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Research Article

Novel potential carbohydrate sources for white-leg shrimp, *Penaeus vannamei* in a biofloc system: alternatives for sugarcane molasses in the Amazon region

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ABSTRACT. This study evaluated alternative carbohydrate sources available in the Brazilian Amazon for use in biofloc systems for the cultivation of white shrimp (*Penaeus vannamei*). The motivation stems from the limited accessibility in this region of sugarcane molasses, a conventional carbon source for the production of bioflocs. Four sources of carbohydrates were tested: coffee grounds, cassava meal, tapioca starch, and molasses, for 35 days. Juvenile shrimp (initial weight 0.14 g) were stocked at a density of 300 ind m^{-3} in 12 70-L polyethylene tanks, across four treatments with three replications. The effects of the springs on water quality, zootechnical performance of shrimp, and centesimal composition of biofloc and animals were evaluated. All sources maintained water quality within the recommended range for the species. However, the molasses treatment resulted in significantly higher zootechnical performance, with a final weight of 0.61 g and a weekly gain of 0.09 g ($P < 0.05$). Regarding composition, only moisture content varied significantly between treatments, and coffee grounds and molasses differed from cassava meal and tapioca gum. In addition, shrimp produced with coffee grounds differed significantly from those treated with tapioca gum. In conclusion, although molasses yielded the best performance, all alternative sources also proved efficient. The results show the potential of regional inputs as viable alternatives, expanding the applicability of biofloc technology in areas where molasses is not readily available, contributing to the consolidation of aquaculture practices adapted to Amazonian conditions, and promoting greater productive and environmental autonomy in the activity.

Keywords: aquaculture; shrimp culture; sustainability; growth; survival; carbohydrate

INTRODUCTION

The biofloc or biofloc technology (BFT) system is a closed aquaculture production system that requires little or no water renewal, thereby enhancing biosecurity and reducing effluent discharge into the environment (Avnimelech 1999, McIntosh et al. 2000, Ebeling et al. 2006, Emerenciano et al. 2022). This system can recycle accumulated organic matter by adding a carbohydrate source to the water; it supports the establishment of a bacterial community capable of degrading these residues and converting the toxic nitrogenous compounds into microbial biomass. This process improves the quality of the water in the system and allows/enables the growth of shrimp at densities higher than 350 ind per m^3, with survival rates of over

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70% (Samocha et al. 2004, Crab et al. 2012, Xu et al. 2012, Silva et al. 2015, Silveira et al. 2020). The bioflocs also have a high protein content and can be consumed by farmed shrimp, thereby reducing the protein content of the feed used and lowering costs (De Schryver et al. 2008, Ballester et al. 2010, Crab et al. 2012, El-Sayed 2020).

One of the main sources of carbohydrates used to produce bioflocs is sugarcane molasses (SM), in either liquid or solid (powdered) form. Molasses is a byproduct of sugar refining (Schneider et al. 2006, Samocha et al. 2007) and contains mineral elements and vitamins that can be used to enhance bacterial growth (Squio & Aragão 2004). The addition of this source of carbohydrates can also contribute to the conversion of nitrogen into microbial protein, which can help to control ammonia concentration in the water (Samocha et al. 2007, Ray & Lotz 2014, Maia et al. 2016, Tinh et al. 2021a,b), thereby reducing the concentration of nitrogenous compounds in the system, while also increasing the suspended solids and the level of dissolved organic carbon (Schneider et al. 2006, Panigrahi et al. 2019).

However, while SM is widely used as a source of carbohydrates for the production of bioflocs, it is not readily available in some regions due to logistical difficulties or high costs, as observed in much of the Brazilian Amazon. In this context, it is necessary to identify new locally available carbohydrate sources to more effectively develop BFT (Rajkumar et al. 2016), since the BFT system is already being used to produce native fish species in this region. Species such as the tambaqui (*Colossoma macropomum*) and the arapaima (*Arapaima gigas*) have become increasingly prominent in the Brazilian aquaculture sector, especially when raised in intensive biofloc-based systems (Emerenciano et al. 2017c, Lima et al. 2021, Aguilar et al. 2025). Clearly, research aimed at discovering new alternative sources of carbohydrates and at improving these aquaculture systems will be essential for both consolidating the sector and developing environmentally responsible practices appropriate to local realities. Although the BFT system is used in this region only for freshwater species, it could also be used for marine species, such as the shrimp *Penaeus vannamei*, widely cultivated on the Amazon coast, mainly in conventional systems. The main productive center of this species in the region is the state of Pará, located in the northeastern portion of the territory, also known as the Salgado region. This area is home to approximately 789 cultivation units, distributed in about 80 ha of water depth, bringing together around 70% of local producers. In 2023, regional *P. vannamei* aquaculture production reached 151 t, corresponding to approximately 0.11% of the national farmed shrimp production (ABCCam 2025). Although the production of this species has been occurring for decades in the region, the use of traditional cultivation systems for exotic species is prohibited, and breeding is allowed only in systems considered closed (COEMA-PA 2018). In this context, the implementation of the biofloc system emerges as an environmentally appropriate and legally accepted alternative, promoting the sustainable use of natural resources and more efficient control of water quality. In addition to the ecological benefits, this technology has important practical implications for small producers and farmers in the Amazon region, as it enables greater productivity in reduced areas, reduces water and external input consumption, and better utilizes local organic waste. In this way, adopting the biofloc system can strengthen family aquaculture, generate new economic opportunities, and contribute to the sustainability of Amazonian aquaculture.

