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THE EFFECTS OF DIFFERENT STOCKING DENSITIES ON NURSERY PERFORMANCE OF BANANA SHRIMP (*FENNEROPENAEUS MERGUIENSIS*) REARED UNDER BIOFLOC CONDITION

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Abstract

The effects of banana shrimp *Fenneropenaeus merguiensis* stocking density on water quality, growth performance, survival rate and body composition was assessed in a biofloc system with limited water exchange. The study was conducted for 32 days with an average larvae weight of 10 ± 0.85 mg in fiberglass tanks containing 120 L of water at four stocking densities. Five experimental treatments consisted of a control (density 1000 shrimps/m^3) with 50% daily water exchange and four biofloc treatments with limited water exchange (0.5% daily) at four stocking levels (1000 shrimps, T1; 2000 shrimps, T2, 3000 shrimps, T3 and 4000 shrimps, T4/m^3). According to the results, total ammonia nitrogen (0.99 mg/L) and nitrite levels showed higher amounts in the control compared with the other treatments (P<0.05). Growth performance and survival rate (95.55%) in the biofloc treatment with a density of 1000 shrimps/m^3 were higher than the other treatments (P<0.05). The proximate composition of shrimp body and biofloc produced in rearing tanks depended on the stocking density, so the shrimp body ash increased along with the enhancement of stocking density. The lowest amount of ash (31.53 ± 0.81%) and protein (26.38 ± 1.26) of bioflocs was observed in T1 treatment. The present study showed that stocking density affects the water quality, growth performance, survival rate and body composition of banana shrimp larvae in a biofloc system. More improved indices of water quality, growth performance and survival rate were observed with the least stocking density of 1000 shrimps/m^3 in the limited water exchange system.

Key words: biofloc, banana shrimp, stocking density, growth performance, biochemical composition, limited water exchange

Banana shrimp (*Fenneropenaeus merguiensis*) is an ideal candidate for cultivation due to its special characteristics such as suitability for captive breeding in ponds, tolerance to different environmental conditions (euryhaline and eurythermal), availability in natural habitats, low protein requirement, easy access to wild broodstock, and easy cultivation of larvae and post-larvae (Hoang et al., 2002; Shrivastava et al., 2017). Currently, the global shrimp farming industry faces several challenges including environmental degradation, climate change, and the spread of pathogens (Jory, 2019; Yeganeh et al., 2020). Additionally, feed and energy costs, and shrimp diseases contribute negatively to the shrimp production (Anderson et al., 2019). A zero- or minimal-water exchange aquaculture can be achieved successfully with biofloc technology (BFT) (Khanjani and Sharifinia, 2020). This technology will reduce the frequency of discharges of aquatic waste nutrients into the environment, and it would also reduce the likelihood of escapes, as well as the prevalence of disease (El-Sayed, 2021; Emerenciano et al., 2022).

For heterotrophic bacteria to grow in a biofloc system, the carbon-to-nitrogen ratio must be high (above 10) and the aeration must be intense (Ebeling et al., 2006). The biofloc system absorbs dissolved nitrogen compounds and improves water quality (Khanjani and Sharifinia, 2022). In addition, it has been demonstrated that the biofloc produced in this system may also be used to feed the shrimp and fish (Cuzon et al., 2004; Otoshi et al., 2011; Das and Mandal, 2021 a, b; Poli et al., 2021; Khanjani et al., 2022 b).

