinity fluctuations and different temperatures, which means their growth is rapid even outside their natural habitat. The objective of this study is to verify the growth of Pacific white shrimp (*Penaeus vannamei*) in a water recirculation aquaculture system (RAS) and demonstrate that the shrimp industry can be practiced sustainably. A total of 60 animals were distributed in a completely randomized design, with six replications at a stocking density of one animal per 15 L, resulting in 10 animals per experimental unit. The Pacific white shrimp used in the study were from the Speed Line Aqua lineage (Aquatec) with an initial weight of 9.93 ± 1.16 g, grown in saltwater with a salinity of 20. Feeding occurred three times a day with balanced commercial food; daily water quality monitoring was conducted. The shrimp were weighed at the beginning of the experimental period, as well as every 15 days for 60 days, to obtain performance parameters (weight gain, feed consumption, apparent feed conversion, specific growth rate, and protein efficiency rate). With the performance data, the Gompertz model was applied to describe shrimp growth. Based on the general results, RAS can be used for shrimp in a super-intensive system. The values estimated by the Gompertz model accurately described the growth of Pacific white shrimp in RAS systems within a weight range of 10.84 g (minimum) to 69.25 g (maximum). The optimal weight for maximum growth performance was identified as 40.05 g live weight for this farming system. The daily maturity rate (b) was estimated to be 0.0196 g d^{-1}, representing the average daily mass gain an organism accumulates as it progresses toward full maturity.

Keywords: *Penaeus vannamei*; Pacific white shrimp; development; RAS; closed recirculation system

INTRODUCTION

The Pacific white shrimp, *Penaeus vannamei*, is one of the main commodities for shrimp aquaculture (FAO 2016) due to the availability of stocks and larvae for sale (Boyd & Clay 2002), as well as its ability to grow at high stocking densities and deal with large variations in water salinity (Briggs et al. 2004). The production of *P. vannamei* accounts for 83% of global cultivation, with 5.8 million tons produced worldwide in 2020 (FAO 2022). Brazilian production reached 112,000 t in 2020, increasing to 120,000 t in 2021 despite the COVID-19 pandemic (Rocha 2022).

Although global production of farmed shrimp has increased in recent years, major producing countries have experienced a decline in production due to health-related problems, including vibriosis (*Vibrio* spp.) and white spot disease (*Whispovirus*).

Shrimp mortality due to disease often occurs when the organic content in the farming system is high. Therefore, maintaining water quality is critical in widespread shrimp production (Prachumwat et al. 2020). Conventional improvements (such as expanding cultivation areas and utilizing open systems in shrimp production) have several constraints, including unstable water quality and high susceptibility to infectious dis-

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eases, which often result in decreased shrimp productivity. On the other hand, the use of the recirculating aquaculture system (RAS) offers more flexible, predictable, hygienic, and environmentally friendly shrimp production, even at high densities, contributing to a more sustainable shrimp industry (Suantika et al. 2000, 2018).

RAS technology has the advantage of highly efficient use of water resources, primarily due to the water treatment process that occurs during its circulation throughout the components. It includes physical and biological filtration units, which can solve the problems arising from the high level of organic content in the system and minimize the risk of infection by pathogenic bacteria that may exist in new untreated seawater (Suantika et al. 2000, Rojo-Cebreros et al. 2017, Wullur et al. 2019, Nogueira-Matias et al. 2020). Intensive shrimp farming produces large amounts of nitrogen and phosphorus waste (Jasmin et al. 2020, Iber & Kasan 2021).

Another key consideration in shrimp farming is understanding the growth of these animals in a specific environment and diet. There is, therefore, a need to develop mathematical models that better describe the characteristics and growth rates, as well as the relationships between these aspects. This information is crucial for understanding shrimp growth processes, contributing to the expansion of current knowledge about growth and the utilization of nutrients to achieve biomass, and enhancing current feeding systems. According to Dumas et al. (2010), mathematical models are analytical solutions to differential equations that can be fitted to growth data using nonlinear regression. Likewise, regression analysis examines the relationship between two or more quantitative variables, allowing one variable to be considered as a function of another. The primary objectives of regression analysis are based on three purposes: description, control, and prediction (Filho et al. 2020).