One potential alternative is cassava (*Manihot sculenta*), from which several important carbohydrate sources, such as cassava meal (CM, 44.75% C) and tapioca starch (TS, 69.41% C), can be extracted. Cassava is cultivated in many regions around the world, primarily in tropical countries, providing a low-cost, easily produced crop (Oliveira & Santos 2018). The use of cassava derivatives as a source of carbohydrates for the production of bioflocs and their application in shrimp farming has been tested from several different perspectives. Tinh et al. (2021a), for example, tested the effects of the frequency of the addition of carbohydrates derived from TS on the production of *P. vannamei*, while Ekasari et al. (2014) verified their influence on the immunological system in farmed *P. vannamei*. Rajkumar et al. (2016) and Pamanna et al. (2017a,b) verified the effects of different sources of carbohydrates on the quality of the water, the composition of the bioflocs, and the growth performance of *P. vannamei*, while Chakrapani et al. (2022) focused on the influence of the composition of the microbial community on the growth, enzyme activity, and digestive patterns of *P. vannamei*. Fugimura et al. (2014), in turn, assessed the effects of bioflocs produced from CM, together with residues from beer production and SM, on the growth performance of juvenile southern white shrimp, *Penaeus schmitti*, while Lobato et al. (2019) evaluated different contents of the silage of the residues derived from the industrial processing of tilapia used in the diet of *P. vannamei* raised in a BFT system, using SM and CM as sources of carbohydrates.

Another alternative source of carbohydrates with which it has easy logistical and financial access in the region is coffee grounds (CG). In Brazil, coffee (*Coffea arabica*) cultivation predominates, which represents approximately 70.6% of the country's commercial production (EMBRAPA 2025). Although its carbohydrate concentration (35.42% C) is lower than that found in cassava products, the CG that are obtained after the preparation of the drink are rich in nutrients, nitrogen, carbon, proteins, minerals, and organic matter (Mussatto et al. 2011, Souza & Lima 2019, Almeida et al. 2021). CG have several agricultural uses, such as organic fertilizer. They are considered a valuable resource in sectors such as agriculture, where they are used as natural fertilizers and insect repellents for plants (Ferreira 2011). Although the benefits of its use in agriculture are well known, there are no reports of its use in aquaculture, particularly as a carbohydrate source for the production of bioflocs for shrimp farming, which should be the first such report. The agricultural reuse of the residues generated by the production and consumption of coffee has been a priority objective for coffee-consuming countries, not only for economic reasons, but also to establish sustainable practices by incorporating a normally discarded residue, thereby aggregating value and reducing environmental impacts (Oliveira & Santos 2018). This process of reuse is fundamental to a circular economy. It is widely applied in aquaculture (Maio et al. 2017), as an economic model that reduces waste and excessive consumption of natural resources, based on the sustainable principles of reduce, reuse, and recycle (Korhonen et al. 2018).

The proximate centesimal composition of humidity, lipids, ash, and protein is an important indicator of the nutritional value of aquatic animals (Wang et al. 2021). Shifts in the nutritional composition of bioflocs produced from different carbohydrate sources can be explained by the microbiological composition of the flocs, as the biochemical constitution of the microorganisms directly affects the nutritional quality of the bioflocs (Fugimura et al. 2014). The analysis of the use of different carbohydrate sources in BFT systems is necessary to determine their viability and their influence on the composition of both bioflocs and shrimp.

The present study assessed the potential of three alternative sources of carbohydrates: CG, CM, and TS, as a substitute for the use of SM in a BFT system used to raise the marine white-leg shrimp, *P. vannamei*, in the Amazon region. The study focused on water quality parameters, zootechnical performance, and the centesimal composition of both bioflocs and shrimp.

MATERIALS AND METHODS

Experimental design

The experiment was conducted in the Crustacean Production Laboratory of the Oceanological Investigations Institute of the Autonomous University of Baja California at Ensenada, Mexico, over a period of 35 days. The initial stock consisted of juvenile white-leg shrimp, *P. vannamei*, with an initial mean weight of 0.14 ± 0.03 g, stocked at a density of 300 ind per m³, corresponding to 21 ind per repetition, distributed across 12 rectangular polyethylene tanks with a nominal volume of 70 L. The experimental design consisted of four treatments with three repetitions, monitored over 35 days.

The bioflocs used in this study were produced in a previous experiment that evaluated the influence of carbohydrate sources: CG, CM, TS, and SM on biofloc formation. The C:N ratio used was 15:1, following the protocols described by Ebelling et al. (2006), Avnimelech (2007), and adapted by Gaona et al. (2011). To calculate the amount of each source tested, the following average carbohydrate percentages were used: CG = 54.81%, CM = 57.54%, TS = 53.39% and SM = 33.18%. Each experimental unit (tank) was filled to 75% of its capacity with clean water, and the remaining 25% with water rich in bioflocs derived from a previous experiment. This enriched water had total ammonia nitrogen and nitrite concentrations within acceptable levels for the species, with total suspended solids (TSS) at similar levels across the four treatments (CG = 27.10 mg L^{-1}, CM = 31.14 mg L^{-1}, TS = 31.28 mg L^{-1}, and SM = 34.33 mg L^{-1}). Cassava products were obtained from suppliers in the state of Pará, in the Brazilian Amazon region, while Arabica coffee (*C. arabica*) grounds were obtained from a Mexican research institute. Each experimental unit was continuously aerated with a radial compressor (1.0 HP), with air distributed through aerotubes, while the water temperature was maintained at 25°C using heaters.