Aquatic performance depends on many factors in the biofloc system. Biofloc production is affected by a number of biological factors including stocking density, supplemental feed and natural food availability (Xu and Pan, 2014; Zhu et al., 2016; Esparza-Leal et al., 2020; Dinda et al., 2020; Das and Mandal, 2021 a, b; Dorothy et al., 2021; Khanjani et al., 2022 b; Emerenciano et al., 2022). Similarly, abiotic factors (temperature, dissolved oxygen, salinity, total suspended solids, pH, alkalinity, light exposure, total ammonium nitrogen, nitrite and nitrate) also influence the shrimp production in BFT systems (Hostins et al., 2015; Pierri et al., 2015; Khanjani and Sharifinia, 2021). Adding carbon sources, exchanging water, and adding substrates are also crucial to the long-term performance of shrimp (Huang et al., 2017; Olier et al., 2020;

Minabi et al., 2020; Khanjani and Sharifinia, 2022). In addition to ecological parameters and management practices, the growth and survival of aquatic organisms determine the ultimate yield. Increasing stocking density requires large amounts of feed, resulting in excessive nutrient loads that need to be recycled by microbial communities (Tao et al., 2021; El-Sayed, 2021). The nutrients may lead to eutrophication of the systems, which could contribute to biofloc development (Avnimelech, 2007; Khanjani and Sharifinia, 2020; El-Sayed, 2021). Feed wastes and animal excrements decompose into ammonia, which is assimilated by algae and heterotrophic bacteria into cellular proteins (Khanjani et al., 2022 b; Emerenciano et al., 2022). The addition of organic carbon is necessary to maintain an appropriate ratio of C:N for bacterial growth and biofloc production (Minabi et al., 2020; Khanjani and Sharifinia, 2022).

A transitional nursery phase between the hatchery and grow-out ponds is a common practice in shrimp farming industry in many countries (Correia et al., 2014). However, high stocking density in the nursery phase may negatively affect the shrimp growth and survival rate due to cannibalism and degradation of water quality (Arnold et al., 2006; Shrivastava et al., 2017). Survival rate, growth performance, body composition and health status of shrimp are affected by stocking density, i.e. by increasing the density, survival rate and growth performance decrease (Wasielesky et al., 2013; Liu et al., 2017). Various reports have been presented regarding the optimum stocking density of penaeid shrimps, including *Penaeus monodon* (Arnold et al., 2009; Tao et al., 2019), *Litopenaeus vannamei* (Rezende et al., 2019; Rodríguez-Olague et al., 2021; Poli et al., 2021; Tao et al., 2021) and *Penaeus indicus* (Sivanandavel and Soundarapandian, 2010; Anand et al., 2021). There is no information on the effect of stocking density on the performance of banana shrimp in a biofloc system with limited water exchange. Determining the optimal stocking density of cultivated aquatics is very important for farmers to achieve higher production and profitability in a system with limited water exchange. In the present study, water quality, growth performance, survival rate and biochemical composition of banana shrimp (*F. merguiensis*) post-larvae at different stocking densities in a heterotrophic system with limited water exchange were investigated.

Material and methods

Experimental design

The present study was conducted in the aquatic reproduction center of Bandar Kolahi (Hormozgan Province, southern Iran) for 32 days. Banana shrimp post-larvae with an average weight of 10 ± 0.85 mg were obtained from the above breeding center. Fifteen circular polyethylene tanks with the volume of 300 L were used. Prior to the stocking, the tanks were disinfected and then rinsed with water. Each tank was filled with 120 L of filtered water (with sand filter) at a salinity of 29 ppt. One control (C) (with stocking density of one shrimp per L (1000 shrimps/m^3) and four biofloc treatments in three replicate with different stocking densities including one shrimp per L (1000 shrimps/m^3, T1), two shrimps per L (2000 shrimps/m^3, T2), three shrimps per L (3000 shrimps/m^3, T3) and four shrimps per L (4000 shrimps/m^3, T4) in a system with limited water exchange were considered (Table 1).

