BOLETIM DO INSTITUTO DE PESCA
Scientific Article

Evaluation of feeding table optimizations in Pacific white shrimp nursery biofloc systems

Alfredo Mori Padilla[1], Mateus Aranha Martins[1*], Ramon Felipe Siqueira Carneiro[1], Francisco de Castro Lima Franch[1], Marco Antônio de Lorenzo[1], Felipe do Nascimento Vieira[1]

[1]Universidade Federal de Santa Catarina, Departamento de Aquicultura – Florianópolis (SC), Brazil.

*Corresponding author: m.aranha.martins@gmail.com

ABSTRACT

A 45-day experiment was conducted to optimize feeding rates in the nursery phase of Pacific white shrimp reared in biofloc systems (BFT). Four treatments were evaluated in quadruplicate, according to the Van Wyk table: maximum feeding rate; minimum feeding rate; minimum feeding rate minus 10%; and maximum feeding rate plus 10%. Post-larvae (0.08 ± 0.00 g) were cultured at the density of 2,000 shrimp·m^{-3}, and water quality, solids production, and productive performance were all monitored. No significant difference was observed in final mean weight (1.47 ± 0.17 g), productivity (2.34 ± 0.20 kg·m^{-3}) and survival (85.29 ± 5.44%) among treatments, but feed conversion ratio was significantly lower in the minimum feeding rate and minimum feeding rate minus 10% treatments, indicating efficient feed conversion without compromising growth. These treatments also resulted in lower values of toxic nitrogen compounds and total suspended solids, suggesting a positive impact on water quality. Although these rates proved suitable, continuous adjustments are needed owing to variations in the BFT system. This study provides guidelines for optimizing feeding management in superintensive BFT nursery systems.

Keywords: Post-larvae; *Penaeus vannamei*; Feeding management; Biofloc systems.

Otimização da taxa de alimentação do camarão-branco-do-pacífico em sistema de bioflocos na fase de berçário

RESUMO

Realizou-se um experimento de 45 dias para otimizar as taxas de alimentação na fase de berçário do camarão-branco-do-pacífico em sistemas de bioflocos (BFT). Quatro tratamentos foram avaliados em quadruplicata: taxa máxima de alimentação de acordo com a tabela Van Wyk; taxa mínima de alimentação de acordo com a tabela Van Wyk; taxa mínima -10% de alimentação de acordo com a tabela Van Wyk; e taxa máxima +10% de alimentação de acordo com a tabela Van Wyk. As pós-larvas (0,08 ± 0,00 g) foram cultivadas na densidade de 2.000 camarões·m^{-3}, e qualidade da água, produção de sólidos e desempenho produtivo foram monitorados. Não houve diferença significativa no peso médio final (1,47 ± 0,17 g), produtividade (2,34 ± 0,20 kg·m^{-3}) e sobrevivência (85,29 ± 5,44%), mas o fator de conversão alimentar foi significativamente menor em taxa mínima de alimentação e taxa mínima -10% de alimentação, indicando uma conversão alimentar eficiente sem prejudicar o crescimento. Esses tratamentos resultaram em menores valores de compostos nitrogenados tóxicos e sólidos suspensos totais, sugerindo um impacto positivo na qualidade da água. Embora essas taxas tenham sido adequadas, destaca-se a necessidade de ajustes contínuos por causa das variações no sistema BFT. Este estudo contribui para a otimização do manejo alimentar em sistemas de berçário superintensivos em BFT.

Palavras-chave: Pós-larva; *Penaeus vannamei*; Manejo alimentar; Sistemas de bioflocos.

Received: January 3, 2024 | **Approved:** April 15, 2024
Section editor: Fabiana Garcia

INTRODUCTION

The Pacific white shrimp (*Penaeus vannamei*) is one of the most relevant and widely cultivated marine shrimp species, accounting for 51.7% of the world's crustacean production (FAO, 2022). Native to the tropical and subtropical regions of the Pacific Ocean, this species has become the primary choice in global aquaculture based on its rapid growth rate, high adaptability to different farming conditions, and the nutritional quality of its meat (FAO, 2022). Technological advances and improved management practices have allowed the intensification of shrimp farming, increasing productivity and the efficiency of cultivation systems (El-Sayed, 2021; Emerenciano et al., 2021).

Intensified aquaculture represents an innovative and sustainable approach to the cultivation of aquatic organisms with the aim of maximizing food efficiency and ensuring the health of both the production system and the surrounding environment (Nunes and Parsons, 2006). The intensified aquaculture approach seeks to address these challenges by focusing on the optimization of feed efficiency (da Silva et al., 2022). Through strict control of water quality, balanced nutrient supply, and the implementation of advanced technologies, intensified systems aim to ensure that the amount of feed provided to aquatic organisms precisely matches their nutritional needs (da Silva et al., 2022).

Biofloc technology differs from traditional aquaculture systems since it focuses on the creation and manipulation of bioflocs as an essential part of the aquatic ecosystem (Avnimelech, 1999; Wasielesky Jr. et al., 2006). These bioflocs are made up of a complex community of microorganisms, including bacteria, protozoa, and algae, which develop in suspension in the water. One of the main advantages of biofloc technology is its ability to efficiently recycle nutrients (de Schryver et al., 2008; Serra et al., 2015). This recycling of nutrients reduces the need for frequent water changes and contributes to improving water quality, minimizing its consumption and negative environmental impacts (Krummenauer et al., 2014). In addition, the presence of bioflocs as a natural food source for farmed organisms can reduce dependence on commercial feed, making farming more economical and sustainable (Wasielesky Jr. et al., 2006; Emerenciano et al., 2013).

Proper feeding management is one of the fundamental pillars for the success of Pacific white shrimp aquaculture during the nursery phase (Van Wyk, 1999; da Silva et al., 2022). This initial stage of cultivation is of utmost importance as it directly influences the healthy development and growth of young shrimp, establishing the foundation for a successful production cycle (Carvalho and Nunes, 2006). During the nursery phase, shrimp experience rapid growth and high metabolic activity. Efficient feeding management during this phase is essential to optimize survival rates, maximize weight gain, and reduce the time needed to reach the desired standards (Audelo-Naranjo et al., 2012; Emerenciano et al., 2013).

Formulation of the feed should take into account the balanced composition of proteins, lipids, carbohydrates, vitamins and minerals, ensuring that shrimp receive all the essential nutrients for proper development (Braga et al., 2016). In addition, feeding frequency and volume should be adjusted according to shrimp growth and the specific conditions of the farming system (Van Wyk, 1999).

Feeding management in the nursery phase is not limited solely to shrimp nutrition; it also encompasses aspects, such as water quality control, temperature, and lighting, as these factors directly influence the metabolic rate and feeding behavior of shrimp (Van Wyk, 1999).

