

*Research Article*

## Effects of carbon sources on the growth performance and water quality in nursery culture of blue shrimp (*Penaeus stylirostris*) under biofloc conditions

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**ABSTRACT.** Blue shrimp (*Penaeus stylirostris*) has been less studied in biofloc technology systems than white shrimp (*Penaeus vannamei*). Given current environmental challenges, generating experimental data is crucial for diversifying aquaculture. This study evaluated the effects of four supplementary carbon sources on water quality and the productive performance of *P. stylirostris* cultured in biofloc during the nursery phase. A completely randomized design with five treatments in triplicate was used: wheat flour (WF), corn flour (CF), sorghum flour (SF), sugar (SU), and a control (C) with no additional carbon. The postlarvae of blue shrimp were collected from the natural environment (estero de La Cruz), Sonora, Mexico. After acclimatization and quarantine (15 days, in a recirculating system), the organisms (0.270 g) were cultured (300 ind m<sup>-3</sup>) in BFT for 42 days in 150 L tanks. Water quality and productive response variables were monitored. The addition of external carbon improved water quality and productive response compared to the control treatment. Carbon sources led to differences in dissolved oxygen and total suspended solids ( $P < 0.05$ ). There were no differences in the average levels of toxic nitrogen compounds ( $P > 0.05$ ), which remained within acceptable limits. CF showed the highest values for final weight (3.96 g ind<sup>-1</sup>), survival (74.81%), biomass gain (133.18 g tank<sup>-1</sup>), specific growth rate (6.30% d<sup>-1</sup>), weight gain rate (1,310.63%), and the lowest feed conversion ratio (1.68) ( $P > 0.05$ ). The nursery of *P. stylirostris* is technically feasible in biofloc systems, with a productive response similar to that of *P. vannamei*. These results contribute to the knowledge of the species in systems with zero water exchange and highlight its potential as a productive alternative.

**Keywords:** *Penaeus stylirostris*; biofloc technology; carbon sources; water quality; productive performance; sustainability

### INTRODUCTION

In 2022, global production of aquatic animals reached a new world record of 185 million tons. Farmed production accounted for 94 million tons, representing 51% of the total, surpassing capture production for the first time (FAO 2024). For several decades, the trend has indicated that aquaculture is the only source capable of meeting the growing demand for aquatic products.

Shrimp is one of the most highly valued products worldwide due to its high nutritional value and flavor (AlFaris et al. 2022); however, its cultivation is mostly based on the white shrimp *Penaeus vannamei*, which reached a total of 6.8 million tons in 2022 (FAO 2024). Climate change is altering the aquatic environment, affecting water temperature and salinity (Du et al. 2019) and the stability of freshwater and saltwater ecosystems (Henson et al. 2017). These imbalances can negatively affect shrimp production in both capture

fisheries and aquaculture. Shrimp production is highly dependent on environmental conditions, creating both opportunities and challenges (Asche et al. 2022).

In aquaculture, diversification of cultivable species is desirable, as is the use of environmentally friendly production systems (Thomas et al. 2021). Applying these strategies can reduce uncertainty in the production of aquatic feeds. Therefore, it is imperative to conduct studies on the blue shrimp *Penaeus stylirostris* in biofloc systems to develop viable cultivation alternatives.

Biofloc is a heterogeneous aggregate of suspended organic particles and associated microorganisms, bound together by a matrix of extracellular polymeric substances (Martínez-Córdova et al. 2015, Moreno-Arias et al. 2017). The addition of organic carbon from external sources improves the performance of biofloc systems (Liu et al. 2014, Avnimelech, 2015).

Exogenous carbon stimulates the growth of heterotrophic bacteria, which consume organic matter and promote the removal of ammonia nitrogen (Ebeling et al. 2006, García-Ríos et al. 2019). These supports maintaining water quality within the culture systems and minimizes its use. Various carbon sources have been used in biofloc systems, including simple compounds such as glucose, sucrose, and molasses, as well as polysaccharides such as starch and flours from wheat, corn, and sorghum (Crab et al. 2010, Liu et al. 2014, García-Ríos et al. 2019).

Some studies have concluded that the proximate composition of bioflocs can vary depending on the type of organic carbon source used (Crab et al. 2010, Wei et al. 2016). Additionally, it has been shown that carbon sources, as well as carbon:nitrogen (C:N) ratios, promote changes in microbial diversity (Cardona et al. 2015, Wei et al. 2016, Panigrahi et al. 2019a), which can significantly influence the performance of the culture system (Xu et al. 2016), along with gut microbiota diversity, health status, and productive performance (Cardona et al. 2015, Panigrahi et al. 2019b).

The type of carbon source added to biofloc technology (BFT) systems significantly influences water quality and the productive response of the cultivated species (Serra et al. 2015). At a commercial level, BFT systems have been used during the nursery phase of shrimp, a crucial stage that can define their productive performance as adults (Emerenciano et al. 2026). Although molasses has traditionally been used as a carbon source, manipulating it can be complicated. Additionally, this product is used in livestock

production and other industries; consequently, its availability is limited in some regions (Silva et al. 2026). In this context, evaluating cereal flours as alternative carbon sources is relevant not only from a functional perspective but also from an economic and regional perspective.