Analysis of water quality

Four water quality parameters -temperature (ºC), pH, salinity, and dissolved oxygen concentration (mg L^{-1})- were measured daily throughout the study period using a 556 MPS multiparameter probe (YSI Inc., USA). The concentrations of total ammonia (NAT), nitrite ($N\text{-}NO_2$), nitrate ($N\text{-}NO_3$), alkalinity ($CaCO_3$ mg L^{-1}), and the volume of bioflocs and TSS were analyzed every three days using a Hach 3900 spectrophotometer. Imhoff cones were used to determine the volume of bioflocs (mL L^{-1}), with 1-L samples of water deposited and the volume of bioflocs measured after 20 min (Avnimelech 2007). The TSS were determined by the filtration gravimetry of 20 mL samples through GF50-A glass-fiber filters.

Dietary management and zootechnical parameters

The shrimp were fed Azteca commercial diet, containing 35% crude protein, which was provided twice a day, at 09:00 and 15:00 h. The amount of feed provided was regulated based on a feeding table (Jory 1995). The biometric analyses were conducted weekly, on a sample of five shrimp from each experimental unit, which were weighed individually on an analytical digital scale with a precision of 0.1 mg (Marte®), and then returned to the same tank. At the end of the experiment, the final weight (g), survival rate (%), weekly weight gain (WWG), and feed conversion factor (FCF) were calculated using the following equations:

Final weight (g) = mean weight calculated for all the shrimp collected at the end of the experiment

Survival (%) = final number of shrimp / initial number of shrimp × 100

WWG = mean final weight (g) - initial weight (g) / number of weeks

FCF = feed provided / increase in biomass.

Analysis of the centesimal composition

At the end of the experiment, 50 mL of the water enriched with bioflocs and all the shrimp from each experimental unit were sent to a commercial laboratory for analysis. The samples were analyzed in triplicate to determine their proximate composition (protein, lipids, moisture, and ash) according to the AOAC (2000) procedure. The raw protein content was determined by the micro-Kjeldahl method, which is based on the measurement of the percentage of nitrogen (%N) in the sample:

$$\%\text{ nitrogen }(\%\text{N}) = \frac{[(\text{volume HCl} \times \text{normality of the HCl} \times 0.014) \times 100]}{\text{weight of the sample (g)}}$$

while % protein = %N × 6.25, where %N is the percentage of nitrogen, and 6.25 is the conversion factor. The percentages of lipids, humidity, and the ash content were calculated based on the formulas of Bligh & Dyer (1959), Reeb et al. (1999), and AOAC (2000), respectively:

$$\%\text{ lipids} = \frac{(\text{weight of lipids} \times 100)}{\text{weight of the sample}}$$

$$\%\text{ humidity} = \frac{(\text{weight of the humid sample} - \text{weight of the dry sample}) \times 100}{\text{weight of the humid sample}}$$

$$\%\text{ ash} = \frac{(\text{weight of the ash}) \times 100}{\text{weight of the wet sample}}$$

Statistical analysis

The data were analyzed using IBM SPSS Statistics, version 26.0 (IBM Corporation, 1989-2011, USA). The first step was to verify the normality of the data using the Shapiro-Wilk test and the homoscedasticity of the data using Levene's test. Variation in physical and chemical water parameters, zootechnical performance, and centesimal composition was assessed using a one-way analysis of variance (ANOVA). When significant differences among treatments were detected ($P < 0.05$), Tukey's test for multiple pairwise comparisons was used. When the assumptions underlying a parametric procedure were not met, the nonparametric Kruskal-Wallis test was used. The percentage survival rates were adjusted using the arcsine-square-root transformation before analysis. A 5% significance level ($P < 0.05$) was used for all analyses.

RESULTS

The basic parameters of water quality - temperature, pH, dissolved oxygen, and salinity - did not vary significantly ($P > 0.05$) among the different treatments (Table 1) and were within the recommended range for the rearing of *P. vannamei*. N-NO_3 also varied minimally ($P > 0.05$) among the treatments. However, the other chemical parameters -NAT, N-NO_2, and $CaCO_3$- varied significantly among treatments ($P < 0.05$), as did floc volume and total suspended solids.

At the end of the experiment (day 35), the mean final weight (g) and weekly weight gain (g) of the shrimp in the SM treatment were significantly higher ($P < 0.05$) than those of all the other treatments (Table 2). However, the significant differences in growth rates only became apparent after the 21st day of the experimental period (Fig. 1).

In the centesimal analysis conducted at the end of the 35 days of the experimental period, significant variation ($P < 0.05$) among treatments was observed only for humidity, with no significant differences in the content of bioflocs or shrimp (Table 3). In contrast, no significant variation ($P > 0.05$) was found in the ash, lipid, or protein content in any case. In the bioflocs, humidity was significantly higher ($P < 0.05$) in the CG and SM treatments than in those of the cassava products, while in the case of the shrimp, the only difference was that humidity was significantly higher ($P < 0.05$) in the CG treatment in comparison with the TS.

Table 1. Mean values (± standard deviation, SD) of water quality parameters during rearing of *Penaeus vannamei* in BFT system with different carbohydrate sources (CG: coffee grounds, CM: cassava meal, TS: tapioca starch, SM: sugarcane molasses). Different uppercase letters on the same line indicate significant differences (*P* < 0.05) between treatments.