The modeling process involves defining objectives, constructing a diagram to identify the main factors involved in the system to be modeled, formulating appropriate mathematical functions, collecting data to estimate parameters, solving equations, evaluating and verifying the model, and programming a simulation (Oviedo-Rondón & Waldroup 2002).

One of the most widely used systems is the closed system with water treatment and recirculation, known as RAS, which is already in use in research laboratories, for the cultivation and maintenance of ornamental fish, and in large public and private aquariums worldwide (Roy et al. 2025). From the 1980s onwards, studies on the use of recirculation systems intensified in Japan, USA, Israel, and several European countries (Verdegem et al. 2023). In Brazil, investor interest in growing fish in closed systems is relatively recent, particularly in the context of this system used for shrimp (Valenti et al. 2021). Therefore, this study aimed to use RAS to verify the growth of Pacific white shrimp (*P. vannamei*).

MATERIALS AND METHODS

The experiment was conducted at the Sustainable Aquaculture Laboratory at Universidade Brasil, Fernandópolis Campus, with a 60-days experimental period. The experiment was conducted in accordance with the ethical guidelines of Brazil's National Council for the Control of Animal Experimentation. The materials and methods (Protocol 1900057) used in the present trial were approved by the Ethics Committee on Animal Use of this university.

Recirculation system

An RAS was used in six experimental units, each consisting of a polyethylene box with a useful volume of 150 L. Each unit was equipped with individual systems for aeration, water supply, and drainage, with a water renewal rate of 2.5 L min^{-1}. The temperature was controlled by an electrical resistance heater with a thermostat.

A biological filter with 0.1 m^3 of moving bed biofilm reactor (MBBR) Biological Bio Media was used, comprising approximately 9,600 parts, with an approximate density of 0.98 g cm^3 and a protected surface area of 402 m^2. These Bio Medias were packed in a 150-L polyethylene box. The hydraulic system used to recirculate the water consisted of a 1/2 CV Single-Phase BC-98 Schneider centrifugal water pump connected to 1-inch polyethylene piping, with 0.5-inch taps for the boxes.

The water salinity during the study was maintained at 20 g L^{-1}, a suitable level for research with Pacific white shrimp. The marine salt mixture Tropic Marin® Pro-Reef was employed, recognized for its balanced composition of essential ions. The saline solution was prepared by dissolving 21.5 g of salt per liter of water at 25°C, with gradual adjustments based on measurements from a calibrated refractometer (Kasvi, Model K52-100) using a 35 ppt standard solution and manual correction for the target range. Salinity stabilization was ensured through continuous agitation and triple verification, supplemented by daily freshwater replenishment to offset evaporation. This protocol established specific isotonic conditions for the crustaceans, simulating low-salinity estuarine environments. The choice of Tropic Marin® Pro-Reef allowed for maintaining not only the NaCl concentration but also trace elements such as magnesium and calcium, minimizing osmotic stress and ensuring the physiological viability of the organisms throughout the experiment.

Biological material

A total of 60 shrimp were distributed in a completely randomized design, with six replications. The stocking density was 67 shrimp m^{-3}, which is considered a low-density production system, given the defined experimental model, with a total of 10 shrimp per experimental unit. The Pacific white shrimp used in the study were from the Speed Line Aqua lineage (Aquatec) and had an initial weight of 9.93 ± 1.16 g. Biometrics were performed to determine the average initial weight, which was used to direct them to the quarantine and adaptation period. During the quarantine period, they were fed commercial feed with 38% crude protein and were evaluated for the presence of pathogenic organisms.

Food

The individuals were fed three times a day with commercial feed according to shrimp consumption. The diet used was the commercial one from the Density 38 J brand, with pellet sizes ranging from 2 to 3 mm, containing 38% crude protein, 9% ether extract, 4% crude fiber, 12% mineral matter, 3% calcium, and 1.5% phosphorus.