Northwest Mexico has extensive agricultural areas where cereal flours such as corn, wheat, and sorghum are readily available at low cost (Jaramillo-Villanueva et al. 2015). Therefore, studying vegetable flours as carbon sources in BFT systems can help optimize productive performance and promote sustainable shrimp farming schemes adapted to local conditions.

There is limited background information on the culture of blue shrimp in BFT. Emerenciano et al. (2012) analyzed the contribution of biofloc to the maturation of *P. stylirostris* compared with that of fish farmed in earthen ponds. Subsequently, Cardona et al. (2016a) compared the bacterial community of the water and gut of this species cultured in biofloc and in clear water. The contribution of the natural microbiota of biofloc as a complement to the nutrients contained in the pelleted feed of *P. stylirostris* has also been studied (Cardona et al. 2015). Another study evaluated the effect of biofloc on antioxidant activity, lipid nutrition, and productive response in broodstock (Cardona et al. 2016b).

The objective of this study was to evaluate the effects of different carbon sources on water quality and the productive performance of *P. stylirostris* during the nursery phase in a biofloc system, and to determine whether cereal flours can be a technically viable alternative for this species with aquaculture potential.

## MATERIALS AND METHODS

### Collection and acclimatization of experimental organisms

Blue shrimp postlarvae (*P. stylirostris*) were collected from their natural habitat in the La Cruz estuary, Bahía de Kino, Sonora, Mexico, between 28°45' and 28°50'N and 111°50' and 111°56'W. The total area is 23 km<sup>2</sup>, and the average channel depth is 1 m at low tide. The bottom is composed mainly of fine material, of slime and sandy-slime, and the waters are of high turbidity (Grijalva-Chon et al. 1996).

During field collection, the postlarvae were distinguished by their bluish coloration (due to the greater number of chromatophores). In the laboratory, the identification was confirmed using the keys of Calderón-Pérez et al. (1989). Capture took place in

August 2024 using mesh nets (1,000  $\mu$ ). During transportation, low density (500 ind L<sup>-1</sup>) and low temperature (21-23°C) were maintained to reduce damage and stress in organisms.

The selected individuals were placed in a recirculating aquaculture system (28°C; 35 of salinity) and quarantined for two weeks at the Marine Species Reproduction Laboratory at the Kino Experimental Unit of the University of Sonora (UNISON). They were monitored daily for signs of physical damage or unusual behavior. Organisms with any evident injury were removed. During this period, the shrimp were fed (to apparent satiation) every 6 h with a commercial diet (Vimifos®; crude protein 35%, lipids 7.5%, crude fiber 3%, ash 12%, and moisture 12%). It was previously pulverized and sieved to 500-800  $\mu$ .

### Experimental design

A simple randomized experiment with four treatments and one control was conducted in triplicate. The treatments consisted of four carbon sources: sugar (SU), corn flour (CF), wheat flour (WF), sorghum flour (SF), and a control (C) with no additional carbon source. The experimental units were twelve 200-L plastic tanks (usable volume of 150 L). Each tank was filled with seawater (35 g L<sup>-1</sup>) that had been previously filtered through a #20 silica sand filter, followed by two cartridge filters of 10 and 5  $\mu$ m, and disinfected with commercial 5.4% sodium hypochlorite at a concentration of 0.25 mL L<sup>-1</sup>. Twelve hours later, the water was neutralized through aeration and the addition of sodium thiosulfate pentahydrate (HACH) at a concentration of 0.025 g L<sup>-1</sup>.

### Maturation of the culture water and shrimp stocking

In each experimental unit, biofloc was promoted for 10 days before shrimp stocking. It consisted of a single addition of 2.5 g of the respective carbon source per 100 L, along with the same feed ratio (2.5 g per 100 L). Each tank was stocked with 45 blue shrimp postlarvae (300 shrimp m<sup>-3</sup>) with an average weight of 0.276  $\pm$  0.01 g ind<sup>-1</sup>. The bioassay lasted 42 days and was conducted under semi-controlled conditions of water temperature, salinity, and photoperiod (12:12 h light:dark).

During the bioassay, feeding was performed four times daily at 6 h intervals (6:00, 12:00, 18:00, and 24:00 h). Feed was placed in 6-inch diameter feeders made of polyvinyl chloride (PVC) pipe with a 200  $\mu$ m NITEX® mesh screen, positioned at the bottom of the tank. The diet consisted of commercial pelleted feed

Vimifos® (previously described). The feed ratio was 10% of the biomass at the start of the study. Weekly adjustments were made based on the average weight of the organisms and daily inspection of uneaten feed in the feeders. Constant aeration was provided by a Fuji regenerative electric blower (VFC200P-5T Npt 42 cfm 1-inch, 1/3 hp) via plastic tubing and two 2 inch aerating stones in each experimental unit. The air flow rate was 90 L min<sup>-1</sup>, which kept the flocs in suspension. No water exchanges were performed; only levels lost through evaporation were replenished.