Variable	Mean ± SD recorded in the treatment				*P*
	CG	CM	TS	SM	
Temperature (°C)	25.46 ± 0.36	25.65 ± 0.12	25.43 ± 0.30	25.59 ± 0.04	> 0.05
pH	8.68 ± 0.04	8.54 ± 0.04	8.63 ± 0.06	8.61 ± 0.04	> 0.05
Dissolved oxygen (mg L^{-1})	6.36 ± 0.04	6.51 ± 0.04	6.40 ± 0.03	6.54 ± 0.04	> 0.05
Salinity	36.00 ± 0.67	35.25 ± 0.38	35.33 ± 0.58	35.87 ± 0.21	> 0.05
Ammonia (NAT, mg L^{-1})	0.18 ± 0.01^{a}	0.12 ± 0.02^{b}	0.19 ± 0.04^{a}	0.15 ± 0.02^{ab}	0.002
Nitrite (N-NO_2 mg L^{-1})	0.27 ± 0.01c	0.44 ± 0.04^{a}	0.35 ± 0.02^{b}	0.30 ± 0.04bc	0.001
Nitrate (N-NO_3 mg L^{-1})	1.88 ± 0.10	2.15 ± 0.82	1.88 ± 0.61	1.95 ± 0.17	> 0.05
Alkalinity ($CaCO_3$ mg L^{-1})	146.18 ± 1.34^{a}	142.21 ± 1.12^{b}	144.82 ± 1.48^{a}	146.10 ± 2.07^{a}	0.001
Volume of flocs (ml L^{-1})	2.56 ± 0.92^{ab}	4.28 ± 1.81^{a}	2.70 ± 1.35^{ab}	1.42 ± 0.06b	0.006
Total suspended solids (mg L^{-1})	30.85 ± 1.32^{b}	34.16 ± 4.99^{ab}	32.55 ± 1.78^{ab}	36.85 ± 3.67^{a}	0.031

Table 2. Mean values for the zootechnical performance during rearing of *Penaeus* vannamei in the BFT system with different carbohydrate sources (CG: coffee grounds, CM: cassava meal, TS: tapioca starch, SM: sugarcane molasses). Different uppercase letters on the same line indicate significant differences (*P* < 0.05) between treatments.

Variable	Mean ± standard deviation recorded in the treatment				*P*
	CG	CM	TS	SM	
Initial weight (g)	0.14 ± 0.03	0.14 ± 0.03	0.14 ± 0.03	0.14 ± 0.03	
Final weight (g)	0.41 ± 0.19^{b}	0.45 ± 0.23^{b}	0.38 ± 0.22^{b}	0.61 ± 0.34^{a}	0.001
Survival (%)	88.89 ± 2.75	90.47 ± 4.76	88.89 ± 2.75	88.88 ± 5.50	>0.05
Weekly weight gain (g $week^{-1}$)	0.05 ± 0.003^{b}	0.06 ± 0.008^{b}	0.04 ± 0.021^{b}	0.09 ± 0.007^{a}	0.007
Feed conversion factor	1.97 ± 0.11	1.81 ± 0.26	2.28 ± 0.67	1.35 ± 0.15	>0.05

DISCUSSION

While some physical and chemical parameters of the water did vary significantly among treatments, they were within the range of values recommended for the farming of *P. vannamei* in biofloc systems (Emerenciano et al. 2017a, Martins et al. 2017, Hosain et al. 2021) and thus likely not have had any noticeable impact on the performance of the *P. vannamei* biofloc system analyzed here, which indicates that, regardless of the carbohydrate source, the bacterial flocs maintained adequate stability in water quality. The levels of ammonia and nitrite were also within acceptable limits, indicating that the application of these alternative carbohydrate sources was effective in controlling these nitrogenous compounds (Boyd & Clay 2002, Samocha et al. 2007, Sousa et al. 2014).

Alkalinity levels below 100 mg L^{-1} are known to negatively affect water quality and the zootechnical performance of *P. vannamei* when raised in biofloc systems (Furtado et al. 2011). The mean level recorded in the different treatments was approximately 144 mg L^{-1}, which was clearly adequate for the system tested here. Similarly, while some significant variation were recorded among treatments in the volume of bioflocs and TSS, the values recorded in all the treatments were below the threshold levels, 15 mL L^{-1} (bioflocs), 500 mg L^{-1} (TSS), considered to represent deleterious levels of microbial activity or suspended organic matter, respectively (Gaona et al. 2011, Emerenciano et al. 2017b). Concentrations above these thresholds would favor excessive heterotrophic community development, leading to increased dissolved oxygen consumption and the risk of branchial occlusion. In the present study, however, the highest mean bioflocs volume (4.28 mL L^{-1}) was recorded in the CM treatment. The mean TSS concentration (36.85 mg L^{-1}) recorded in the molasses treatment was well below levels considered potentially harmful to the health and growth of the shrimp.

Few published data are available on the use of the alternative carbohydrate sources tested in the present

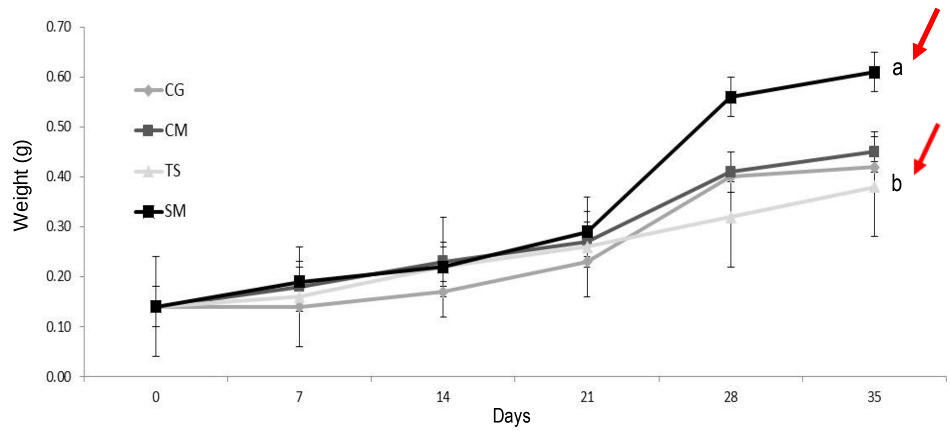

Figure 1. Mean values (± standard deviation) increase in weight (g) of the *Penaeus vannamei* rearing in biofloc systems with different sources of carbohydrates (CG: coffee grounds, CM: cassava meal, TS: tapioca starch, SM: sugarcane molasses). The different letters (a or b) indicate significant differences ($P < 0.05$) between treatments.