Water quality monitoring

Water quality monitoring was conducted daily to evaluate the temperature, hydrogen potential (pH), alkalinity, oxygen concentration, nitrite, nitrate, and ammonia levels in the water using a Multiparameter Photometer for Aquaculture Hanna model HI83303-01 (Table 1). The values found for water quality were within ideal conditions for shrimp cultivation, as suggested by Kubitza (2018).

Assessment of zootechnical parameters

To obtain the zootechnical parameters, the shrimp were weighed on a precision scale (0.01 g) at the beginning of the experimental period, and every 15 days for 60 days, to obtain the performance parameters (weight gain, feed consumption, apparent feed conversion, protein efficiency rate, specific growth rate).

The following formulas were used:

$$\text{Live weight gain (g)} = \text{final weight} - \text{initial weight}$$

$$\text{Apparent feed conversion (g g}^{-1}) = \frac{\text{feed consumption}}{\text{live weight gain}}$$

$$\text{Protein efficiency rate (g g}^{-1}) = \frac{\text{live weight gain}}{\text{crude protein consumption}}$$

$$\text{Specific growth rate (\% d}^{-1}) = \frac{\ln(\text{final weight}) - \ln(\text{initial weight})}{\text{time (d)}}$$

Obtaining the growth curve and statistical analysis

To describe the growth curve, the Gompertz model was applied: $y = k \times e^{-e^{-b(x-x_0)}}$, where *y*: live weight (g) of the animal at time *x*, expressed as a function of *k*; *k*: live weight (g) at the animal's maturity; *b*: maturity rate (per day); x_0: time (d) at which the growth rate is maximum. Based on the estimated equation, growth rates (g d^{-1}) were calculated as a function of time (t), using the derivative $\frac{dy}{dx} = b \times y \times e^{-b(x-x_0)}$, from the equation described by Winsor (1932). The model parameters were estimated using the modified Gauss-Newton method through nonlinear regression, as implemented in the NLIN procedure from SAS (2014). The parameters indicated in the equations of the nonlinear mathematical models and the performance variables were subjected to analysis of variance using the ANOVA procedure from SAS (2014). The following criteria were used to evaluate the growth curve model as a function of weight: the Akaike information criterion (AIC) (Akaike 1974), the Bayesian information criterion (BIC) (Schwarz 1978), and the number of iterations required for the model to converge, using the NLMIXED and GCONV procedure from SAS (2014).

RESULTS

During the experiment, the water temperature (T°C), hydrogen potential (pH), and alkalinity were all within the expected levels for optimal performance (Table 1). Furthermore, the amount of nitrogen (ammonia and nitrite) remained low throughout the experiment, due to the high rate of aeration and the biological filter's action. The availability of food (feed), water quality, and nutrient concentration did not affect shrimp development.

Temperature is a vital parameter in shrimp growth, feeding behavior, and survival, as well as in determining ammonia toxicity, dissolved oxygen (DO) concentration, and evaporation rates. The average temperature was 29.83°C (Table 1).

Table 1. Values of water quality variables evaluated during the study for *Penaeus vannamei* cultivated in a recirculating aquaculture system (RAS).

Variables	Oxygen (mg L^{-1})	pH	Alkalinity (mg L^{-1})	Ammonia (NH_3) (mg L^{-1})	Nitrite (NO_2-N) (mg L^{-1})	Nitrate (NO_3) (mg L^{-1})	Temperature (°C)	Salinity (%)
Mean	5.90	8.50	218.58	0.15	0.28	0.87	29.83	19.83
Standard deviation	0.85	0.05	6.49	0.09	0.27	1.38	1.60	0.89

DO is the most important water quality parameter to monitor in aquaculture systems. It affects short-term survival, long-term growth, bacterial performance, and system carrying capacity. The average DO was 5.90 mg L^{-1} (Table 1).

pH is another water quality parameter, with an average of 8.50 (Table 1). Protein-rich food contains more nitrogen, which results in increased nitrification and alkalinity. The observed average alkalinity was 218.58 mg L^{-1} (Table 1).