The treatments with an additional carbon source received the respective amounts until a C:N ratio of 12:1 was reached, as shown in Table 1, following the guidelines of Emerenciano et al. (2017) and García-Ríos et al. (2019). This C:N ratio has been used in research on *P. vannamei* cultures (Xu et al. 2016, Panigrahi et al. 2019a). The treatment C was maintained under the same conditions as the other treatments.

### Water quality monitoring

After shrimp stocking, basic water variables were monitored twice daily (8:00 and 20:00 h) in each experimental unit. Temperature, dissolved oxygen (DO), pH, and salinity were measured using a HANNA HI98194 multiprobe. The apparatus was calibrated according to the instructions in its respective operating manual.

For nutrient evaluation, including total ammonia nitrogen (TAN), nitrates (NO<sub>2</sub>-N), nitrates (NO<sub>3</sub>-N), and total suspended solids (TSS), 250 mL of water samples were collected weekly from each experimental unit. These samples were stored on ice and transported to the State University of Sonora (UES, by its Spanish acronym) at the Navojoa Campus for analysis. Nitrogen compounds (ammonia, nitrite, and nitrate) were determined colorimetrically. The methods used were diazotization with ferrous sulfate in an acidic medium (8507) for NO<sub>2</sub>; reduction with cadmium to NO<sub>2</sub> and diazotization (8171) for NO<sub>3</sub>; and salicylate (8155) for NH<sub>4</sub><sup>+</sup>, according to the procedures described in the Hach DR/2800 spectrophotometer (Hach 2007).

TSS was measured using method 8006 (Hach 2007) with a Hach DR/2800 spectrophotometer. The calibration curve was prepared using the traditional gravimetric method by filtering a known volume of water through GFC glass fiber filters.

### Productive performance

Survival was determined by counting the number of individuals at the beginning and end of the culture and

**Table 1.** Carbon sources used in the cultivation of *Penaeus stylirostris* in BFT, and their respective proportion.

Carbon source	Code	Proportion of carbon (dry basis)	Reference
Sugar	SU	0.42	Khairul et al. (2022)
Corn flour	CF	0.41	Prasanthi et al. (2017)
Wheat flour	WF	0.40	Ocheme et al. (2018)
Sorghum flour	SF	0.40	Mohapatra et al. (2019)

expressed as a percentage. The following parameters were also determined:

- Weight gain rate (WGR %) =  $(\text{final weight (g)} - \text{initial weight (g)}) \times 100 / \text{initial weight}$
- Specific growth rate (SGR %) =  $(\text{Ln final weight (g)} - \text{Ln initial weight (g)}) \times 100 / \text{culture time (d)}$
- Biomass (g) = final weight (g)  $\times$  final number of shrimps
- Feed conversion ratio (FCR) = feed consumed (g) / biomass gained (g)

### Statistical analysis

All tests were performed in triplicate, and data are expressed as mean  $\pm$  standard deviation. Normality (Kolmogorov-Smirnov test) and homoscedasticity (Levene's test) of the data were assessed. One-way analysis of variance (ANOVA) was performed (Zar 1996). In cases where the statistical test was significant ( $P < 0.05$ ), Tukey's *post-hoc* multiple comparisons test was applied. Data were processed using Statistica version 7 software (Statsoft Inc.).

## RESULTS

### Water quality

Considering the averages for the entire growing period, significant differences were observed between treatments ( $P < 0.05$ ) for temperature, DO concentration, and TSS. No differences were found for the remaining parameters ( $P > 0.05$ ; Table 2). Regarding nitrogenous compounds, analysis of trends showed that the maximum peaks of TAN (7.1-10.2 mg L<sup>-1</sup>) occurred in week 2 of the culture period; subsequently, they decreased to a range of 1.2-2.0 mg L<sup>-1</sup> at the end of the culture period (Fig. 1a). The concentration of nitrite-nitrogen (NO<sub>3</sub>-N) showed maximum levels (1.3-2.9 mg L<sup>-1</sup>) with a one-week lag relative to TAN in the treatments that received an additional carbon source, except for the control (Fig. 1b). Finally, NO<sub>3</sub>-N showed progressive increases from 7.8-10.3 mg L<sup>-1</sup> in

week 2, to a maximum of 47.9-80.3 mg L<sup>-1</sup> in week 6 (Fig. 1c).

The control treatment showed the lowest TSS (50 mg L<sup>-1</sup>) compared to WF, SF, and SU (80-93 mg L<sup>-1</sup>) ( $P < 0.05$ ; Table 2). All treatments with a supplementary carbon source showed a similar trend, with higher values at week 4 (Fig. 2).

