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Stocking Density Effects on Growth and Survival of *Litopenaeus vannamei* (Boone, 1931) in Nursery: An Investigation for Optimal Cultivation Practices

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ABSTRACT

Shrimp production relies significantly on the physical, chemical, and biological attributes of water. A fundamental grasp of water quality is crucial for effective management of shrimp cultivation. In these 30-days experiment, diverse stocking density nursery culture systems were studied to gather data on water quality and its impact on growth and survival. Physico-chemical parameters, including temperature, pH, salinity, dissolved oxygen, and others, were periodically analyzed. Treatment 1 (T1) demonstrated a high survival rate of 92.1±0.2% and an efficient feed conversion ratio (FCR) of 0.68±0.1, indicating effective feed utilization. In contrast, Treatments 2 and 3 (T2 and T3) exhibited variations in weights, growth rate, survival, and FCR, suggesting the importance of scrutinizing physical-chemical parameters for successful shrimp cultivation in nursery culture systems within an identified ideal range.

KEYWORDS: Nursery, Growth, Litopenaeus vannamei, Density, Survival

1. INTRODUCTION

The fisheries and aquaculture sectors globally play a vital role in providing sustenance, nutrition, economic benefits, and livelihoods for millions of people. Over the past decade, the aquaculture industry has experienced significant growth. In 2022, India ranked as the world's second-largest producer of farmed shrimp after Ecuador, achieved a production of 9 lakh tonnes. However, the expansion of shrimp farming raises concerns about potential environmental impacts, including deteriorating water quality, pathogen transmission, and disease outbreaks. The white shrimp (*Litopenaeus vannamei*) is a notable fisheries product, valued for its attributes such as ease of farming, consistent production, and adaptability to high stocking density, and disease resistance. Stocking density, a crucial consideration in intensive shrimp farming, is intricately linked to the development and survival of white shrimp. Multiple factors contribute to this relationship, encompassing reduced availability of natural feed sources and space, an increased risk of cannibalism, deterioration in water quality, and the unwelcome accumulation of organic matter in bottom sediments. *L. vannamei* shrimp, as indicated by Boyd[4] and Ponce-Palafox et al.[25] can thrive in salinities ranging from 5 to 35ppt, with the optimal range for rearing being 15 to 25ppt.

Asia dominates the global aquaculture production, contributing over 90% to the total. In the Asian region, total inland aquaculture production amounts to 4.77 million tonnes, with crustaceans like shrimps, crayfish, and crabs contributing 0.29 million tonnes (FAO, 2018). Currently, India holds the second position in annual fisheries and aquaculture production globally, following China, as reported by Jelte de Jong[13]. India significantly contributes to global aquaculture output, accounting for 7.3% of the total (Vijayan et al., [34]), and plays a substantial role in the global fish trade, contributing to 5% (FAO, 2017). In 2016, India's fisheries and aquaculture production reached 41,48,407 tonnes, representing 10.0% of the worldwide output, with China leading at 60.1% (FAO, 2016). During the fiscal year 2015-16, the sector generated export revenues of 30,420.83 crore Indian Rupees (INR) (US$ 4.69 billion) (FAO, 2017), providing employment for approximately 14.5 million people directly or indirectly dependent on fisheries and aquaculture for their livelihoods Kumar et al., [16]. Stocking density, inversely correlated with shrimp growth, emerges as one of the most pivotal components of shrimp production. High stocking density can impact shrimp growth and survival by inducing stress responses due to crowding (Mena-Herrera et al. [19], intensifying pressure on natural food resources Hopkins et al., [10]; Allan and Maguire, [1], diminishing metabolism and food conversion efficiency (Sandifier et al., [28]; Martin et al., [19], and elevating total feed costs New, [22].

This study aims to address the existing gap in research by exploring the culture and growth performance of *L. vannamei* under different stocking densities. The investigation focuses on evaluating key aspects such as water quality parameters, survival rates, and overall growth of *L. vannamei* across varying stocking densities. By undertaking this research, the aim is to provide valuable insights into the optimal conditions for the successful cultivation of *L. vannamei*, contributing to a better understanding of shrimp aquaculture practices.

2. MATERIALS AND METHODS

Design of Systems and Experiments

The 30-days study conducted at the Centre of Advanced Study in Marine Biology at Annamalai University in Parangipettai, Tamil Nadu, India, aimed to compare the different stocking density nursery culture systems for *Litopenaeus vannamei* white shrimp. The study focused on assessing shrimp growth, survival, and water quality in circular experimental tanks holding 100 tons of water. To maintain optimal conditions for shrimp development, constant turbulent aeration was provided to the experimental tanks through air stones connected to four blowers, each with a capacity of 120m^3/hour. The aeration originated from the bottom of the tanks, ensuring a well-oxygenated environment for the shrimp. Seawater with a concentration of 32ppt was filtered through a mesh size of 150-250m from the nearby Vellar estuary for use in the tanks. Prior to introducing the shrimp, the tanks underwent a thorough disinfection process using calcium hypochlorite with a chlorine concentration of 35%. This disinfection aimed to achieve a residual chlorine concentration of at least 10 ppm for 48 hours, effectively eliminating potential disease carriers. Following the disinfection period, the residual chlorine level was measured, and sodium thiosulphate was added to neutralize any remaining chlorine, in line with established protocols. Subsequently, water was pumped into the experimental tanks for two to three days. The tanks were fertilized with dolomite (10 g/m3), superphosphate (15 g/m^3), and urea (15 g/m^3) in the two treatment tanks, contributing to the nutritional enrichment of the water for the shrimp. To compensate for evaporation losses, saline water was periodically added to the experimental tanks on a weekly basis. These meticulous procedures and controlled environmental conditions ensured a standardized and optimized setting for the comparative study of *L. vannamei* white shrimp production in the nursery culture systems.