Table 3. Mean values of the centesimal analysis of biofloc and *Penaeus vannamei* shrimp, produced with different carbohydrate sources (CG: coffee grounds, CM: cassava meal, TS: tapioca starch, SM: sugarcane molasses). Different capital letters in the same line indicate significant differences ($P < 0.05$) between treatments.

Variable	Mean ± standard deviation recorded in the treatment				*P*
	CG	CM	TS	SM	
BFT					
Humidity	88.34 ± 0.68^{b}	90.04 ± 0.10^{a}	90.72 ± 0.50^{a}	88.55 ± 0.11^{b}	0.01
Ash	11.32 ± 0.82	10.29 ± 0.17	10.15 ± 0.09	10.71 ± 0.99	>0.05
Lipids	0.19 ± 0.07	0.22 ± 0.07	0.30 ± 0.02	0.23 ± 0.07	>0.05
Proteins	14.96 ± 0.19	14.37 ± 1.07	14.55 ± 1.53	14.28 ± 0.25	>0.05
Shrimp					
Humidity	77.96 ± 1.51^{a}	77.57 ± 0.80^{ab}	74.68 ± 1.44^{b}	77.55 ± 0.29^{ab}	0.02
Ash	1.67 ± 0.27	1.52 ± 0.16	1.39 ± 0.05	1.51 ± 0.15	>0.05
Lipids	1.07 ± 0.15	1.63 ± 0.25	1.39 ± 0.05	0.97 ± 0.19	>0.05
Proteins	27.63 ± 0.67	25.50 ± 0.51	25.36 ± 1.92	25.98 ± 1.50	>0.05

study, namely CG compared to SM. In the present study, the molasses shrimp showed significantly higher average weight and weekly weight gain than the other treatments, although the other parameters did not differ significantly. Rajkumar et al. (2016) observed differences in growth performance of P. vannamei among carbohydrate sources, with shrimp in the wheat flour treatment showing superior performance. Other studies, such as those of Lobato et al. (2019), who compared SM and CM, and Ekasari et al. (2014), who compared molasses and TS, both for biofloc production and the cultivation of *P. vannamei*, did not find significant differences in shrimp growth performance. While the use of molasses is now well-established in BFT systems, and also resulted in a superior growth performance in the shrimp raised in the present study, Suita et al. (2015) found that dextrose may be a better alternative source, given that it resulted in more transparent water, which may have contributed to the greater availability of microorganisms for the shrimp to feed on. Bioflocs may represent up to 20% of the total nutrients ingested by the shrimp (Otoshi et al. 2011, Crab et al. 2012, Xu et al. 2012). Different sources of carbohydrates may affect the microbial composition of the bioflocs, which, in turn, may influence the availability of the nutrients essential to shrimp growth (Crab et al. 2012). While the use of different carbohydrate sources in the BFT system tested here did influence shrimp growth, the consumption of the bioflocs themselves may play an important role as an alternative nutrient source for the shrimp.

In all treatments tested, shrimp survival rates were over 88% and did not vary significantly between treatments. These results are consistent with the findings of Ekasari et al. (2014), who used SM, TS, and rice bran as carbohydrate sources in the cultivation of *P. vannamei*, reporting survival rates ranging from (85-93%), however, they showed significant differences between the sources tested. The presence of bioflocs not only improves the quality of the water, but also provides additional nutrients, which together favour the survival of the shrimp, even at high stock densities (Kuhn et al. 2010, Castro et al. 2021), while also guaranteeing a reduction in mortality in intensive farming systems by providing a biological barrier to the establishment of pathogens (Crab et al. 2012). Although it did not vary significantly across treatments, the FCF was lower in the molasses treatment, indicating greater nutritional efficiency compared to the other treatments. Lobato et al. (2019) obtained similar results when comparing BFT systems for *P. vannamei* based on SM and CM as carbohydrate sources, as they did not show significant differences, but noted that CM had better nutritional efficiency. The different sources used here all demonstrated a positive impact, as bioflocs enriched with bacteria may provide microbial proteins and improve the feed conversion ratio of the shrimp, especially when the carbohydrate source provides an appropriate medium for this microbial growth (Wasielesky et al. 2006).

The molasses and CG treatments had significantly lower yields than the cassava (CM and TS) treatments. Fugimura et al. (2014) obtained similar results in their analysis of humidity levels in bioflocs produced from molasses and CM carbohydrate sources for the southern white shrimp, *Penaeus schimitti*. In the present study, while the humidity of the TS treatment did not differ significantly from that of the molasses and CM treatments, it was significantly lower than that of the CG treatment. Rajkumar et al. (2016) obtained similar results in their analysis of water quality, bioflocs composition, and growth performance in *P. vannamei* using SM, TS, and wheat flour as carbohydrate sources, with no significant variation among treatments. Despite the variation observed here in the humidity levels among treatments, all the sources used (CG, CM, TS, SM) were capable of supporting the formation of bioflocs, which indicated that they are adequate for use in BFT systems for shrimp farming.