### Productive performance

Treatment CF showed significantly higher average values for all production variables ( $P < 0.05$ ), except FCR, which was significantly lower. Treatments WF, SF, and SU generally showed intermediate values between CF and the control (Table 3). The average weekly growth rate of *P. stylirostris* was similar during the first four weeks. Subsequently, the growth trajectories differed, with treatment CF standing out, showing the highest weights (Fig. 3).

## DISCUSSION

In this section, comparisons of water quality and production response were primarily conducted using *P. vannamei* cultures in BFT, since white leg shrimp is the most widely cultivated species worldwide and shares habitat with *P. stylirostris*. In Mexico, the blue shrimp was farmed in commercial earth ponds during the 1980s and early 1990s. However, the emergence of the infectious hypodermal and hematopoietic necrosis virus (IHHNV) caused high mortality rates, while *P. vannamei* demonstrated greater resistance (Lightner, 1999). The cultivation of *P. stylirostris* in biofloc systems may be an alternative to diversify shrimp farming, although information is scarce. Consequently, in this first stage, we evaluated its performance in a nursery with different local carbon sources.

Several reports exist on the use of BFT in shrimp farming (Burford et al. 2004, Crab et al. 2012, Emerenciano et al. 2012, Avnimelech 2015). Among these reports, those focused on evaluating carbon are particularly notable. Molasses, brown sugar, rice bran,

**Table 2.** Water quality variables (mean  $\pm$  standard deviation) in the culture of *Penaeus stylirostris*, with different carbon sources, and one control, during the nursery phase (42 days). Different letters in the same row indicate significant differences (a>b>c; one-way ANOVA; n = 3; P < 0.05). WF: wheat flour, CF: corn flour, SF: sorghum flour, SU: sugar, and C: control. DO: dissolved oxygen, TAN: total ammonia nitrogen, TSS: total suspended solids.

Variable	Treatment					P-value
	WF	CF	SF	SU	C	
Temperature (°C) AM	29.52 $\pm$ 1.19 <sup>b</sup>	29.52 $\pm$ 0.97 <sup>b</sup>	29.46 $\pm$ 0.93 <sup>b</sup>	29.63 $\pm$ 0.95 <sup>b</sup>	30.09 $\pm$ 1.62 <sup>a</sup>	0.038
Temperature (°C) PM	29.79 $\pm$ 0.92 <sup>b</sup>	29.87 $\pm$ 0.92 <sup>b</sup>	29.82 $\pm$ 0.92 <sup>b</sup>	30.03 $\pm$ 0.85 <sup>b</sup>	30.45 $\pm$ 1.53 <sup>a</sup>	0.040
DO (mg L <sup>-1</sup> ) AM	5.34 $\pm$ 0.29 <sup>a</sup>	5.09 $\pm$ 0.34 <sup>ab</sup>	5.06 $\pm$ 0.36 <sup>bc</sup>	5.00 $\pm$ 0.37 <sup>c</sup>	4.97 $\pm$ 0.35 <sup>bc</sup>	0.031
DO (mg L <sup>-1</sup> ) PM	5.20 $\pm$ 0.34 <sup>a</sup>	5.28 $\pm$ 0.27 <sup>ab</sup>	5.22 $\pm$ 0.27 <sup>b</sup>	5.12 $\pm$ 0.33 <sup>b</sup>	5.22 $\pm$ 0.28 <sup>b</sup>	0.027
pH AM	7.53 $\pm$ 0.22	7.58 $\pm$ 0.19	7.57 $\pm$ 0.18	7.57 $\pm$ 0.18	7.59 $\pm$ 0.21	0.075
Salinity	37.97 $\pm$ 1.36	37.93 $\pm$ 1.41	37.88 $\pm$ 1.33	37.90 $\pm$ 1.28	37.92 $\pm$ 1.35	0.922
TAN (mg L <sup>-1</sup> )	3.61 $\pm$ 2.89	3.15 $\pm$ 2.81	3.39 $\pm$ 2.67	3.19 $\pm$ 2.34	4.11 $\pm$ 3.57	0.735
NO <sub>2</sub> -N (mg L <sup>-1</sup> )	1.02 $\pm$ 0.57	1.69 $\pm$ 0.82	1.52 $\pm$ 0.84	1.46 $\pm$ 1.13	1.28 $\pm$ 0.73	0.647
NO <sub>3</sub> -N (mg L <sup>-1</sup> )	57.53 $\pm$ 32.60	50.82 $\pm$ 29.02	46.75 $\pm$ 23.93	41.76 $\pm$ 20.86	50.75 $\pm$ 22.54	0.540
TSS (mg L <sup>-1</sup> )	93.00 $\pm$ 42.75 <sup>a</sup>	80.00 $\pm$ 37.36 <sup>ab</sup>	89.00 $\pm$ 46.34 <sup>a</sup>	89.00 $\pm$ 46.33 <sup>a</sup>	50.00 $\pm$ 24.68 <sup>b</sup>	0.001

wheat bran (WB) and flour, sucrose, dextrose, corn starch, tapioca, glycerin, and calcium acetate, among others, have been tested (Samocha et al. 2007, Asaduzzaman et al. 2010, Emerenciano et al. 2012, Liu et al. 2014, Rajkumar et al. 2015, Suita et al. 2017).