Therefore, proper adjustment of the feeding rate is one of the most important aspects of feeding management in shrimp farming during the nursery phase in biofloc systems. This initial stage is critical for the healthy development of shrimp as it directly influences their growth, survival rate, and efficiency in utilizing nutrients available in the cultivation environment. In that perspective, Van Wyk's (1999) feeding table is a valuable and widely used tool in aquaculture, especially in shrimp farming. This table serves as a guide that assists producers in determining optimal feed rations provided to aquatic organisms, considering factors such as animal size, water temperature, and growth rate for each phase. Adequate feeding is one of the most critical aspects for the success of aquaculture. In this regard, we conducted a 45-day experiment to optimize feeding rates in the nursery phase of Pacific white shrimp reared in biofloc systems (BFT) by adjusting standard feeding tables (e.g., Van Wyk's Table).

MATERIAL AND METHODS

Location

The 45-day experiment was performed at the Marine Shrimp Laboratory (Laboratório de Camarões Marinhos (LCM), part of the Aquaculture Department of the Universidade Federal de Santa Catarina, which is located in Barra da Lagoa, Florianópolis, Santa Catarina, Brazil.

Biological material

We used *P. vannamei* Speedline lineage post-larvae originated from a commercial laboratory, Aquatec Aquacultura LTDA, Canguaretama, Rio Grande do Norte, Brazil. Once at the LCM facilities, post-larvae were kept in a BFT environment in a 50-m^{-3} fiberglass tank (density of 10,000 larvae·L^{-1}) at a salinity of 33 g·L^{-1} until they reached the stage of post-larva 20 (PL 20). Upon reaching the PL 20 stage, post-larvae were transferred to the experimental units, consisting of 16 rectangular plastic tanks with a useful volume of 48 L for each experimental unit (biofloc system without water renewal) equipped with an aeration system and heaters to provide constant temperature.

Experimental design and experimental units

The experimental design was entirely randomized. Four treatments were used with four replicates each: maximum treatment (Max), minimum treatment (Min), maximum+10% treatment (Max+10%), and minimum-10% treatment (Min-10%). The maximum and minimum values were based on the values set in Van Wyk's feeding table (1999). The Max+10% treatment consisted of 10% more than the maximum value in the Van Wyk's feeding table, while the Min-10% treatment consisted of 10% less than the minimum value in the Van-Wyk's feeding table, as shown in Table 1.

Experimental management

Sixteen experimental units in total were used, consisting of polyethylene tanks with a useful volume of 48 L stocked with 2,000 shrimp per m^{-3}. The experimental units were populated with post-larvae (PLs 20) (0.08 ± 0.00 g), and the cultivation was carried out for six weeks until the animals reached approximately 1 g. Ninety-six shrimp were stocked per experimental unit, according to Eq. 1:

$$\text{Number of animals per tank} = \frac{\text{Biomass (g)}}{\text{Mean weight (g)}} \quad (1)$$

One day before stocking, 12 L of inoculum water, which were taken from a mature biofloc shrimp matrix tank (50 m^{-3} of volume, 100 shrimp·m^{-3}), were transferred to each experimental unit, and the remaining volume was filled with 36 L of seawater. Initial inoculum quantity was calculated by Eq. 2.

$$C_1. V_1 = C_2. V_2 \quad (2)$$

Where: C1: concentration of total suspended solids (TSS) in the matrix tank; C2: desired concentration of TSS at the beginning of the experiment (around 200 mg·L^{-1}); V1: volume of the matrix tank; V2: volume of the experimental unit.

After being filled with both inoculum (12 L) and seawater (36 L), the experimental units presented the following physicochemical characteristics (Table 2).

Table 2. Water quality variables at the beginning of the experiment evaluating feeding table improvements in a Pacific white shrimp nursery system.

Variable	Value
Total ammonia nitrogen (mg·L^{-1})	0.10 ± 0.06
Nitrite-N (mg·L^{-1})	0.07 ± 0.00
Nitrate-N (mg·L^{-1})	1.76 ± 0.19
Alkalinity (mg $CaCO_3$·L^{-1})	142 ± 5
Salinity (g·L^{-1})	33.6 ± 0.1
pH	8.33 ± 3.61
Total suspended solids (mg·L^{-1})	371 ± 40
Settleable solids (mg·L^{-1})	4.0 ± 1.2

Data presented as mean ± standard deviation of 16 experimental units.

Table 1. Feeding rates maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to the Van Wyk's (1999) table adopted in the experiment according to the biometrics, for the intensive bioflocs systems cultivation of *Penaeus vannamei*.

Shrimp mean weight (g)	Feeding rate Van Wyk (1999) (% biomass·day^{-1})		Feeding rate Adjusted (% biomass·day^{-1})	
	Max	Min	Max+10%	Min−10%
< 1	35.0	25.0	38.5	22.5
0.1–0.24	25.0	20.0	27.5	18.0
0.25–0.49	20.0	15.0	22.0	13.5
0.5–0.9	15.0	11.0	16.5	9.9
1.0–1.9	11.0	8.0	12.1	7.2

Post-larvae were fed with 40% crude protein commercial marine shrimp feed (Aqua Guabitec) specifically formulated for post-larvae. Every week, 30 post-larvae were collected with a scoop net and placed in a beaker to be weighed using a digital scale with precision down to 0.01 g and then returned to their experimental units to monitor growth and make adjustments to the feed by calculating the proper amount according to the feed rate in the experimental table. The feed was stored for use in the daily feedings and was provided six times a day (8, 10, 12, 14, 16, and 18 h) to all experimental units, according to the quantities for each group.

Water quality analysis

Throughout the experiment, water quality variables were monitored. Temperature and dissolved oxygen were measured twice a day using a multiparameter device (YSI Pro 2030); the first measurement took place at 8 h and the second measurement at 17 h. The pH (Tecnal® pH-meter), salinity (YSI EcoSense EC300A), TSS (Strickland and Parsons, 1972), settleable solids (SS) (Imhoff cone), alkalinity (APHA; AWWA; WEF, 2005), total ammonia nitrogen (TAN) (Grasshoff et al., 1983), and nitrite-N (NO_2^--N) (Strickland and Parsons, 1972) were analyzed twice a week. Nitrate-N (NO_3^--N) was measured at the beginning, middle, and end of the experiment, using the Hach NitraVer 5 Kit (nitrate reagent powder pillows).

Control of alkalinity, total suspended solids, and freshwater replacement

Calcium hydroxide ($Ca(OH)_2$) was added to maintain alkalinity above 150 $mg \cdot L^{-1}$. TSS were maintained at concentrations between approximately 400 and 600 $mg \cdot L^{-1}$ (Schveitzer et al., 2013) by removing the excess through filtration with a 20-µm bag filter. Water was not renewed during the cultivation; only fresh water was used to replace losses from evaporation.