Ammonia is the primary metabolic waste product of shrimp, resulting from the bacterial decomposition of uneaten food. The average value for ammonia (NH_3) was 0.15 mg L^{-1}, for nitrite (NO_2-N) 0.28 mg L^{-1}, and for nitrate (NO_3) 0.87 mg L^{-1} (Table 1).

The average values of shrimp production performance are presented (Table 2), showing accelerated growth and weight gain. Even though a recirculation system was used, the performance was superior to data on shrimp grow-out in external fattening ponds; the gain in weekly weight was 1.32 g.

In this study, we worked with a density of approximately 67 shrimp m^{-3}, which proved to be adequate for their growth. During the study, Pacific white shrimp had an average daily feed consumption of 399.2 mg, equivalent to a protein intake of 151.69 mg, resulting in a nitrogen consumption of 24.27 mg per animal. Part of this amount was destined for muscle growth, and the other part was incorporated into the aquatic environment. Shrimp foods typically contain 33 to 45% protein and 1.2 to 1.3% phosphorus. Only 24 to 37% of the nitrogen and 13 to 28% of the phosphorus in such feeds are converted into shrimp biomass.

The values of the performance variables evaluated during the study are presented in Table 2. The averages were as follows: 9.93 g for initial weight, 21.28 g for final weight, 399.2 mg for daily feed consumption, and 1.44 g g^{-1} for feed conversion. The specific growth rate found was 3.00% per day, and the protein efficiency rate was 1.82 g g^{-1}.

The estimated values of the parameters of the Gompertz equation for live weight are presented in Table 3. The growth curve, estimated for live weight using the Gompertz model, presented a sigmoidal shape (Fig. 1). In Figure 2, it is possible to estimate, using the Gompertz model, the time at which the growth rate is maximum, being estimated at 117.3 days, demonstrating that the shrimp *P. vannamei* shows continuous growth until the fourth month of life.

DISCUSSION

The ideal temperature range for Pacific white shrimp is 28 to 30°C (Kubitza 2018, Prangnell et al. 2019), which encompasses the values observed in this study (Table 1). Shrimp become more susceptible to fungal infections (e.g. *Fusarium* spp.) when the temperature is below ideal, whereas above ideal causes oxygen saturation to get very low, and ammonia toxicity to increase, leaving shrimp more prone to disease (Prangnell et al. 2019).

DO is typically expressed in mg L^{-1} or percentage saturation. Maintaining DO concentration at 4-8 mg L^{-1} (52-105% saturation at sea level and 30°C) and preferably above 5 mg L^{-1} (65% saturation), as we did in this study (5.90 mg L^{-1}), is in accordance with the recommendations by Prangnell et al. (2019). Oxygen solubility decreases as water temperature and salinity increase and as atmospheric pressure decreases (e.g. at higher altitudes). The low amount of DO reduces the performance of shrimp and aerobic bacteria normally present in the culture system (Lobato et al. 2020).

Kubitza (2018) and Prangnell et al. (2019) denote that the best pH range for shrimp growth is between 6 and 9. A pH level that is too low can be harmful to shrimp and bacteria (Ebeling et al. 2006), causing stress to the shrimp and softening of the carapace, which affects growth and survival, as well as increases the risk of toxicity due to nitrite and hydrogen sulfide (Chien 1992). A pH below 6.8 results in a decrease in the activity of nitrifying bacteria, while at a pH above 9.0, the proportion of non-toxic ammonia increases drastically (DeLong 2009). Chen et al. (2015) reported that long-term exposure to a low pH level (6.8) reduces the immune response and resistance of juvenile Pacific white shrimp to *Vibrio alginolyticus.*

Table 2. Values of performance variables evaluated during the study for *Penaeus vannamei* cultivated in a recirculating aquaculture system (RAS).