Overall, SM was the carbohydrate source that supported the best performance of the *P. vannamei* biofloc system. However, the other carbohydrate sources evaluated here as CG, CM, and TS also provided satisfactory results for both water quality control and shrimp development. These findings indicate that these carbohydrate sources may be a viable and valuable alternative for shrimp farming in the Brazilian Amazon region, given their local availability, which minimizes costs and potential logistical difficulties. For future reference, we recommend testing these results in commercial production units to validate the applicability and efficiency of the proposed technology.

Credit author contribution

E. Silva, A. Braga, and R. Rocha: supervised the study and wrote the original draft of the manuscript. E. Silva and E. Arámbul-Muñoz: worked on the experiment and data analysis. E. Silva, A. Braga, S. Peixoto, E. Ballester, and R. Rocha: reviewed the manuscript and contributed to conceptualizing the study and methodology. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare that there are no conflicts of interest regarding this research article.

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REFERENCES

Associação Brasileira dos Criadores de Camarões (ABCCam). 2025. [https://abccam.com.br/wp-content/uploads/2020/10/Producao-de-Camarao-2020.pdf]. Reviewed: August 10, 2025.

Aguilar, R., Sánchez, C., Brito, L., et al. 2025. Growth parameters, water footprint, and digestive enzyme activity of pirarucu *Arapaima gigas* juveniles reared in a biofloc system. Aquaculture International, 33: 299. doi: 10.1007/s10499-025-01974-1

Almeida, J.R., Ferreira, T.S. & Costa, M.P. 2021. Reaproveitamento da borra de café na indústria alimentícia: uma abordagem sustentável. Revista Brasileira de Sustentabilidade, 10: 45-58.

Association of Official Analytical Chemistry (AOAC). 2000. Official methods of analysis of the AOAC. AOAC, Washington.

Avnimelech, Y. 1999. C/N ratio as a control element in aquaculture systems. Aquaculture, 176: 227-235. doi: 10.1016/S0044-8486(99)00085-X

Avnimelech, Y. 2007. Feeding with microbial flocs by tilapia in minimal discharge bio-flocs technology. Aquaculture, 264: 140-147. doi: 10.1016/j.aquaculture.2006.11.025

Ballester, E., Abreu, P., Cavalli, R., et al. 2010. Effect of practical diets with different protein levels on the performance of *Farfantepenaeus paulensis* juveniles nursed in a zero-exchange suspended microbial flocs intensive system. Aquaculture Nutrition, 16: 163-172. doi: 10.1111/j.1365-2095.2009.00648.x

Bligh, E.G. & Dyer, W.J. 1959. A rapid method of total lipid extraction and purification. Canadian Journal of Biochemistry and Physiology, 37: 911-917. doi: 10.1139/059-099

Boyd, C.E & Clay, J.W. 2002. Evaluation of Belize Aquaculture, Ltd: A superintensive shrimp aquaculture system. In: Review report prepared under the World Bank, NACA, WWF, and FAO Consortium Program on Shrimp Farming and the Environment, pp. 1-17.

Castro, L., Pinto, R. & Nunes, A. 2021. Nutrient value and contribution of microbial floc to the growth performance of juvenile shrimp, *Litopenaeus vannamei*, fed fatty acid and amino acid restrained diets under a zero-water exchange intensive system. Aquaculture, 531: 735789. doi: 10.1016/j.aquaculture. 2020.735789

Chakrapani, S., Panigrahi, A., Sundaresan, J.V.S., et al. 2022. Utilization of complex carbon sources on biofloc system and its influence on the microbial composition, growth, digestive enzyme activity of Pacific white shrimp, *Penaeus vannamei* culture. Turkish Journal of Fisheries and Aquatic Sciences, 22: 4. doi: 10.4194/TRJFAS18813

Conselho Estadual de Meio Ambiente do Pará (COEMA-PA). [https://www.semas.pa.gov.br/legislacao/files/pdf/2710.pdf]. Reviewed: October 15, 2025.

Crab, R., Avnimelech, Y., Defoirdt, T., et al. 2012. Nitrogen removal techniques in aquaculture for a sustainable production. Aquaculture, 270: 1-14. doi: 10.1016/j.aquaculture.2007.05.006

De Schryver, P., Crab, R., Defoirdt, T., et al. 2008. The basics of bioflocs technology: the added value for aquaculture. Aquaculture, 277: 125-137. doi: 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 control of ammonia nitrogen in aquaculture production systems. Aquaculture, 257: 346-358. doi: 10.1016/j.aquaculture.2006.03.019

Ekasari, J., Azhar, M., De Schryver, P., et al. 2014. Immune response and disease resistance of shrimp fed biofloc grown on different carbon sources. Fish & Shellfish Immunology, 41: 332-339. doi: 10.1016/j.fsi.2014.09.004

Elsayed, A.M. 2020. Use of biofloc technology in shrimp aquaculture: a comprehensive review, with emphasis on the last decade. Reviews in Aquaculture, 13: 676-705. doi: 10.1111/raq.12494

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). 2025. Receita bruta dos cafés do Brasil estimada para o ano 2025 atinge R$ 123,28 bilhões. [https://www.embrapa.br/busca-de-noticias/-/noticia/99162354/artigo-receita-bruta-dos-cafes-do-brasil-estimada-para-o-ano-2025-atinge-r-12328-bilhoes]. Reviewed: March 20, 2025.