Growth performance

At the end of the experiment, all post-larvae were weighed, and the following growth performance variables were calculated: survival (%), apparent feed conversion ratio (FCR), productivity ($kg \cdot m^{-3}$), specific growth rate (SGR) (% day^{-1}), final mean weight (g) and biomass gain (g), using Eqs. 3, 4, 5, 6, 7, and 8, respectively:

$$\text{Survival (\%)} = \frac{\text{Final number of shrimp}}{\text{Initial number of shrimp}} \times 100 \quad (3)$$

$$\text{Feed conversion ratio} = \frac{\text{total feed input (g)}}{\text{biomass increase (g)}} \quad (4)$$

$$\text{Yield } (\text{kg} \cdot \text{m}^{-3}) = \frac{\text{final biomass (kg)}}{\text{tank volume } (\text{m}^3)} \quad (5)$$

$$\text{SGR (\% day}^{-1}) = \text{ln final mean weight (g)} - \text{ln inicial mean weight (g)/cultivation period (days)} \quad (6)$$

$$\text{Final mean weight (g)} = \frac{\text{biomass (g)}}{\text{final number of animals}} \quad (7)$$

$$\text{Biomass increase (g)} = \text{final biomass (g)} - \text{initial biomass (g)} \quad (8)$$

Nitrogen and phosphorus content

At the end of the experiment, samples of approximately 100 g of shrimp were collected from each tank to determine the nitrogen (N) and phosphorus (P) contents of *P. vannamei* shrimp, following Malavolta et al. (1997).

Statistical analysis

A one-way analysis of variance was applied after the assumptions of normality (Shapiro–Wilk) and homoscedasticity (Levene) were analyzed, followed by Tukey's test to verify the differences among treatments. The significance level adopted was 5% for all analyses, which were performed using the Jamovi statistical program, version 2.3 (Jamovi, 2023).

RESULTS

Water quality variables

The results of the experiment revealed no significant difference in the levels of dissolved oxygen measured at 17 h, temperature or salinity ($p > 0.05$). However, significant differences were noted in dissolved oxygen measurements taken in the morning, which, at that time, had the lowest values recorded in the Max+10% treatment (Table 3).

The measured total ammonia showed statistical differences among treatments with higher values for the Max and Max+10% treatments (Table 3, Fig. 1). Nitrite-N values followed the same trend as those for ammonia with statistical differences between the Max and Max+10% treatments compared to the Min and Min−10% treatments (Table 3, Fig. 2). Nitrate-N measured in the Max+10% treatment showed a higher value, differing statistically from the Min and Min-10% treatments (Table 3, Fig. 3). Alkalinity values differed among treatments. The Min treatment had the lowest value measured, and the Max and Max+10% treatments had highest values. The Min−10% treatment presented an intermediate value, statistically equal to that of the other treatments (Table 3).

The measured pH values showed statistical differences among treatments, but with similar values (Table 3). Salinity did not

Table 3. Mean and standard deviation of the water quality parameter during 45 days of nursery cultivation of *Penaeus vannamei* in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table.

Variables	Treatments				p-value
	Min-10%	Min	Max	Max+10%	
DO morning ($mg \cdot L^{-1}$)	6.52 ± 0.18[a]	6.50 ± 0.02[ab]	6.46 ± 0.03[ab]	6.44 ± 0.02[b]	0.016
DO afternoon ($mg \cdot L^{-1}$)	6.38 ± 0.02	6.35 ± 0.06	6.27 ± 0.06	6.30 ± 0.03	0.086
Temperature morning (°C)	28.2 ± 0.1	28.3 ± 0.1	28.3 ± 0.2	28.3 ± 0.1	0.767
Temperature afternoon (°C)	28.4 ± 0.0	28.4 ± 0.1	28.5 ± 0.1	28.4 ± 0.0	0.166
TAN ($mg \cdot L^{-1}$)	0.16 ± 0.01[a]	0.18 ± 0.02[a]	0.38 ± 0.03[b]	0.45 ± 0.09[b]	< 0.001
Nitrite-N ($mg \cdot L^{-1}$)	0.20 ± 0.00[a]	0.22 ± 0.01[a]	0.32 ± 0.03[b]	0.36 ± 0.04[b]	0.005
Nitrate-N ($mg \cdot L^{-1}$)	2.70 ± 0.28[a]	2.69 ± 0.38[a]	3.11 ± 0.26[ab]	3.82 ± 0.33[b]	0.022
Alkalinity (mg $CaCO_3 \cdot L^{-1}$)	175 ± 5[ab]	165 ± 2[a]	182 ± 12[b]	188 ± 3[b]	0.008
pH	8.28 ± 0.00[a]	8.26 ± 0.01[ab]	8.24 ± 0.00[b]	8.24 ± 0.01[b]	0.001
Salinity ($g \cdot L^{-1}$)	33.3 ± 0.2	33.5 ± 0.2	33.4 ± 0.1	33.3 ± 0.1	0.451
TSS ($mg \cdot L^{-1}$)	582 ± 15[a]	596 ± 18[a]	681 ± 34[b]	685 ± 17[b]	< 0.001
SS ($mL \cdot L^{-1}$)	13.4 ± 1.1[ab]	14.2 ± 2.1[ab]	19.3 ± 4.1[bc]	25.0 ± 4.5[c]	< 0.001

Different letters in the same row indicate significant differences between treatments according to the Tukey's test at the significance level of 0.05; DO: dissolved oxygen; TSS: total suspended solids; TAN: total ammonia nitrogen; SS: settleable solids.

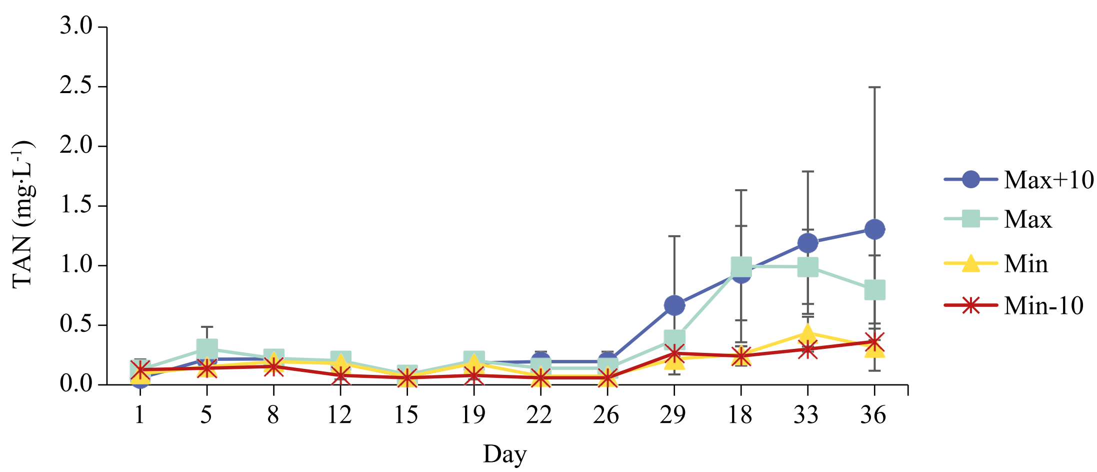

Figure 1. Total ammonia nitrogen (TAN) measured during 45 days of nursery cultivation of *Penaeus vannamei* in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table.