Table 1. Different stocking densities of banana shrimp in the present study

Stocking density (shrimps/m^3)		Water exchange (daily%)	No.
Control	1000	50	C
Treatment 1	1000	0.5	T1
Treatment 2	2000	0.5	T2
Treatment 3	3000	0.5	T3
Treatment 4	4000	0.5	T4

System management and carbohydrate addition

In the control, 50% of the water volume was exchanged daily from the bottom of the tanks. In treatments with limited water exchange, before stocking the post-larvae, 0.5 ml/L of biofloc was added to the treatment tanks as stock. Feeding was done three times a day (8 am, 3 pm, 9 pm) with artificial feed consisting of 38% protein, 9% lipid, 14% ash and 3% fiber. A feeding rate of 14–12% of body weight was used at the beginning and at the end of the study.

The experiment was conducted in an indoor lab under cycles of 12 h light and 12 h darkness. Continuous aeration was provided for each tank using an air compressor. Molasses was used as a carbon source in all biofloc treatments and was added daily to the cultivation tanks at 3:30 pm. Based on the amount of protein (%) in artificial feed during the cultivation, the amount of molasses per treatment was calculated assuming that protein contains 16% nitrogen and shrimp would excrete 65% of protein nitrogen. Assuming that 1000 g of feed contains 38% protein (16% nitrogen), then, 60.8 g of nitrogen would be produced, of which 35% would be digested and transformed into muscle; 39.52 g of nitrogen would be excreted. A C:N ratio of 15:1 required 592.8 g carbon. This was provided by 1482 g molasses because molasses contains 40% carbon, as determined in the laboratory by proximal chemical analysis (Avnimelech, 2015; Emerenciano et al., 2017). Based on the protein content of the diet and the amount of feed provided in each treatment, the experimental treatments were determined (Crab et al., 2012; Emerenciano et al., 2017).

Assessment of water quality parameters

Over the 32-day experiment, pH, salinity, dissolved oxygen (DO), and water temperature were measured

daily at 10 am. The water samples were collected weekly from each tank (100 mL each) followed by spectrophotometric analysis on half of the sample for total ammonium nitrogen (TAN), nitrite (NO_2) and nitrate (NO_3) using the Standard Methods for the Examination of Water and Wastewater (APHA, 2012). Biofloc volume (BV) was determined weekly using Imhoff cones by measuring the volume sedimented from 1,000 ml of water sample (Avnimelech and Kochba, 2009). To determine the total suspended solids (TSS), 100 ml of the water of each tank was filtered with Whatman filter paper No. 42 (predried and preweighed) and dried at 105°C for one to three h until it reached constant weight, then the dried sample was weighed (Azim and Little, 2008).

Growth and nutritional parameters

At the end of the experiment, the shrimps were harvested and the growth indices were calculated as follows (Khanjani et al., 2022 a):

Weight gain (WG) = (final weight – initial weight)

Average daily growth (ADG) (mg/day) = (Final body weight – Initial body weight) / duration of experiment

Specific growth rate (SGR, % day^{-1}) = [(Ln final weight - Ln initial weight) × 100] / duration of experiment

Survival rate (%) = (Number of live shrimps / Initial number of total shrimps stocked) × 100

Feed conversion ratio (FCR) = Total feed consumed (g, dry weight basis) / body weight gain (g, wet weight basis)

Proximate composition of the shrimp and biofloc

An analysis of the proximate composition of the shrimp body was conducted on 70 shrimps from each tank on the day of harvest. Shrimp samples were oven dried for 24 h at 90°C to determine their moisture content (Hussain et al., 2021).

To analyze the biofloc samples, the whole water in the rearing tanks containing biofloc was first filtered with a 20 micron mesh net. The filtered samples were dried in an oven at 72°C for 72 h (Khanjani and Sharifinia, 2021). AOAC (2005) method was used to determine the proximate composition of the shrimp and biofloc samples for crude protein, crude lipid, and ash contents.

Data analysis

Data were analyzed using SPSS software (version 21.0). Statistical assumptions including normality of data distribution and homogeneity of variances were ascertained by Kolmogorov-Smirnov and Levene's tests, respectively, before conducting one-way ANOVA. Duncan's multiple-range test (DMRT) was used for multiple comparisons. Statistical significance level was set at $P<0.05$ and the results were represented as mean ± standard deviation (SD).