Variables	Initial weight (g)	Final weight (g)	Survival Rate (%)	Food consumption/day (mg)	Food conversion ($g\ g^{-1}$)	Specific growth rate (% d^{-1})	Protein efficiency rate ($g\ g^{-1}$)
Mean	9.93	21.28	98.33	399.2	1.44	3.00	1.82
Standard deviation	1.16	2.12	0.83	38.38	0.11	0.32	0.20

Table 3. Estimates of Gompertz equation parameters for live weight of *Penaeus vannamei* cultivated in a recirculating aquaculture system (RAS). AIC: Akaike information criterion = 6.8; BIC: Bayesian information criterion = 4.3, number of interactions = 20. Lower AIC and BIC values indicate a better model fit, balancing goodness-of-fit and model complexity. The model was estimated with 20 interaction terms included.

Variable	Parameters					
	y (g)		*b* ($g\ d^{-1}$)		x_0 (days)	
Live weight	40.05		0.0196		117.3	
Standard error	14.74		0.008		19.55	
Confidence limits	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
	10.84	69.25	0.00393	0.0353	78.59	156.1

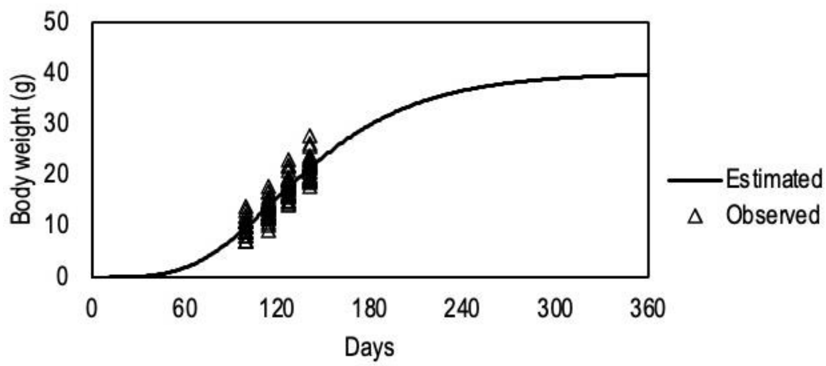

Figure 1. Live weight growth curve for 360 days generated from the Gompertz equation for *Penaeus vannamei* cultivated in a recirculating aquaculture system (RAS).

Protein-rich food contains more nitrogen, which results in increased nitrification and alkalinity. For example, alkalinity in a system fed a 40% protein feed decreases more quickly than in one fed a 35% protein feed (Prangnell et al. 2016). The diet used in the study contained 38% crude protein, a value intermediate compared to the currently used levels in shrimp farms in Brazil. The loss of alkalinity limits the amount of inorganic carbon available for bacterial nitrification, resulting in a decline in pH that limits bacterial activity and leads to an accumulation of ammonia. This deterioration in water quality reduces shrimp performance. The alkalinity value found in the study was 218.58 ± 6.49, which is within the stipulated range for heterotrophic and autotrophic systems (60 to 230), favoring the development of chemoautotrophic bacteria, including nitrifying bacteria that oxidize ammonia to nitrate (Ebeling et al. 2006, Leffler & Brunson 2014).

High ammonia content increases shrimp oxygen consumption, damages gills, decreases immunity, and reduces growth and survival (Chien 1992, Samocha et al. 2019). The amount of ionized ammonia (NH_4^+) and non-ionized (free) ammonia (NH_3) depends especially on pH, as well as temperature and salinity. Non-ionized ammonia is significantly more toxic because it moves more easily across gill membranes (Ramírez-Rochín et al. 2017). In the present study, the values found (0.15 ± 0.09 mg L^{-1}) were below those considered harmful to