differ significantly among treatments, maintaining values close to 33 $g \cdot L^{-1}$ (Table 3). For the variables TSS and SS, the measured values differed statistically among treatments following the same trend, but with greater accumulation in the Max and Max+10% treatments (Table 3, Figs. 4 and 5). Treatments with higher feeding rates presented the highest values of SS and nitrogenous

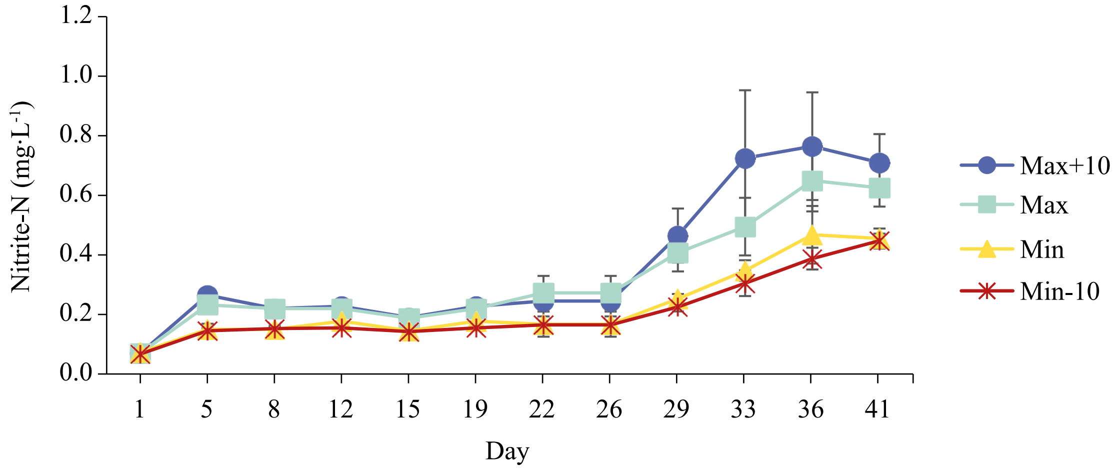

Figure 2. Nitrite-N measured during 45 days of nursery cultivation of *Penaeus vannamei* in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table.

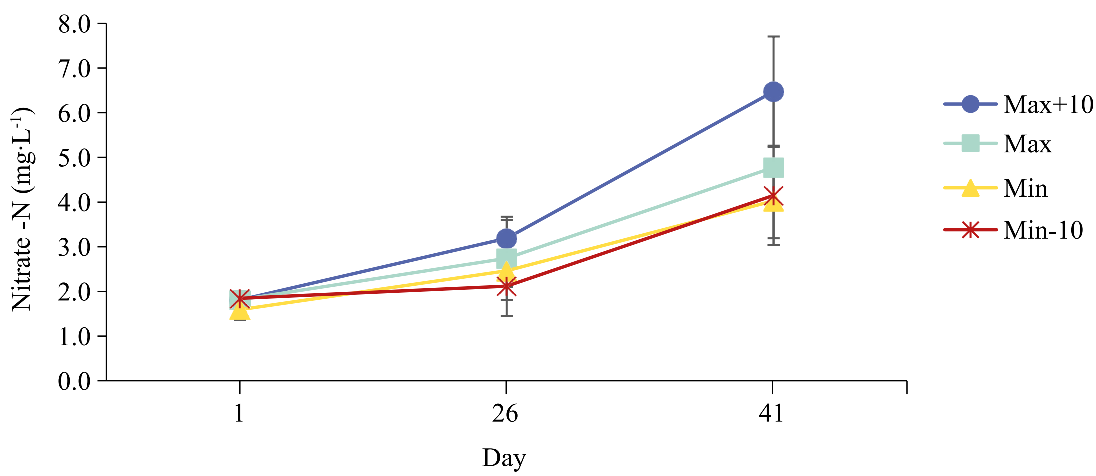

Figure 3. Nitrate-N measured during 45 days of nursery cultivation of *Penaeus vannamei* in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table.

compounds, while treatments with lower feeding rates exhibited the highest values of dissolved oxygen in the morning and pH.

Growth performance

Significant differences in zootechnical performance were only observed for the feed conversion factor, which showed that treatments using the minimum rates resulted in the lowest conversion values (Table 4).

Nitrogen and phosphorus content

Shrimp nitrogen and phosphorus contents showed no significant difference among treatments, as shown in Figs. 6 and 7.

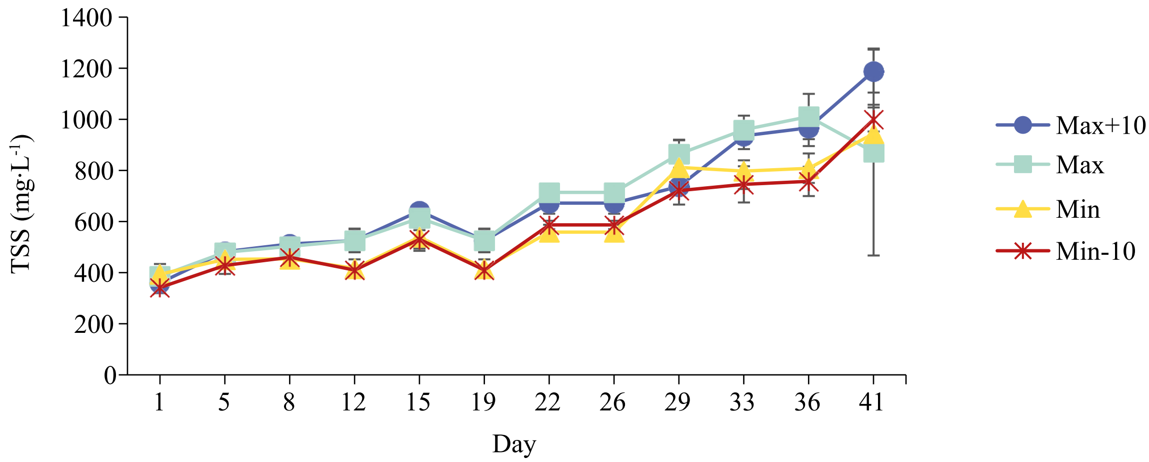

Figure 4. Total suspended solids (TSS) measured during 45 days of nursery cultivation of *Penaeus vannamei* in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table.