A bibliometric analysis revealed that studies related to carbon sources in biofloc systems increased by 20.7% between 2010 and 2022 (Cala-Delgado et al. 2025). However, there are currently no reports on the effects of different carbon sources during nursery culture of *P. stylirostris* in BFT.

According to Rodríguez & Reprieto (1984), temperature, salinity, DO, and pH were within the optimal range for *P. stylirostris*. The differences in DO and TSS between the control and treatments receiving carbon sources were due to the latter having a greater abundance of bioflocs and, consequently, microorganisms; this has been previously reported (Panigrahi et al. 2018, Xu et al. 2022).

A direct relationship has been demonstrated between increased C:N ratio and the presence of TSS, and an inverse relationship with DO content (Khanjani & Sharifinia 2022, Xu et al. 2022), which is consistent with the findings of this bioassay.

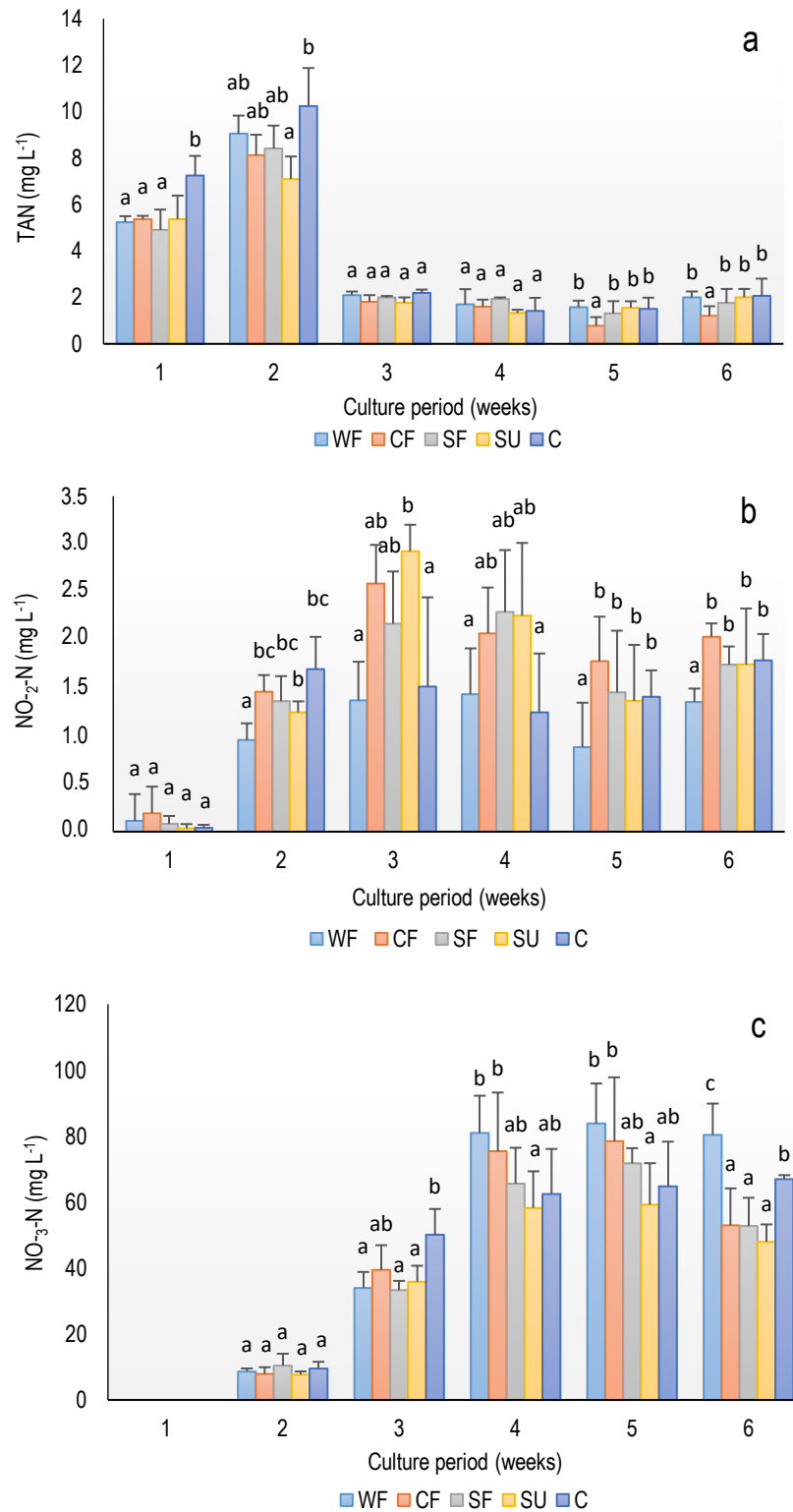
The pH averages showed a similar trend in all treatments, including C, with a range of 7.53 to 7.59. These results align with Mansour et al. (2022), who reported averages of 7.55  $\pm$  0.04 using two carbon sources (sugarcane bagasse and WF). Similarly, Serra et al. (2015) reported average pH values of 7.72  $\pm$  0.2 and 7.97  $\pm$  1.19 in postlarvae and juveniles of *P. vannamei*, respectively, using molasses, sugar cane, dextrose, and rice bran as carbon sources. pH is a crucial variable in BFT systems; levels below 7.0