Emerenciano, M., Ballester, E., Cavalli, R., et al. 2017c. Biofloc technology application as a food source in a limited water exchange nursery system for *Colossoma macropomum*. Aquaculture Research, 48: 447-457. doi: 10.1111/j.1365-2109.2011.02848.x

Emerenciano, M., Ballester, E.L., Cuzon, G., et al. 2017a. Biofloc technology (BFT): a review for aquaculture application and animal food industry. Biotechnology Advances, 36: 1352-1363. doi: 10.5772/53902

Emerenciano, M., Cordova, L., Porchas, M., et al. 2017b. Biofloc technology (BFT): a tool for water quality management in aquaculture. In: Tutu, H. (Ed.). Water quality. Intech, London, pp. 91-109. doi: 10.5772/66416

Emerenciano, M.G.C., Rombenso, A.N., Noble, T.H., et al. 2022. Intensification of penaeid shrimp culture: an applied review of advances in production systems, nutrition and breeding. Animals, 12: 236. doi: 10.3390/ani12030236

Ferreira, A.D. 2011. Influência da borra de café no crescimento e nas propriedades químicas e biológicas de plantas de alface (*Lactuca sativa*). Instituto Politécnico de Braganca. [https://bibliotecadigital.ipb.pt/bitstream/10198/6889/1/tese.pdf.]. Reviewed: March 20, 2025.

Fugimura, M., Flor, H., Melo, E., et al. 2014. Brewery residues as a source of organic carbon in *Litopenaeus schmitti* white shrimp farms with BFT systems. Aquaculture International, 23: 509-522. doi: 10.1007/s10499-014-9832-0

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

Gaona, C.A.P., Poersch, L.H., Foes, G.K., et al. 2011. The effect of solids removal on water quality, growth, and survival of *Litopenaeus vannamei* in a biofloc technology culture system. International Journal of Recirculating Aquaculture, 12: 54-73. doi: 10.21061/ijra.v12i1.1354

Hosain, M.E., Amin, S.M.N., Karim, M., et al. 2021. Effect of salinity on growth, survival, and proximate composition of *Macrobrachium rosenbergii* post larvae as well as zooplankton composition reared in a maize starch based biofloc system. Aquaculture, 533: 736235. doi: 10.1016/j.aquaculture.2020.736235

Jory, D.E. 1995. Feed management practices for a healthy pond environment. In: Browdy, C.L. & Hopkins, J. (Eds.). Swimming through troubled water. Proceedings of the special session on shrimp farming. World Aquaculture Society, Baton Rouge, pp. 118-143.

Korhonen, J., Honkasalo, A. & Seppälä, J. 2018. Circular economy: the concept and its limitations. Ecological Economics, 143: 37-46. doi: 10.1016/j.ecolecon.2017.06.041

Kuhn, D.D., Boardman, G.D., Marsh, L., et al. 2010. Microbial floc meals as a replacement ingredient for fish meal and soybean protein in shrimp feed. Aquaculture, 296: 5157. doi: 10.1016/j.aquaculture.2009.07.025

Lima, F.R.S., Nunes, A.J.P. & Cavalcante, D.D.V. 2021. Desempenho zootécnico do pirarucu (*Arapaima gigas*) cultivado em sistema de bioflocos com diferentes concentrações de proteína. Acta of Fisheries and Aquatic Resources, 9: 55-63

Lobato, O., Ribeiro, F., Mirandabaezab, A., et al. 2019. Production performance of *Litopenaeus vannamei* (Boone, 1931) fed with different dietary levels of tilapia processing waste silage reared in biofloc system using two carbon sources. Aquaculture, 501: 515-518. doi: 10.1016/j.aquaculture.2018.12.006

Maia, E.P., Brito, L.O., Gálvez, A.O., et al. 2016. Intensive culture system of *Litopenaeus vannamei* in commercial ponds with zero water exchange and addition of molasses and probiotics. Revista de Biología Marina y Oceanografía, 51: 61-67. doi: 10.4067/S0718-19572016000100006.

Maio, F., Rem, P., Daldé, K., et al. 2017. Measuring resource efficiency and circular economy: a market value approach. Resources, Conservation & Recycling, 122: 163-171. doi: 10.1016/j.resconrec.2017.02.009

Martins, G.B., Tarouco, F., Rosa, C.E., et al. 2017. The utilization of sodium bicarbonate, calcium carbonate or hydroxide in biofloc system: water quality, growth performance and oxidative stress of Nile tilapia (*Oreochromis niloticus*). Aquaculture, 468: 10-17. doi. 10.1016/j.aquaculture.2016.09.046

McIntosh, B.J., Samocha, T.M., Jones, E.R., et al. 2000. The effect of a bacterial supplement on the high-density culturing of *Litopenaeus vannamei* with lowprotein diet on outdoor tank system and no water exchange. Aquacultural Engineering, 21: 215-227. doi: 10.1016/S0144-8609(99)00030-8

Mussatto, S., Carneiro, L., Silva, J., et al. 2011. A study on chemical constituents and sugars extraction from spent coffee grounds. Carbohydrate Polymers, 83: 368-374. doi. 10.1016/j.carbpol.2010.07.063

Oliveira, L.M & Santos, C.A. 2018. Subprodutos da mandioca e sua aplicabilidade na alimentação. Revista de Ciência e Tecnologia de Alimentos, 7: 22-35. doi: 10.31533/pubvet.v15n08a895.1-11

Otoshi, C.A., Moss, D.R. & Moss, S.M. 2011. Growth enhancing effect of pond water on four size classes of Pacific white shrimp, *Litopenaeus vannamei*. Journal of the World Aquaculture Society, 42: 417-422. doi: 10.1111/J.1749-7345.2011.00482.X

Pamanna, A., Chandrasekhara-Rao, A., Ranjith, K., et al. 2017a. Water quality on survival percentage of *L. vannamei* in biofloc treatments grown with different carbon sources. Biochemical and Cellular Archives, 17: 595-599.