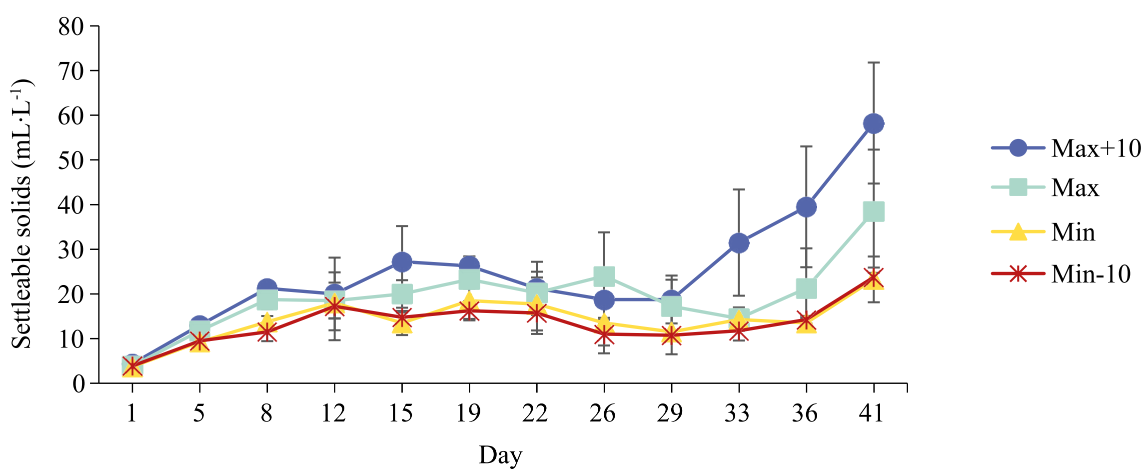

Figure 5. Settleable solids measured during 45 days of nursery cultivation of *Penaeus vannamei* in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table.

DISCUSSION

Biofloc technology is an advanced technique that utilizes a diverse community of microorganisms, forming biological aggregates known as bioflocs, which act as a source of natural food. This results from their balanced composition derived from the microorganisms that make up the microbial flocs. The flocs contain crude protein, fatty acids, essential amino acids, and minerals at satisfactory levels for shrimp (Burford et al., 2004).

At the end of the experimental period, it was confirmed that water quality variables were maintained according to the ideal

Table 4. Mean and standard deviation of the zootechnical and production inputs during 45 days of nursery cultivation of *Penaeus vannamei* in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table.

Variable	Treatments				p-value
	Min-10%	Min	Max	Max+10%	
Initial mean weight (g)	0.08 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	-
Final mean weight (g)	1.46 ± 0.10	1.55 ± 0.09	1.39 ± 0.20	1.46 ± 0.17	0.637
Yield (kg·m^{-3})	2.26 ± 0.09	2.50 ± 0.07	2.27 ± 0.27	2.31 ± 0.13	0.069
FCR	1.63 ± 0.09[a]	1.66 ± 0.05[a]	2.57 ± 0.11[b]	2.77 ± 0.13[b]	< 0.001
SGR (% day^{-1})	20.76 ± 0.53	20.76 ± 0.42	20.35 ± 1.01	20.76 ± 0.84	0.602
Biomass gain (g)	108.70 ± 4.57	120.20 ± 3.43	109.13 ± 13.38	111.00 ± 6.43	0.069
Final biomass (g)	116.38 ± 4.57	127.88 ± 3.43	116.81 ± 13.38	118.68 ± 6.43	0.069
Survival (%)	82.81 ± 4.62	85.68 ± 4.76	87.50 ± 5.31	85.16 ± 7.81	0.723
Feed input (g)	177.63 ± 3.47[a]	200.52 ± 4.90[a]	279.88 ± 29.97[b]	307.47 ± 6.15[b]	< 0.001

FCR: feed conversion ratio; SGR: specific growth rate; different letters on the same line indicate significant differences between treatments according to the Tukey's test at a significance level of 0.05.

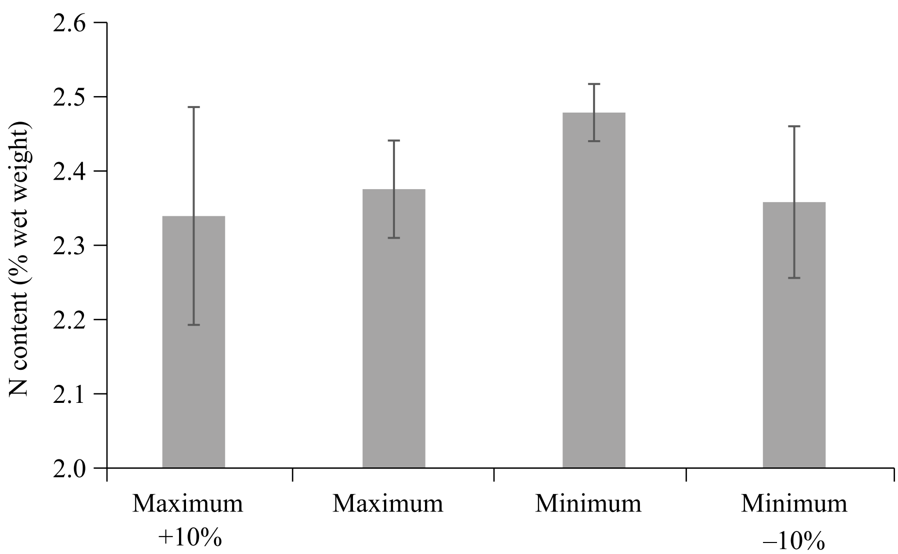

Figure 6. Nitrogen content in *Penaeus vannamei* nurseries in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum-10% (Min-10%) of feeding management according to Van Wyk's table. One-way analysis of variance, and p-value = 0.234.

ranges for the nursery culture of *P. vannamei*, as reported by Van Wyk and Scarpa (1999). This finding can be attributed to the use of a mature biofloc inoculum at the beginning of the experiment. This inoculum consisted of a diverse microbial community composed of nitrifying and heterotrophic bacteria, developing in suspension in the water (Martins et al., 2022). This microbial community is essential for the establishment of a stable and functional ecosystem, because it promotes the transformation of organic waste into solid particles, which serve as a natural food source for shrimp in the nursery stage (Said et al., 2022).