should be avoided because they limit the metabolism of nitrifying bacteria (Ebeling et al. 2006, Emerenciano et al. 2017). The values obtained in this study were above the critical level.

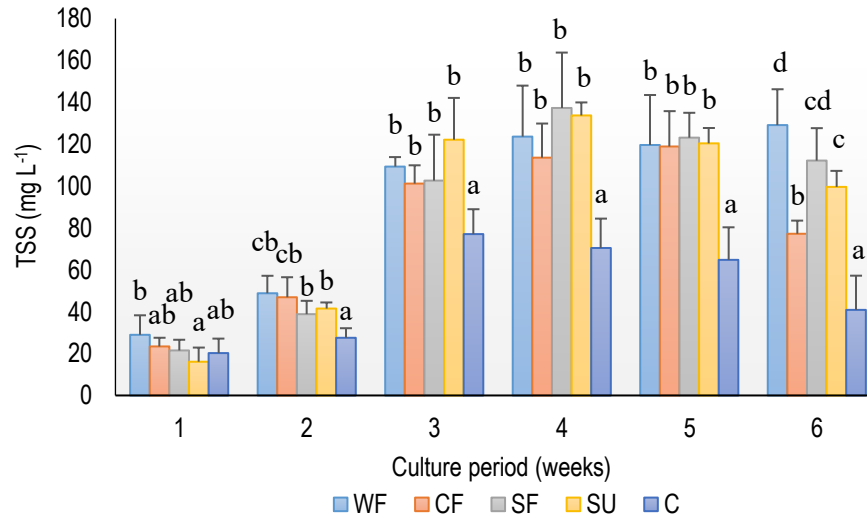
TSS exhibited the expected trend, with higher values in treatments receiving an additional carbon source. Monitoring TSS is essential because it significantly influences the stability of culture systems (Emerenciano et al. 2017). In this regard, Ray et al. (2011) revealed that when TSS values reach 200 mg L<sup>-1</sup>, nitrite and nitrate concentrations are lower; similarly, they reported a higher growth rate of *P. vannamei* (1.7 g week<sup>-1</sup>) at 200 mg L<sup>-1</sup> than at 300 mg L<sup>-1</sup> (1.3 g week<sup>-1</sup>).

However, in postlarvae and juveniles, these values should be lower; in a nursery study of *P. vannamei*, Peiro-Alcantar et al. (2019) used postlarvae (initial weight of 12 mg ind<sup>-1</sup>) and substrates: WB, oat bran (OB), and amaranth seeds (AS) to promote biofloc formation; and reported TSS levels (88 to 115 mg L<sup>-1</sup>). In another bioassay with *P. vannamei* (initial weight of 0.56 g ind<sup>-1</sup>) cultivated in biofloc, TSS ranged from 88.4 to 98.9 mg L<sup>-1</sup> (Flores-Valenzuela et al. 2021); consequently, the levels recorded in this study are within these ranges.

The nitrogen compound curves showed a trend similar to previous reports, which document an increase in TAN at the beginning of the culture, followed by its transformation to NO<sub>2</sub>-N and NO<sub>3</sub>-N, which ultimately accumulates in the system (Moreno-Arias et al. 2017, Suita et al. 2017). These processes are mediated by ammonium-oxidizing and nitrite-oxidizing bacteria (Ebeling et al. 2006, Flores-Valenzuela et al. 2021). The lack of significant differences in TAN and NO<sub>2</sub>-N levels among the treatments suggests that all treatments



**Figure 1.** Mean values (+standard deviation) of a) total ammonia nitrogen (TAN), b) NO<sub>2</sub>-N, and c) NO<sub>3</sub>-N in BFT cultures of *Penaeus stylirostris* with different carbon sources and a control. WF: wheat flour, CF: corn flour, SF: sorghum flour, SU: sugar, and C: control (different letters in the same week indicate significant differences).



**Figure 2.** Total suspended solids (TSS; mean + standard deviation) in *Penaeus stylirostris* BFT culture with different carbon sources and one control. WF: wheat flour, CF: corn flour, SF: sorghum flour, SU: sugar, and C: control (different letters in the same week indicate significant differences).