Treatment Details

T1= Stocking density @ 4 pcs/litre

T2= Stocking density @ 6 pcs/litre

T3= Stocking density @ 8 pcs/litre

Assessment of water quality parameters

Temperature, pH, salinity, DO (dissolved oxygen), Total Ammonia Nitrogen (TAN), Nitrite-Nitrogen (NO_2-N), Nitrate-Nitrogen (NO_3-N), Ammonia Nitrogen (NH_3-N), Phosphate-Phosphorus (PO_4-P), Chlorophyll a, Total Suspended Solids (TSS) and Turbidity were all measured at regular intervals. A mercury bulb thermometer was used to determine the temperature of the water. A hand refractometer and a Scan-Eutech device from Singapore were used to assess salinity and pH, respectively. According to Strickland and Parson [30], dissolved oxygen was measured using a modified Wrinkler's technique. Standard procedures were used to quantify ammonia, nitrites, nitrates, and chlorophyll levels twice a week (APHA, [2]). The Strickland and Parsons technique Strickland and Parsons [30] was used to evaluate total suspended solids (TSS) in water samples collected for suspended material analysis.

Performance of Shrimp Growth

On a weekly basis, the following procedures were applied to calculate the average body weight (ABW), specific growth rate (SGR), survival rate and feed conversion ratio (FCR) of *L. vannamei* seeds. At the end of the experiment, shrimps were collected and the survival rate was calculated Khanjani et al., [16].

ABW (g) = Total weight of Shrimp collected (g) / Number of Shrimps

SGR = Final weight – Initial weight (g) / Num. of culture days * 100

Statistical

To characterise the variance of each parameter, the mean (AVG) and standard deviation (SD) were computed as descriptive statistics. A one-way ANOVA and the Kruskal-Wallis (KW) test were used to analyse the variation among the selected culture waters. The principal component analysis (PCA) method was used to find correlations and trends in water quality while lowering computational burden. Pearson correlation analysis was performed to identify the most important elements impacting water quality, and the findings were displayed as corrplots. All of the statistical studies described above were carried out using R version 4.0.5 (R Development Core Team, 2018). The Kruskal-Wallis test was carried out with the help of the 'dplyr' component of the 'R' programming language Kassambara, [15]. The "ggfortify" R software was ran using Principal Component Analysis (PCA) Tang et al., [31]. The Pearson correlation analysis was performed using the 'ggcorrplot' function of the 'R' programme Kassambara and Kassambara, [14].

3. RESULTS AND DISCUSSION

Physicochemical characteristic

Water quality is crucial in aquaculture for the growth and survival of different stocking-density nursery cultured species. Shrimp growth, development, and maturity can be impacted by any water quality changes. As a result, water quality was monitored on a regular basis during the experiment period. The result of Mean with Standard Deviation (SD) of water quality parameters in shrimp *L. vannamei* nursery culture are presented in Table 1.

Table 1. Water quality parameters (Mean and SD) of the experimental tanks were recorded during the culture period. Different superscript letters in a row indicate significant difference (p<0.05) between treatments.

Tests	T1	T2	T3
Temperature (°C)	29.96±0.10[a]	29.62±0.31[a]	28.84±0.9[a]
pH	8.26±0.1[a]	8.04±0.12[b]	7.66±0.34[b]
Salinity (ppt)	31.51±0.3[a]	31.32±0.27[a]	31.46±0.19[a]
Total Ammonia Nitrogen (ppm)	0.048±0.02[a]	0.046±0.02[a]	0.124±0.08[a]
Nitrite Nitrogen (ppm)	0.118±0.02[a]	0.152±0.04[ab]	0.212±0.07[b]
Nitrate Nitrogen (ppm)	2.074±0.14[a]	2.168±0.09[b]	2.332±0.11[b]
Ammonia Nitrogen (ppm)	0.42±0.25[a]	0.6±0.36[a]	0.78±0.51[a]
Phosphate-Phosphorus (ppm)	0.13±0.02[a]	0.134±0.03[a]	0.214±0.06[a]
Dissolved oxygen (mg/l)	7.74±0.15[a]	7.56±0.21[a]	6.78±0.07[b]
Chlorophyll a (µg/l)	2.72±1.62[a]	2.10±1.29[a]	2.16±1.16[a]
Total Suspended Solids (ppm)	110.5±0.62[a]	124.66±1.99[b]	253.42±1.22[c]
Turbidity (NTU)	9.22±0.67[a]	11.732±0.37[b]	18±0.42[c]