In our study, we observed that the levels of solids remained according to the recommended values for the species (Schveitzer et al., 2013; Gaona et al., 2016). Additionally, in treatments with a lower amount of feed, i.e., Min and Min-10% treatments, we

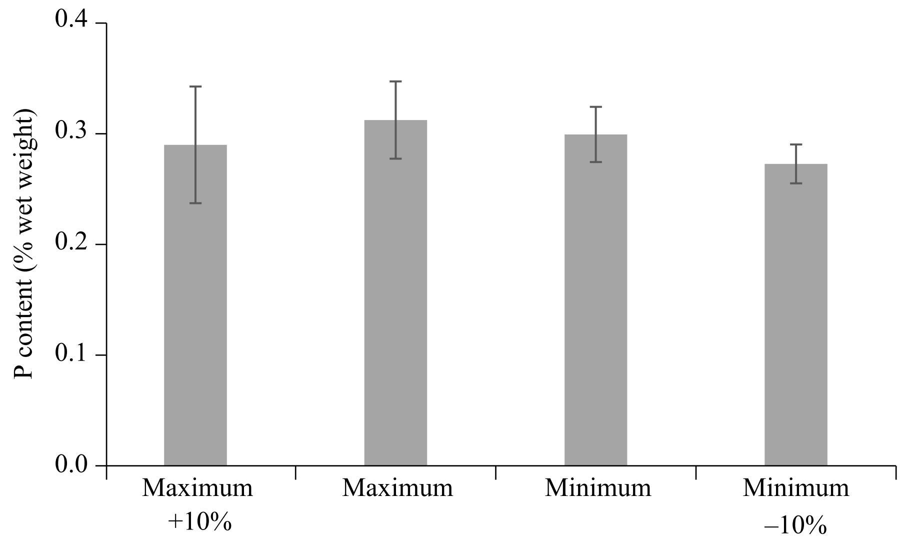

Figure 7. Phosphorus content of *Penaeus vannamei* nurseries in biofloc systems with different feeding strategies, maximum (Max), minimum (Min), maximum+10% (Max+10%), and minimum–10% (Min–10%) of feeding management according to Van Wyk's table. One-way analysis of variance, and p-value = 0.464.

found that the concentration of solids was statistically lower compared to the other treatments, i.e., Max and Max+10%. This result is promising and has significant implications as it requires less solid removal and may have a reduced environmental impact from effluents.

In the present study, the initial levels of alkalinity and pH (142 ± 5 mg $CaCO_3 \cdot L^{-1}$ and 8.33 ± 3.61, respectively) decreased until the application of calcium hydroxide in the different treatments. The amount of calcium hydroxide added daily was responsible for maintaining the pH above 8.2. The levels of alkalinity in all experimental units were maintained above 120 mg $CaCO_3 \cdot L^{-1}$ through the supplementation of hydrated lime at 20% of the weight of feed provided daily at the beginning of the experiment and adjusted throughout the culture period, following the recommendations of Furtado et al. (2011) and Van Wyk and Scarpa (1999) for shrimp culture.

The metabolism of both heterotrophic and nitrifying bacteria results in the consumption of alkalinity in aquaculture environments (Ebeling et al., 2006). To counter this, calcium hydroxide was applied at the rate of 20% of the feed offered daily in the rearing tanks, thus keeping the system stabilized between the rates of alkalinity consumption and the water's inorganic carbon reserves (Furtado et al., 2014).

The higher feed conversion ratios observed at higher feeding rates can be attributed to two main factors: wasteful feeding behavior of the shrimp, and lower utilization of flocs as a food source owing to higher food availability (Zheng et al., 2008). Table 4 shows that fewer feed inputs resulted in average weights without a significant difference compared to treatments with higher feed inputs, along with an acceptable feed conversion of 1.63. This emphasizes the importance of optimizing both the feeding rate and the number of daily meals under various management conditions.

The results of the present study corroborate the findings of da Silva et al. (2022), who used feeding tables from Van Wyk (1999) and Garzade Yta et al. (2004), including the minimum and maximum feeding rates based on the Van Wyk's (1999) table. Da Silva et al.'s study (2022) found that the minimum rate resulted in a final mean weight and yield that were not significantly lower than the shrimp fed the maximum rate. In the present study, the final weight of post-larvae did not differ significantly among the treatments either, demonstrating that the growth performance of the animals was not impaired by the lower feeding rates.

The treatments with the lowest feeding rates resulted in good growth performance, along with favorable feed conversions, for the cultivation of shrimp post-larvae in the nursery phase. The lower FCR, coincident with growth performance that did not differ from that of the maximum rates, indicates that the quantities used in the feeding rate and feed did not cause malnourishment. This highlights the possibility of reducing the feed inputs of shrimp culture in the nursery phase in BFT without impairing productive performance. Considering that feed costs can account for > 60% of overall costs in superintensive shrimp operations, this would be an important advancement (Almeida et al., 2022). A reduced feed input would not only improve the efficiency of aquaculture operations, but it would also reduce environmental impacts related to the manufacture of aquafeeds in the form of reduced fish meal and fish oil, thus, for example, reducing pressure on wild fish stocks (Naylor et al., 2009).

Superintensive biofloc systems can recycle nutrients and transform organic waste into a natural food source for shrimp (Avnimelech, 2007; Samocha et al., 2007). In this context, adjustments to feeding tables can be more conservative since shrimp can meet some of their nutritional needs through bioflocs present in the system. This allows a reduction in dependence on commercial feeds, resulting in cost savings and a lower environmental impact (Quintero and Roy, 2010; Rego et al., 2017).

We observed consistent yield across all treatments, even with variations in feed input. Notably, reduced feed input did not significantly impact productivity, suggesting the system's robustness in maintaining consistent yields under lower feeding conditions. This observation bears practical implications for optimizing feed management strategies, demonstrating the potential for maintaining productivity, while, at the same time, potentially reducing feed costs. Importantly, our findings align with comparable productivity levels reported in studies by Ray et al. (2010) and Furtado et al. (2014), reinforcing the reliability of the observed trends.

In aquaculture, in general, and shrimp culture, in particular, feeding management can shape overall animal body composition. Factors such as diet formulation (Chen et al., 2022), feeding frequency (Xu et al., 2020), and nutrient availability (Lemos et al., 2021) can directly impact nutrient uptake. Our study emphasizes the importance of researching feeding practices for sustainable shrimp farming in order to promote improved growth efficiency and reduced environmental impact. Particularly, our results indicate no significant differences in shrimp nitrogen and phosphorus content among the different feeding rates. This suggests that the different strategies did not influence nutrient accumulation in shrimp. This finding prompts a closer look at nutrient utilization during the nursery phase, a field of investigation which could offer valuable insights for optimizing biofloc-based shrimp culture practices in a sustainable manner.

CONCLUSION

An adjusted feeding rate of 10% less than the minimum value provided in Van Wyk's (1999) table did not statistically impair shrimp final mean weight, productivity, and survival, allowing for a significantly lower value of FCR when compared with that of the Max and Max+10% groups. Moreover, the Min-10% treatment resulted in a lower deterioration of water quality based on the significantly lower values of nitrogenous compounds and SS when compared with the Max and Max+10% treatments.

CONFLICT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

Data will be made available by the authors upon reasonable request.

AUTHORS' CONTRIBUTIONS

Conceptualization: Padilla AM, De Lorenzo MA, Vieira FN; **Formal analysis:** Padilla AM, Martins MA; **Investigation:** Padilla AM, Martins MA, Carneiro RFS, Franch FCL; **Methodology:** Padilla AM; **Supervision:** De Lorenzo MA, Vieira FN; **Project administration:** Vieira FN; **Resources:** Vieira FN; **Writing – original draft:** Padilla AM, Martins MA, Carneiro RFS; **Writing – review and editing:** Padilla AM, Martins MA, Franch FCL, De Lorenzo MA, Vieira FN; **Final approval:** Martins MA.