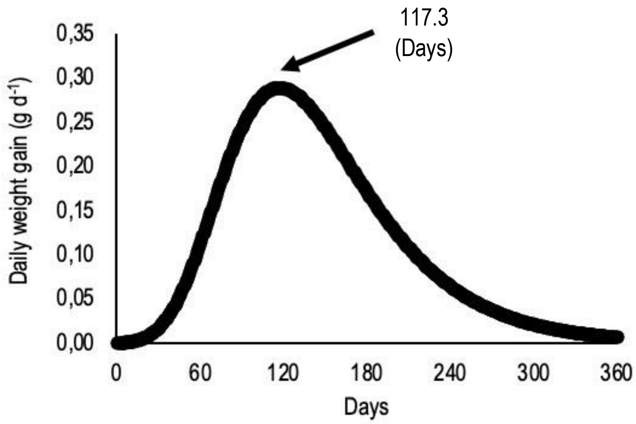

Figure 2. Daily weight gain for live weight over 360 days generated from the equation derived from Gompertz using the estimated value of "*b*" (maturity rate) for *Penaeus vannamei* cultivated in a recirculating aquaculture system (RAS).

the growth of *P. vannamei*, which ranges from 0.6 to 2.8 mg L^{-1} of NH_3 (Lin & Chen 2001). Ammonia tolerance increases with increasing water salinity, which must be taken into account in closed water circulation systems. Nitrite is formed by the oxidation of ammonia by oxidative bacteria and is toxic to shrimp, although less so than ammonia, especially in salt water. Nitrite toxicity, however, can become a serious problem in newly started systems because populations of nitrite-oxidizing bacteria develop later and remain for a longer period than the population of ammonia-degrading bacteria. Nitrite toxicity increases with pH and decreases with salinity.

Tolerance to nitrite increases as the shrimp grows (Chien 1992), and nitrite levels > 0.6 mg L^{-1} should be considered as a warning for shrimp farming systems. In this study, the values were below this limit (0.28 mg L^{-1}). In salinities 0.6-2.0, the range of 5.7 to 15.0 mg L^{-1} of nitrite could cause the death of 50% of the shrimp exposed by 96 h at these quantities. At salinities of 15-38, the mortality of 50% of shrimp exposed for 96 h to nitrite will occur in a range of 76.0 to 321.0 mg L^{-1} (Ramírez-Rochín et al. 2017).

The observed growth performance exceeded typical results from shrimp grow-out operations in outdoor ponds. In this study the weekly weight gain was 1.32 g (Table 1), in the study by Maia et al. (2012) in fattening nurseries it was 0.84 g, that is, presenting values higher than even production data, which demonstrates that the animals adapted very well to the system, due to the conditions that were offered, such as a balanced diet according to with their requirement and the water quality maintained during the study period (Table 1). Therefore, the environment was conducive for the animals to express their maximum growth potential, a desirable factor for determining the growth curve in this production system.

In this study, we worked with a density of approximately 67 shrimp m^{-3}, which proved to be adequate for shrimp growth. In the study by Muangkeow et al. (2007), shrimp were stocked at a density of 40 shrimp m^{-2}, whereas shrimp raised in super-intensive systems typically use stocking densities of 100 to 500 shrimp m^{-2} (Fast 1992). Under these conditions, more waste is produced, which has the potential to support further studies on alternative farming systems. There is also a difficulty in comparing this study with others in the literature, since data are scarce regarding the topic addressed in the present study.

Nitrogen and phosphorus not incorporated into animal biomass are discarded as residues in the water and sediment of the production system (Briggs & Funge-Smith 1994, Lawrence et al. 2001, Burford et al. 2002), directly impacting the aquatic environment, where these compounds must be recycled.

To reduce the load of waste (nitrogen and phosphate) in the aquatic environment, an appropriate diet for Pacific white shrimp is necessary, which depends on a better understanding of animal growth in different breeding environments. According to Emmans (1981), to calculate nutritional requirements and indicate the food intake of a given animal during its development, it is mandatory to know its growth potential. Each animal species has a particular growth curve, which depends on appropriate measures and is not environmentally limited. He emphasizes that various aspects, such as maturity, composition, and nutrient deposition rates in the body, can impact growth. Therefore, the use of mathematical models and equations is necessary to clearly and accurately demonstrate the growth of these animals according to their age, for the development of feeding programs (Gous et al. 1999).