Results

Water quality

The results of physicochemical parameters in banana shrimp rearing tanks under the influence of different stocking densities are presented in Table 2. The lowest amount of DO (5.21 mg/L) and pH (7.97) was observed in T4 and the lowest salinity (29.44 ppt) was observed in the control, which showed a significant difference with the other treatments ($P<0.05$). The highest amount of TAN (0.99 mg/L) and NO_2 (5.1 mg/L) were observed in the control. Among the biofloc treatments, the lowest amounts of TAN (0.24 mg/L) and NO_2 (2.15 mg/L) were obtained in T1. The amount of BV in the range of 1.03 (C) to 8.16 ml/L (T4) was obtained. Also, the amounts of TSS in biofloc treatments were higher than the control and the difference was significant ($P<0.05$).

Table 2. Values of physicochemical parameters of banana shrimp rearing tank water under the influence of different stocking densities (Mean ± SD)

Parameters	C	T1	T2	T3	T4
T (°C)	28.22±0.48 a	28.37±0.56 a	28.41±0.61 a	28.36±0.51 a	28.35±0.57 a
DO (mg/L)	6.38±0.39 a	6.21±0.34 a	5.89±0.3 b	5.68±0.28 c	5.21±0.31 d
pH	8.23±0.06 a	8.15±0.05 b	8.14±0.04 b	8.06±0.04 c	7.97±0.03 d
Salinity (ppt)	29.44±0.4 a	30.17±0.92 a	30.11±0.89 a	30.08±0.82 a	30.17±0.85 a
TAN (mg/L)	0.99±0.30 a	0.24±0.16 c	0.33±0.21 bc	0.46±0.22 b	0.59±0.24 b
NO2 (mg/L)	5.1±2.26 a	2.15±0.7 c	2.55±1.04 bc	2.9±0.92 b	3.34±1.16 b
NO3 (mg/L)	1.71±0.86 d	3.16±1.12 c	4.08±0.67 b	5.05±1.29 a	5.47±1.43 a
BV (ml/L)	1.03±0.27 c	4.7±2.37 b	5.18±2.19 b	7.47±3.08 a	8.16±2.73 a
TSS (mg/L)	37.57±20.55 c	142.3±73.22 b	161.6±81.81 b	224.12±100.13 a	250.3±95.58 a

Values (mean ± SD) in the same row with different letters are significantly different from each other ($P<0.05$).

Table 3. Survival rate and growth performance of Banana shrimp under different stocking densities (Mean ± SD)

Parameters	C	T1	T2	T3	T4
Final weight (mg)	786.32±98.60 b	842.67±68.1 a	694±73 c	580.67±75.63 d	425.33±81.4 e
ADG (mg/day)	24.26±3.08 b	26.02±2.13 a	21.37±2.3 c	17.83±2.36 d	12.97±2.54 e
SGR (% day^{-1})	13.64±0.92 b	13.85±0.66 a	13.25±0.67 c	12.69±0.69 d	11.72±0.74 e
Survival rate (%)	90.55±0.96 b	95.55± 0.48 a	85.14±1.87 c	81.38±1.7 d	76.04±3.12 e
FCR	1.17±0.11 c	1.07±0.07 d	1.07±0.09 d	1.29±0.15 b	1.83±0.31 a

Values (mean ± SD) with different letters in rows are significantly different from each other (P<0.05).