Pamanna, D., Chandrasekhara-Rao, A., Ravindra-Kumar-Reddy, D., et al. 2017b. Growth performance of *Litopenaeus vannamei* in biofloc treatments grown with different carbon sources. Biochemical and Cellular Archives, 17: 589-593.

Panigrahi, A., Sundaram, M., Syama-Dayal, J., et al. 2019. Effect of carbon and nitrogen ratio (C:N) manipulation on the production performance and immunity of Pacific white shrimp *Litopenaeus vannamei* (Boone, 1931) in a biofloc based rearing system. Aquaculture Research, 50: 29-41. doi: 10.1111/are.13857

Rajkumar, M., Pandey, R., Bharti, V., et al. 2016. Effect of different biofloc system on water quality, biofloc composition and growth performance in *Litopenaeus vannamei* (Boone, 1931). Aquaculture Research, 47: 3432-3444. doi: 10.1111/are.12792

Ray, A. & Lotz, J. 2014. Comparing a chemoautotrophic based biofloc system and three heterotrophic based systems receiving different carbohydrate sources. Aquaculture Engineering, 63: 54-61. doi: 10.1016/j.aquaeng.2014.10.001

Reeb, J.E & Milota, M.R. 1999. Moisture content by the oven dry method for industrial testing. Western Dry Kiln Association, Corvallis.

Samocha, T.M., Lawrence, A.L., Lee, P.G., et al. 2004. Production of the Pacific white shrimp, *Litopenaeus vannamei*, in high density greenhouse enclosed raceways using low salinity groundwater. Journal of Applied Aquaculture, 15: 1-19. doi: 10.1300/J028v 15n03_01

Samocha, T.M., Painaik, S.M., Horowitz, A., et al. 2007. Use of molasses as carbon source in limited discharge nursery and growout systems for *Litopenaeus vannamei*. Aquacultural Engineering, 36: 184-191. doi: 10.1016/j.aquaeng.2006.10.004

Schneider, O., Sereti, V. & Eding, E.H. 2006. Molasses as C source for heterotrophic bacteria production on solid fish waste. Aquaculture, 261: 1239-1248. doi: 10.1016/j.aquaculture.2006.08.053

Silva, E., Silva, J., Soares, R., et al. 2015. Influence of stocking density on the zootechnical performance of *Litopenaeus vannamei* during the nursery phase in a biofloc system. Boletim do Instituto de Pesca, São Paulo, 41: 777-783. doi: 10.20950/1678-2305.2015 v41nep777

Silveira, L.G.P., Poersch, L.H., Rosas, V.T., et al. 2020. Hyperintensive stocking densities for *Litopenaeus vannamei* growout in biofloc technology culture system. Journal of the World Aquaculture Society, 51: 1290-1300. doi: 10.1111/jwas.12718

Sousa, D., Suita, S., Wasielesky, W., et al. 2014. Use of molasses as a carbon source during the nursery rearing of *Farfantepenaeus brasiliensis* (Latreille, 1817) in a biofloc technology system. Aquaculture Research, 45: 270-277. doi. 10.1111/j.1365-2109.2012.03223.x

Souza, A.L. & Lima, P.R. 2019. Sustentabilidade e aproveitamento de subprodutos na alimentação humana. Estudos em Nutrição Sustentável, 5: 120-134.

Squio, C.R. & Aragão, G.M.F. 2004. Estratégias de cultivo para produção dos plásticos biodegradáveis poli (3hidroxibutirato) e poli(3hidroxibutiratoco3 hidroxi-valerato) por bactérias. Química Nova, 27: 615-622.

Suita, S., Ballester, E., Abreu, P., et al. 2015. Dextrose as carbon source in the culture of *Litopenaeus vannamei* (Boone, 1931) in a zero exchange system. Latin American Journal of Aquatic Research, 43: 526-533. doi: 10.3856/vol43-issue3-fulltext-13

Tinh, T., Hai, T., Verreth, J., et al. 2021a. Effects of carbohydrate addition frequencies on biofloc culture of Pacific white shrimp (*Litopenaeus vannamei*). Aquaculture, 534: 736271 doi: 10.1016/j.aquaculture. 2020.736271

Tinh, T., Hai, T., Verreth, J., et al. 2021b. Effects of carbohydrate sources on a biofloc nursery system for whiteleg shrimp (*Litopenaeus vannamei*). Aquaculture, 531: 735795 doi: 10.1016/j.aquaculture.2020. 735795

Wang, F., He, J., Jiang, S., et al. 2021. Comparison of nutritional quality and nutrient compositions of three edible tissues from different sourced cultured female mud crabs (*Scylla paramamosain*). Journal of Food Composition and Analysis, 104: 104163. doi: 10.1016/ j.jfca.2021.104163

Wasielesky, W.J., Atwood, H.I., Stokes, A., et al. 2006. Effect of natural production in brown water superintensive culture system for white shrimp *Litopenaeus vannamei*. Aquaculture, 258: 396-403. doi: 10.1016/j.aquaculture.2006.04.030

Wei, Y., Liao, S. & Wang, A. 2016. The effect of different carbon sources on the nutritional composition, microbial community and structure of bioflocs. Aquaculture, 465: 88-93. doi: 10.1016/j.aquaculture. 2016.08.040

Xu, W.J., Pan, L.Q., Zhao, D.H., et al. 2012. Preliminary investigation into the contribution of bioflocs on protein nutrition of *Litopenaeus vannamei* fed with different dietary protein levels in zero water exchange culture tanks. Aquaculture, 22: 335-342. doi: 10.1111/ anu.12249

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