FUNDING

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

Finance Code 001

ACKNOWLEDGEMENTS

The authors would like to thank the laboratory colleagues that helped in performing the experiment.

REFERENCES

Almeida, M.S.D.; Gimenes, R.M.T.; Furtado, P.S.; Poersch, L.H.; Wasielesky Jr., W.F.B.; Fóes, G.K.; Mauad, J.R.C. 2022. Economic analysis of intensive and super-intensive *Litopenaeus vannamei* shrimp production in a Biofloc Technology system. *Boletim do Instituto de Pesca*, 48: e692. https://doi.org/10.20950/10.20950/1678-2305/bip.2022.48.e692

American Public Health Association (APHA); American Water Works Association (AWWA), Water Environment Federation (WEF). 2005. *Standard methods for the examination of water and wastewater*. 21st ed. Washington, D.C. APHA.

Audelo-Naranjo, J.M.; Voltolina, D.; Romero-Beltrán, E. 2012. Culture of white shrimp (*Litopenaeus vannamei* Boone, 1931) with zero water exchange and no food addition: an eco-friendly approach. *Latin American Journal of Aquatic Research*, 40(2): 441-447. https://doi.org/10.3856/vol40-issue2-fulltext-19

Avnimelech, Y. 1999. Carbon/nitrogen ratio as a control element in aquaculture systems. *Aquaculture*, 176(3-4): 227-235. https://doi.org/10.1016/S0044-8486(99)00085-X

Avnimelech, Y. 2007. Feeding with microbial flocs by tilapia in minimal discharge bio-flocs technology ponds. *Aquaculture*, 264(1-4): 140-147. https://doi.org/10.1016/j.aquaculture.2006.11.025

Braga, A.; Magalhães, V.; Hanson, T.; Morris, T.C.; Samocha, T.M. 2016. The effects of feeding commercial feed formulated for semi-intensive systems on *Litopenaeus vannamei* production and its profitability in a hyper-intensive biofloc-dominated system. *Aquaculture Reports*, 3: 172-177. https://doi.org/10.1016/j.aqrep.2016.03.002

Burford, M.A.; Thompson, P.J.; McIntosh, R.P.; Bauman, R.H.; Pearson, D.C. 2004. The contribution of flocculated material to shrimp (*Litopenaeus vannamei*) nutrition in a high-intensity, zero-exchange system. *Aquaculture*, 232(1-4): 525-537. https:/doi.org/10.1016/s0044-8486(03)00541-6

Carvalho, E.A.; Nunes, A.J. 2006. Effects of feeding frequency on feed leaching loss and grow-out patterns of the white shrimp *Litopenaeus vannamei* fed under a diurnal feeding regime in pond enclosures. *Aquaculture*, 252(2-4): 494-502. https://doi.org/10.1016/j.aquaculture.2005.07.013

Chen, Y.; Chi, S.; Zhang, S.; Dong, X.; Yang, Q.; Liu, H.; Tan, B.; Xie, S. 2022. Evaluation of Methanotroph (*Methylococcus capsulatus*, Bath) bacteria meal on body composition, lipid metabolism, protein synthesis and muscle metabolites of Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture*, 547: 737517. https://doi.org/10.1016/j.aquaculture.2021.737517

da Silva, W.A.; de Morais, A.P.M.; do Vale Figueiredo, J.P.; Rafael, R.E.Q.; de Oliveira, C.Y.B.; do Nascimento Vieira, F. 2022. Production of pacific white shrimp in biofloc system with different food management strategies. *Boletim do Instituto de Pesca*, 48: e707. https://doi.org/10.20950/1678-2305/bip.2022.48.e707

de Schryver, P.; Crab, R.; Defoirdt, T.; Boon, N.; Verstraete, W. 2008. The basics of bio-flocs technology: the added value for aquaculture. *Aquaculture*, 277(3-4): 125-137. https://doi.org/10.1016/j.aquaculture.2008.02.019

Ebeling, J.M.; Timmons, M.B.; Bisogni, J.J. 2006. Engineering analysis of the stoichiometry of photoautotrophic, autotrophic, and heterotrophic removal of ammonia–nitrogen in aquaculture systems. *Aquaculture*, 257(1-4): 346-358. https://doi.org/10.1016/j.aquaculture.2006.03.019

El-Sayed, A.F.M. 2021. Use of biofloc technology in shrimp aquaculture: a comprehensive review, with emphasis on the last decade. *Reviews in Aquaculture*, 13(1): 676-705. https://doi.org/10.1111/raq.12494

Emerenciano, M.; Cuzon, G.; Paredes, A.; Gaxiola, G. 2013. Evaluation of biofloc technology in pink shrimp *Farfantepenaeus duorarum* culture: growth performance, water quality, microorganisms profile and proximate analysis of biofloc. *Aquaculture International*, 21(6): 1381-1394. https://doi.org/10.1007/s10499-013-9640-y

Emerenciano, M.G.; Miranda-Baeza, A.; Martínez-Porchas, M.; Poli, M.A.; Vieira, F.D.N. 2021. Biofloc technology (BFT) in shrimp farming: past and present shaping the future. *Frontiers in Marine Science*, 8: 813091. https://doi.org/10.3389/fmars.2021.813091

Food and Agriculture Organization (FAO). 2022. *The State of World Fisheries and Aquaculture 2022*. Rome: FAO.

Furtado, P.S.; Gaona, C.A.; Poersch, L.H.; Wasielesky, W. 2014. Application of different doses of calcium hydroxide in the farming shrimp *Litopenaeus vannamei* with the biofloc technology (BFT). *Aquaculture International*, 22: 1009-1023. https://doi.org/10.1007/s10499-013-9723-9

Furtado, P.S.; Poersch, L.H.; Wasielesky Jr., W. 2011. Effect of calcium hydroxide, carbonate and sodium bicarbonate on water quality and zootechnical performance of shrimp *Litopenaeus vannamei* reared in bio-flocs technology (BFT) systems. *Aquaculture*, 321(1-2): 130-135. https://doi.org/10.1016/j.aquaculture.2011.08.034

Gaona, C.A.P.; da Paz Serra, F.; Furtado, P.S.; Poersch, L.H.; Wasielesky, W. 2016. Effect of different total suspended solids concentrations on the growth performance of *Litopenaeus vannamei* in a BFT system. *Aquacultural Engineering*, 72-73: 65-69. https://doi.org/10.1016/j.aquaeng.2016.03.004

Garzade Yta, A.; Rouse, D.B.; Davis, D.A. 2004. Influence of nursery period on the growth and survival of *Litopenaeus vannamei* under pond production conditions. *Journal of the World Aquaculture Society*, 35(3): 357-365. https://doi.org/10.1111/j.1749-7345.2004.tb00099.x

Grasshoff, K.; Ehrhardt, M.; Kremling, K. 1983. *Methods of seawater analysis*. 2nd ed. New York: Verlag Chemie Weinhein.