Many nonlinear mathematical models are being used to describe the growth and deposition of nutrients in animals. However, there is debate about the best model to adopt, as Fitzhugh Jr. & Taylon (1971) suggest that the choice of the best model is influenced by two key factors: the possibility of biological interpretation of the parameters and the quality of adjustment. Within these aspects, the Gompertz function was considered the most appropriate to describe the growth of Pacific white shrimp fed a commercial diet in a RAS, as this crustacean has an initial weight close to zero, which makes it difficult to adjust other models.

Nonlinear models incorporate adjustments for growth and nutrient deposition curves, and are widely used to determine the nutritional requirements of animals (Marcato et al. 2010). This way, it is possible to determine a specific feeding program for Pacific white shrimp using these equations. The estimated values of the parameters of the Gompertz equation for live weight are presented in Table 3.

The Gompertz growth model, when applied to estimate live weight over time, produces a sigmoidal curve characterized by three distinct phases: an initial exponential acceleration, followed by a progressive deceleration as maturity is approached, and finally a plateau representing the asymptotic weight. This S-shaped trajectory is intrinsic to the Gompertz function, which mathematically captures the self-limiting nature of biological growth by incorporating an inflection point where growth rate transitions from increasing to diminishing returns. According to Vargas et al. (2005), when the curve exhibits the largest and longest plateau, the animal's growth efficiency is greater. When environmental interactions influence animal size, growth rates are highly flexible, with specific growth and mortality being the fundamental characteristics that determine population growth (Werner & Gilliam 1984). According to Duarte (1975), weight at maturity (Wm) is a parameter that genetically expresses the development potential and the interaction of genes that determine growth, making it an asymptotic measure resulting from previous stages of growth.

In Figure 2, the Gompertz model was used to estimate the time at which the growth rate is maximum (117.3 days), demonstrating that *P. vannamei* exhibits continuous growth until its fourth month of life. This value found is in line with the study by Tian et al. (1993), who estimated the maximum growth rate at 110 to 115 days for *P. vannamei* in a semi-intensive cultivation system, with the Wm estimated at around 20 g, a value much lower than that found in this study of around 40 g, a difference that can be explained by the great advances in genetic improvement of shrimp in recent years.

This growth is also influenced by the food the animal receives and the climatic conditions of the region where it is located, as well as its health status, genetics, biotype, breed, weight, age, and body condition (Mazzini et al. 2003). To calculate nutritional requirements and indicate an animal's food intake during its development, its growth potential must be discovered. By understanding the interactions between nutrient requirements and the development of an animal throughout its life or during the productive period, it is possible to identify nutritional deficiencies and achieve maximum performance, discern the limits of production, and make appropriate adjustments to improve animal productivity.

CONCLUSIONS

The production levels found in this study are within the parameters expected for intensive production. The quality of the water obtained during the study was maintained by the RAS biological system, remaining within tolerable levels for shrimp farming. This factor is one of the most important in shrimp farming, especially when using a system with high stocking density, where any change in the physical-chemical parameters of the water can harm the growth and survival of these shrimp. Based on the general results, it is suggested that RAS can be used for marine shrimp in a super-intensive system.

The Gompertz model presented an excellent fit to describe shrimp growth. This nonlinear equation described the growth of animals with a slaughter weight range close to reality (10.84 to 69.25 g). It estimated the maturity rate (*b*) at 0.0196 g d^{-1}, which can be used in nutrition and genetic improvement programs. The time and growth variables estimated by the equation reflected the current practice of shrimp farming worldwide. These estimated values will directly inform the formulation of diets and enhance our understanding of the performance of Pacific white shrimp (*P. vannamei*).

Credit author contribution

C.F.M. Mansano: conceptualization, validation, methodology, formal analysis, writing-original draft; B.G. Perinelli: funding acquisition, project administration, supervision, review, and editing; L.S. Nascimento: methodology, validation, supervision, review, and editing; P.F. Rocha & B.I. Macente: methodology, data curation, formal analysis, review, and editing; L.S. Vanzela: methodology, data curation, formal analysis, review, and editing; A.A. Navarrete & A.P. Lemes: formal analysis, review and editing. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

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