**Table 3.** Productive response of *Penaeus stylirostris*, cultured in biofloc technology with different carbon sources, and one control, during the nursery phase (42 days). Different letters in the same row indicate significant differences ( $a > b > c$ ; one-way ANOVA;  $n = 3$ ;  $P < 0.05$ ). IW: initial weight; FW: final weight; FCR: feed conversion rate; SGR: specific growth rate; WGR: weight gain rate. WF: wheat flour, CF: corn flour, SF: sorghum flour, SU: sugar, and C: control.

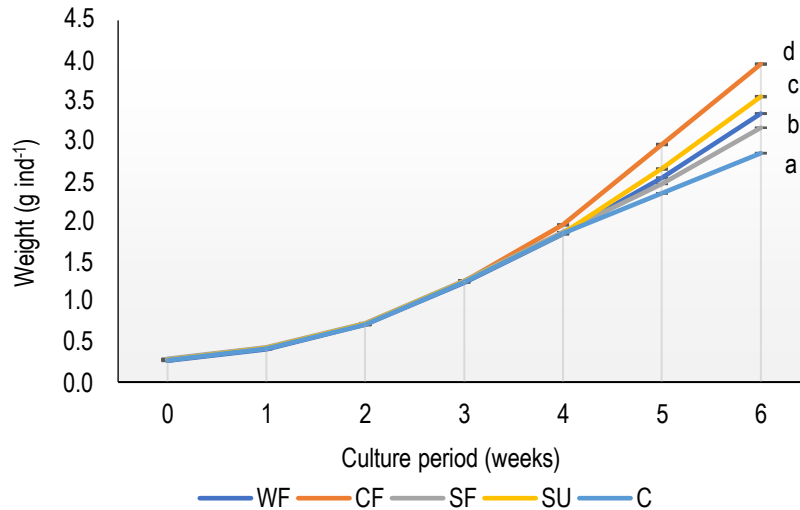
Variable	Treatment					P-value
	WF	CF	SF	SU	C	
IW (g ind <sup>-1</sup> )	0.266 ± 0.01 <sup>b</sup>	0.281 ± 0.01 <sup>ab</sup>	0.289 ± 0.00 <sup>a</sup>	0.276 ± 0.01 <sup>ab</sup>	0.272 ± 0.01 <sup>ab</sup>	0.004
FW (g ind <sup>-1</sup> )	3.34 ± 0.01 <sup>c</sup>	3.96 ± 0.01 <sup>a</sup>	3.16 ± 0.00 <sup>d</sup>	3.55 ± 0.01 <sup>b</sup>	2.85 ± 0.00 <sup>c</sup>	0.001
Survival (%)	68.15 ± 1.28 <sup>b</sup>	74.81 ± 1.28 <sup>a</sup>	67.41 ± 1.29 <sup>b</sup>	68.15 ± 2.57 <sup>b</sup>	51.85 ± 3.39 <sup>c</sup>	<0.001
Biomass(g)	102.45 ± 1.96 <sup>bc</sup>	133.18 ± 2.59 <sup>a</sup>	95.98 ± 1.77 <sup>c</sup>	108.9 ± 4.06 <sup>b</sup>	66.43 ± 4.26 <sup>d</sup>	<0.001
FCR	1.81 ± 0.01 <sup>c</sup>	1.68 ± 0.02 <sup>d</sup>	1.9 ± 0.02 <sup>b</sup>	1.76 ± 0.05 <sup>cd</sup>	2.24 ± 0.09 <sup>a</sup>	<0.001
SGR (%)	6.03 ± 0.05 <sup>b</sup>	6.3 ± 0.07 <sup>a</sup>	5.7 ± 0.02 <sup>c</sup>	6.08 ± 0.07 <sup>b</sup>	5.59 ± 0.04 <sup>c</sup>	0.001
WGR (%)	1157.86 ± 26.18 <sup>b</sup>	1310.63 ± 44.18 <sup>a</sup>	993.70 ± 7.17 <sup>c</sup>	1187.46 ± 39.04 <sup>b</sup>	945.74 ± 16.96 <sup>c</sup>	<0.001

(including the control) were equally effective at immobilizing toxic nitrogen and converting it into microbial biomass.

Both TAN and NO<sub>2</sub>-N cause physiological alterations, growth retardation, and, at high concentrations, mortality (Lin & Chen 2003). Although the average levels of TAN (3.15 to 4.11 mg L<sup>-1</sup>) and N-NO<sub>2</sub> (1.02 to 1.46 mg L<sup>-1</sup>) remained slightly above the optimum for shrimp farming (Emerenciano et al. 2017), these were below the intervals previously reported in shrimp farming in BFT by Moreno-Arias et al. (2017) with TAN: 0.40-0.89 mg L<sup>-1</sup> and NO<sub>2</sub>-N 4.86-6.31 mg L<sup>-1</sup>;

as well as by Flores-Valenzuela et al. (2021) with TAN: 6.04-7.54 mg L<sup>-1</sup> and NO<sub>2</sub>-N: 4.21-5.53 mg L<sup>-1</sup>.