Jamovi (2023). *The jamovi project*. Version 2.3 [Computer Software]. Available at: https://www.jamovi.org. Accessed on: May 30, 2024.

Krummenauer, D.; Samocha, T.; Poersch, L.; Lara, G.; Wasielesky Jr., W. 2014. The reuse of water on the culture of Pacific white shrimp, *Litopenaeus vannamei*, in BFT system. *Journal of the World Aquaculture Society*, 45(1): 3-14. https://doi.org/10.1111/jwas.12093

Lemos, D.; Coelho, R.; Zwart, S.; Tacon, A.G.J. 2021. Performance and digestibility of inorganic phosphates in diets for juvenile shrimp (*Litopenaeus vannamei*): dicalcium phosphate, monocalcium phosphate, and monoammonium phosphate. *Aquaculture International*, 29: 681-695. https://doi.org/10.1007/s10499-021-00651-3

Malavolta, E.; Vitti, G.C.; Oliveira, S.A. 1997. *Avaliação do estado nutricional das plantas: princípios e aplicações*. 2nd ed. Piracicaba: Potafos.

Martins, M.A.; Mouriño, J.L.P.; Seiffert, W.Q.; do Nascimento Vieira, F. 2022. Predictive functional profiling of water bacterial community in the integrated culture of Pacific white shrimp and Nile tilapia under heterotrophic and mature biofloc systems. *Aquaculture Research*, 53(15): 5428-5433. https://doi.org/10.1111/are.16000

Naylor, R.L.; Hardy, R.W.; Bureau, D.P.; Chiu, A.; Elliott, M.; Farrell, A.P.; Forster, I.; Gatlin, D.M.; Goldburg, R.J.; Hua, K.; Nichols, P.D. 2009. Feeding aquaculture in an era of finite resources. *Proceedings of the National Academy of Sciences of the United States of America*, 106(36): 15103-15110. https://doi.org/10.1073/pnas.0905235106

Nunes, A.J.P.; Parsons, G.J. 2006. A computer-based statistical model of the food and feeding patterns of the Southern brown shrimp *Farfantepenaeus subtilis* under culture conditions. *Aquaculture*, 252(2-4): 534-544. https://doi.org/10.1016/j.aquaculture.2005.07.020

Quintero, H.E.; Roy, L.A. 2010. Practical feed management in semi-intensive systems for shrimp culture. In: Alday-Sanz, V. (ed.). *The shrimp book*. St. Louis: U.S. Soybean Export Council. p. 443-453.

Ray, A.J.; Lewis, B.L.; Browdy, C.L.; Leffler, J.W. 2010. Suspended solids removal to improve shrimp (*Litopenaeus vannamei*) production and an evaluation of a plant-based feed in minimal-exchange, superintensive culture systems. *Aquaculture*, 299(1-4): 89-98. https://doi.org/10.1016/j.aquaculture.2009.11.021

Rego, M.A.S.; Sabbag, O.J.; Soares, R.; Peixoto, S. 2017. Risk analysis of the insertion of biofloc technology in a marine shrimp *Litopenaeus vannamei* production in a farm in Pernambuco, Brazil: A case study. *Aquaculture*, 469: 67-71. https://doi.org/10.1016/j.aquaculture.2016.12.006

Said, M.M.; El-Barbary, Y.A.; Ahmed, O.M. 2022. Assessment of performance, microbial community, bacterial food quality, and gene expression of whiteleg shrimp (*Litopenaeus vannamei*) reared under different density biofloc systems. *Aquaculture Nutrition*, 3499061. https://doi.org/10.1155/2022/3499061

Samocha, T.M.; Patnaik, S.; Speed, M.; Ali, A.M.; Burger, J.M.; Almeida, R.V.; Ayub, Z.; Harisanto, M.; Horowitz, A.; Brock, D.L. 2007. Use of molasses as carbon source in limited discharge nursery and grow-out systems for *Litopenaeus vannamei*. *Aquacultural Engineering*, 36(2): 184-191. https://doi.org/10.1016/j.aquaeng.2006.10.004

Schveitzer, R.; Arantes, R.; Costódio, P.F.S.; do Espírito Santo, C.M.; Arana, L.V.; Seiffert, W.Q.; Andreatta, E.R. 2013. Effect of different biofloc levels on microbial activity, water quality and performance of *Litopenaeus vannamei* in a tank system operated with no water exchange. *Aquacultural Engineering*, 56: 59-70. https://doi.org/10.1016/j.aquaeng.2013.04.006

Serra, F.P.; Gaona, C.A.; Furtado, P.S.; Poersch, L.H.; Wasielesky, W. 2015. Use of different carbon sources for the biofloc system adopted during the nursery and grow-out culture of *Litopenaeus vannamei*. *Aquaculture International*, 23: 1325-1339. https://doi.org/10.1007/s10499-015-9887-6

Strickland, J.D.H.; Parsons, T.R. 1972. *A practical handbook of seawater analysis*. 2nd ed. Ottawa: Fisheries Research Board of Canada.

Van Wyk, P. 1999. Nutrition and feeding of *Litopenaeus vannamei* in intensive culture systems. In: Van Wyk, P.; Davis-Hodgkins, M.; Laramore, R.; Main, K.L.; Mountain, J.; Scarpa, J. (eds.). *Farming marine shrimp in recirculating freshwater systems*. Fort Pierce: Harbor Branch Oceanographic Institute. p. 125-139.

Van Wyk, P.; Scarpa, J. 1999. Water quality requirements and management. In: Van Wyk, P.; Davis-Hodgkins, M.; Laramore, R.; Main, K.L.; Mountain, J.; Scarpa, J. (eds.). *Farming marine shrimp in recirculating freshwater systems*. Fort Pierce: Harbor Branch Oceanographic Institute. p. 141-161.

Wasielesky Jr., W.; Atwood, H.; Stokes, A.; Browdy, C.L. 2006. Effect of natural production in a zero exchange suspended microbial floc based super-intensive culture system for white shrimp *Litopenaeus vannamei*. *Aquaculture*, 258(1-4): 396-403. https://doi.org/10.1016/j.aquaculture.2006.04.030

Xu, W.; Xu, Y.; Su, H.; Hu, X.; Xu, Y.; Li, Z.; Wen, G.; Cao, Y. 2020. Effects of feeding frequency on growth, feed utilization, digestive enzyme activity and body composition of *Litopenaeus vannamei* in biofloc-based zero-exchange intensive systems. *Aquaculture*, 522: 735079. https://doi.org/10.1016/j.aquaculture.2020.735079

Zheng, Z.H.; Dong, S.L.; Tian, X.L. 2008. Effects of intermittent feeding of different diets on growth of *Litopenaeus vannamei*. *Journal of Crustacean Biology*, 28(1): 21-26. https://doi.org/10.1651/07-2858R.1