Table 4. Amounts (in terms of dry weight %) of banana shrimp body composition and bioflocs produced in the cultivation tanks under the influence of different stocking densities (Mean ± SD)

Treatment	Crude protein (% DW)	Crude lipid (% DW)	Ash (% DW)
Shrimp			
C	75.32±0.89 b	6.14±0.17 b	10.03±0.21 c
T1	76.59±0.83 a	6.92±0.21 a	10.99±0.29 b
T2	76.81±0.91 a	6.88±0.17 a	10.84±0.32 b
T3	76.48±0.66 a	6.82±0.22 a	11.44±0.37 a
T4	76.44±0.51 a	6.83±0.23 a	11.64±0.34 a
Biofloc			
T1	26.38±1.26 c	1.02±0.04 a	31.53±0.81 c
T2	26.81±0.94 c	0.97±0.03 a	33.98±1.09 b
T3	27.89±0.85 b	0.88±0.05 b	34.20±0.92 b
T4	28.97±1.19 a	0.84±0.04 b	36.42±0.88 a

Values (mean ± SD) in the same column with different letters are significantly different from each other (P<0.05).

Growth performance and survival rate

The results of banana shrimp growth performance and survival rate under different stocking densities are presented in Table 3. The results showed that the final weight (842.67 mg), ADG (26.02 mg/day) and SGR (13.85% per day) were the highest in T1 and there was a significant difference with the other treatments (P<0.05). The lowest survival rate was 76.04% and the highest FCR was 1.83 in T4 treatment showing a significant difference with the other treatments (P<0.05).

Proximate analysis of body composition and biofloc produced

The results of proximate composition of banana shrimp body and biofloc produced in rearing tanks are given in Table 4. The results showed that the shrimps cultured in the control had the lowest amount of protein (75.32%), lipid (6.14%) and ash (10.03% of dry weight). Analysis of proximate composition of bioflocs indicated that the highest amount of protein (28.97%) and ash (36.42% of dry weight) was obtained in T4. Lipid levels in bioflocs ranged from 0.84 to 1.02% of dry weight in T4 and T1 treatments, respectively.

Discussion

Water quality

Despite the effect of shrimp stocking density on water quality parameters, the parameters remained within the accepted range for penaeid shrimp rearing (Rezende et al., 2019; Khanjani et al., 2020; Ponce-Palafox et al., 2019; Ali et al., 2020). The results of the present study were in line with those of Arnold et al. (2009) for *P. monodon* and Rezende et al. (2019) for *L. vannamei* in which they examined different stocking densities in a cultivation system with limited water exchange during the nursery period and measured variations in water quality parameters according to densities. Studies have found that DO levels for penaeid shrimp culture should range between 5.23 and 7.10 mg/L (Shrivastava et al., 2017; Khanjani et al., 2020). During the experimental period, the DO level of the water in the tanks varied from 5.21 mg/L to 6.38 mg/L, which remained within the acceptable range. In both *F. merguiensis* (Anand et al., 2014) and *L. vannamei* (Balakrishnan et al., 2011), DO levels were significantly different when the stocking density was increased. The lowest level of DO was found in T4 treatment, which is probably due to the higher TSS

content and higher respiration rates. Previous studies have mentioned that the DO levels in rearing tanks are affected by water temperature, metabolic rate, TSS and biomass (Shrivastava et al., 2017; Rezende et al., 2019; Khanjani and Sharifinia, 2022).

Penaeid shrimp grow best at a pH between 7.8 and 8.7 (Shrivastava et al., 2017; Rezende, et al., 2019). In the present study, pH values were consistent with those reported by Wang (2004), Legarda et al. (2018) and Khanjani et al. (2020) for *L. vannamiei* rearing. The pH values in the biofloc treatments were lower than those in the control as a result of the addition of carbonaceous organic matter to the rearing tanks, which enhances the growth and production of heterotrophic bacteria (Khanjani et al., 2021 a). The salinity values were within the acceptable range for banana shrimp farming. The higher amount of salinity in biofloc treatments was due to the accumulation of salt from uneaten feeds in the cultivation tanks with limited water exchange (Alves et al., 2017). Nitrogen compounds (TAN and NO_2) were lower in the biofloc treatments than the control, which was also in agreement with previous studies (Gaona et al., 2011; Wasielesky et al., 2013). In a system with limited water exchange, the carbonaceous organic matter in the rearing tanks probably leads to the growth of heterotrophic bacteria and the uptake of nitrogen compounds (Legarda et al., 2018; Ali et al., 2020; Khanjani et al., 2021 c). Among biofloc treatments, the lowest amount of nitrogen compounds (TAN, NO_2, NO_3) was observed in T1, which was probably due to lower density and consequently less feed and, therefore, lower production of nitrogen compounds (Rodríguez-Olague et al., 2021).