CF had a greater effect than the other treatments and the control group, suggesting that the nature of the organic carbon source is a determining factor in productive performance. Our results agree with Tran et al. (2021), who cultured *P. vannamei* postlarvae (0.075 ± 0.006 g ind<sup>-1</sup> and 250 ind m<sup>-2</sup>) and used corn starch and molasses as carbon sources. The results showed that corn starch promoted a higher growth rate (SGR) and average body weight, and lower FCR, compared to molasses.



**Figure 3.** *Penaeus stylirostris* weight (mean  $\pm$  standard deviation) cultured in BFT with different carbon sources and one control. WF: wheat flour, CF: corn flour, SF: sorghum flour, SU: sugar, and C: control (different letters in week 6 indicate significant differences).

In general, all external carbon sources (WF, CF, SF, and SU) improved productive performance compared to control C. These results are consistent with previous findings indicating that promoting biofloc formation with carbon sources significantly improves final weight, weight gain, SGR, and FCR in *P. vannamei* (Wasiolesky et al. 2006, Xu & Pan 2012), *P. monodon* (Arnold et al. 2009), and *P. semisulcatus* (Megahed 2010).

The higher survival rate in the cornmeal treatment (74.81%) compared to the control (51.8%) may be correlated with better water quality and a greater presence of bioflocs in the culture. The results of this study are consistent with those of Suita et al. (2017), who reported survival rates of  $79.1 \pm 11.4\%$  with dextrose and  $68.6 \pm 7.4\%$  with molasses in *P. vannamei* postlarvae over 30 days.

The lower feed intake was reflected in the smaller FCR observed in the CF treatment ( $1.68 \pm 0.02$ ) compared to the control ( $2.38 \pm 0.04$ ). This result is clear evidence that biofloc functions as a high-quality supplemental protein and energy source (De Schryver et al. 2008, Avnimelech 2015). Previous studies have documented that microbial floc contains 30 to 50% crude protein on a dry basis (Tacon et al. 2002), thereby reducing dependence on supplemental feed and maximizing shrimp energy balance efficiency (Ju et al. 2008).

CF is a polysaccharide, and it is assumed that the complexity of the starch matrix reduced the assimi-

lation rate by heterotrophic bacteria (Ray et al. 2011) and increased biofloc formation. In a previous study using molasses, tapioca flour, and WF, it was found that WF reduced total ammonia, maintained good water quality, and achieved the best shrimp growth rate ( $4.57 \pm 0.03$  g) and a 90.3% survival rate (Rajkumar et al. 2015), which indicates that cereals as a carbon source contribute significantly to the productive performance of shrimp in biofloc systems.

Complex starches, such as CF, provide sustained carbon release throughout the culture period. The difference in efficiency between them is primarily attributed to the digestibility of corn starch. CF and its derivatives have an acceptable protein content, low levels of anti-nutritional factors, and are rich in minerals, vitamin B, and vitamin E (Lin et al. 2023).

Additionally, CF, as a carbon source, could promote the selective colonization of beneficial bacteria in the intestine. Guergoletto et al. (2010) indicate that some fibers have prebiotic effects, selectively stimulating the growth of one or more bacteria, thereby improving the host's nutrition and health. Massive sequencing of the 16S rRNA gene, along with determination of the functional profiles of the bacterial microbiota in *P. stylirostris*, could elucidate the metabolic pathways involved.

The results obtained in this study were largely compared with those of *P. vannamei*; however, given that these are evolutionarily related species with similar habitats and biology, and both are native to the eastern

Pacific (Rodríguez & Reprieto 1984), it is reasonable to assume that the nursery of *P. stylirostris* in BFT is technically feasible. Further studies are needed that include more extended periods to reach a marketable size.

## CONCLUSIONS

The nursery of blue shrimp (*P. stylirostris*) can be successfully carried out in a BFT system. Under the bioassay conditions, the productive parameters were similar to those of *P. vannamei*, the most important species in the shrimp farming industry. The external carbon sources evaluated (WF, CF, SF, and SU) improved shrimp productivity; however, cornmeal was the most effective. Further studies are needed to determine the productive parameters for *P. stylirostris* cultures up to marketable size. Bioassays evaluating diets and immune response, among other factors, are also required. Given the accelerated environmental changes and the continued presence of diseases affecting *P. vannamei*, the cultivation of *P. stylirostris* in a biofloc system emerges as a viable alternative.

## Credit author contribution

M. de J. Zúñiga-Panduro, R.H. Barraza-Guardado: conceptualized the study, performed the trial, and wrote the manuscript; A. Arvizu-Ruiz: performed the trial; A. Miranda-Baeza: conceptualized the study, performed the trial, and wrote the manuscript interpreted results and prepared the final draft. All authors reviewed the manuscript.

## Conflict of interest

The authors declare no conflict of interest.

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