Carbohydrate addition to zero-water exchange systems for shrimp culture can effectively increase the activity of nitrogen cycle bacteria, thereby reducing inorganic nitrogen levels. Avnimelech (2015) determined that by adding carbohydrates to the water and regulating the C:N ratio, the assimilation of nutrients by heterotrophic bacteria, as well as the biofloc formation, could be optimized, leading to the removal of TAN and NO_2. TAN is increased during the first few days of culture and is then oxidized into NO_2 and NO_3 by both ammonia oxidizers and nitrite oxidizers; this is a coupled process (Das and Jana, 2003; Esparza-Leal et al., 2015; Moreno-Arias et al., 2017; Zhang et al., 2017; Rodrigues et al., 2018). NO_3 is the final product of nitrification process and its amount was higher in biofloc treatments than the control. All treatments recorded NO_3 levels below the critical levels for shrimp rearing (Furtado et al., 2015; Satanwat et al., 2020). Avnimelech (2015) determined that BV and TSS were true indicators of biofloc formation. In the present study, biofloc development was within acceptable limits based on BV and TSS. With increasing density, BV and TSS values increased, which is probably due to the amount of feed and organic carbon used. Results of the present study are consistent with the results of Samocha et al. (2007), Rajkumar et al. (2016) and Ali et al. (2020). Samocha et al. (2007) suggested a TSS value of less than 500 mg/L for the rearing period of penaeid shrimp.

Growth performance and survival rate

There has consistently been a negative correlation between the shrimp growth performance, survival rate and stocking density in studies on *F. merguiensis* (Araneda et al., 2008; Wasielesky et al., 2013; Dorothy et al., 2021). Increased stocking density resulted in significant reductions in average final individual weight, ADG and SGR of *F. merguiensis*. T1 had the highest and T4 had the lowest SGR. Araneda et al. (2008), Sookying et al. (2011), Shrivastava et al. (2017) and Dorothy et al. (2021) also concluded that increasing shrimp density and biomass would negatively affect the growth performance. With an increase in stocking density in the BFT treatments, the shrimp growth was reduced, possibly due to a reduced quality of water and physical stress caused by crowding at higher stocking densities.

In this study, despite similar density, growth performance was better in T1 with limited water exchange than in the control. Thus, it can be said that BFT has a higher carrying capacity than clear water culture systems. Similarly, Rajkumar et al. (2016) and Dorothy et al. (2021) reported suitable shrimp growth in the BFT system. Shrimp density increased FCR and the difference between the treatments was significant. In T4, the FCR was greater, which indicates that this parameter was affected by high stocking density, as well as by the reduction of shrimp's ability to graze on the microbial community at high densities. In the case of *P. monodon*, Shakir et al. (2014) obtained similar results, as did Wasielesky et al. (2013) for *L. vannamei*. In the present study, the FCR in T2 and T1 treatments was better than the control, which was probably due to the presence of microbial flocs in the cultivation tanks. The microbial community provides an excellent natural food source for shrimp, especially during the nursery phase (Emerenciano et al., 2012; Godoy et al., 2011). With an improvement in the utilization of natural productivity, a lower FCR is predicted and this effect is reflected by the shrimp's specific growth rate (Mishra et al., 2008; Sarker et al., 2019).

There were significant differences in survival rate among the treatments. Survival rate was significantly lower in the treatments with higher stocking density (T3 and T4) and the highest rate of survival was observed in T1. Results from Moss and Moss (2004), Krummenauer et al. (2011), Otoshi et al. (2007), Wasielesky et al. (2013) and Rezende et al. (2019) were in agreement with these findings. According to Li et al. (2006), high stocking densities negatively affected the growth and survival rates of Chinese shrimp, *Fenneropenaeus chinensis*. Under identical stocking density, the survival rate in T1 was higher than in the control probably due to the better water quality in T1 treatment. The presence of biofloc in the rearing system with limited water exchange leads to the uptake of inorganic nitrogen compounds and improves the water quality (Khanjani and Sharifinia, 2022).

Shrimps are highly sensitive to parameters of water quality, particularly NH_3 and NO_2 (Santacruz Reyes and Chien, 2012). Adding organic carbon source to the system may cause a decrease in toxic metabolites, leading to a better growth and survival due to the biofloculation in zero- or low-water exchange systems. There is a combination of factors responsible for a decrease in juvenile penaeid survival rate at high stocking densities. Among them are the reduction in available space and natural productivity, as well as the degradation of water quality and the accumulation of anaerobic sediment (Moss and Moss, 2004; Wasielesky et al., 2013).

Proximate analysis of body composition and biofloc produced

In the present study, a significant difference was observed in the biochemical composition of banana shrimp in the biofloc treatments and the control. The lowest amount of protein, lipid and ash was obtained in the control. The improvement in the biochemical composition of the shrimp body in the biofloc treatments is probably due to the presence of rich microbial mass formed in the rearing tank (Dorothy et al., 2021). Results of the present study agree with the results of Dorothy et al. (2021), Khanjani et al. (2020), Xu and Pan (2012), Rajkumar et al. (2016) and Emerenciano et al. (2013) who reported that the amount of protein, lipid and ash of the shrimp body in the biofloc treatments with limited water exchange was higher than the control. Bioflocs are rich sources of protein, lipid (especially essential fatty acids), and minerals (Emerenciano et al., 2014; Khanjani and Sharifinia, 2020) whose consumption by aquatic animals leads to improved carcass quality (Avnimelech, 2015; El- Sayed, 2021). The total increase in shrimp body ash under biofloc conditions is due to the continuous availability of abundant minerals and trace elements in the biofloc (Xu and Pan, 2012). Protozoa in the biofloc contains sterols and other forms of lipid in their chemical composition, the consumption of which by shrimp leads to an increase in the body lipid (Loureiro et al., 2012; Khanjani and Sharifinia, 2020).

Biofloc consumption can significantly improve the feed efficiency, health status, nutritional value, and shelf life of shrimp in addition to a significant reduction in feed cost (Xu and Pan, 2012; Ray et al., 2019; Khanjani et al., 2020; El-Sayed, 2021). In the present study, the range of biochemical compounds of bioflocs including protein, lipid and ash was consistent with the studies of Lara et al. (2017), Khanjani et al. (2020), Khanjani et al. (2021 c), Neto et al. (2015) and Emerenciano et al. (2014). The protein content of bioflocs increased with increasing stocking density, probably due to the addition of more feed and organic matter, followed by an increase in flocculation density and changes in microbial and microorganism communities (Martınez-Cordova et al., 2015). Biofloc had a low lipid content in all treatments, ranging between 0.84 and 1.02%. Many studies have found that lipid content varies considerably among bioflocs based on many factors, including the source of carbon (Khanjani et al., 2021 b) and the type of microbes associated (Moreno-Arias et al., 2018; Mugwanya et al., 2021). As the shrimp stocking density increased, the ash content of the bioflocs increased, possibly due to more feed intake and increased salt concentration in the rearing tanks. In conclusion, the present study showed that the banana shrimp stocking density affects water quality, growth performance, survival rate and body composition under biofloc-based culture system. The most suitable water quality, growth performance and survival rate of banana shrimp were observed at the lowest density of 1000 shrimps/m^3 with limited water exchange in T1 treatment.

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