Temperature, pH, salinity, and dissolved oxygen are all important environmental parameters that influence photosynthesis in water, physiological responses of cultured organisms, oxidative stress, immunological suppression, organic material decomposition, and subsequent biochemical processes. In the present study, temperature ranged from 29.1 to 30.2°C, with maximum temperature recorded at T3 and minimum at T2. The statistical analysis demonstrated that water temperature changed notably between different stocking nursery cultures KW $\chi 2= 4.13$; df = 2; P> 0.05 (Figure 1a). The result of pH ranged between 7.2 to 8.5 with minimum pH recorded at T3 and maximum pH recorded at T1. Significant findings were also found in the statistical analysis (KW $\chi 2= 10.33$; df = 2; P<0.05; Figure 1b). The minimal fluctuations in salinity suggest relatively stable conditions across T1, T2, and T3. In the present study, salinity content varied from 31 to 32ppt (Figure 1c). Additionally, the statistical analysis showed that comparing the various density nursery culture systems, there was a significant difference in the water salinity (KW $\chi 2= 1.9$; df = 2; P>0.05; Figure 1d). Variations in the factors listed above have an impact on shrimp growth and survival rates. The results of this study coincide closely with the trends shown in other studies (Godoy et al., [9]; Tierney and Ray, [32]).

In the context of water quality, nutrients are compounds found in water that play a crucial role as they can be directly utilized by living organisms to facilitate cellular growth. Aquatic species rely on essential nutrients, including ammonia, nitrate, nitrite, and phosphate, as highlighted in research by Hlordzi et al. [10]. The monitoring of ammonia concentrations is of paramount importance due to various factors. These include the reduced excretion of ammonia by aquatic species, elevated levels of ammonia in the bloodstream, and the negative effects on both membrane integrity and enzyme-catalysed activities. High levels of ammonia in water can have detrimental effects, compromising the blood's efficiency in transporting oxygen and leading to an increase in oxygen consumption in tissues and gills. Moreover, environments with depleted oxygen levels, bacteria can contribute to the formation of ammonia by breaking down nitrogenous compounds. It is noteworthy that water contains both ionized (NH4) and unionized (NH3) forms of ammonia. In the specific context of aquaculture ponds, the unionized form (NH3) is considered more harmful due to its ability to rapidly penetrate cell membranes. The concentration of NH3 is influenced by several environmental factors, including temperature, pH, and, to a lesser extent, salinity, as evidenced by studies conducted by Bower and Bidwell [3] and Venkateswarlu et al. [33]. These considerations underscore the complexity of managing and understanding the dynamics of ammonia in aquatic environments, particularly in the context of aquaculture practices. In aquatic ecosystems, nitrite and nitrate is often the key nutrient that controls the growth of plankton. In the present study, the peak levels of nitrite and nitrate were found in T3 and trough were found in T1 and significant differently KW $\chi 2= 5.32$; df = 2; P<0.05 and KW $\chi 2= 7.09$; df = 2; P<0.05 respectively (Figure 1a, b). These elevated levels however, were in line with those documented by da Silva et al. [6], who conducted research in a closed system during the nursery period, with nitrite and nitrate concentrations reaching 1.01 (mg L-1) and 20.94 (mg L-1) in respective to the final week of the experiment.

The primary source of ammonia compounds in aquaculture systems is the direct excretion of farmed shrimp along with additional feed. Ammonia is a significant consequence of the breakdown of proteins in crustaceans. When ammonia levels are high, blood oxygen transport is reduced. Ammonia that has not been ionized (NH+4) is acknowledged to be more dangerous. Even though the NH+4 levels should only be about 0.1 mg/L, it is advised that the total ammonia concentration not exceed 1 mg/L. The concentration of TAN in this study varied from 0.02 at T2 to 0.25ppm at T3, and the findings of the statistical analysis indicate a significant difference (KW $\chi 2= 3.24$; df = 2; P>0.05) (Figure 1e). The results of Ammonia-Nitrogen showed significant differences (KW $\chi 2= 1.76$; df = 2; P>0.05) (Figure 2c) with low values recorded at T1 and high values at T3. As low TAN and NH3-N, it indicates that nitrification was taking place in all treatments at the beginning of the experiment. It looks that, nitrification was noted at T3 as elevated value TAN and NH3-N at the end of the trial. Accordingly, water must be replaced often in intensive to super-intensive nursery culture systems to prevent ammonia levels from growing since ammonia becomes hazardous when it reaches a particular concentration. The range of the results was 0.01 to 1.50 ppm. These findings well agreed with an earlier study conducted by Mustafa et al., [21] and da Silva et al. [6].

Phosphate is an essential ingredient in aquaculture ponds because it regulates phytoplankton development and broadens the base of the food chain. Phosphate concentration results varied significantly (KW $\chi 2= 3.62$;

df = 2; P>0.05; Figure 2d), with values ranging from 0.10 to 0.28 ppm, with maximum value recorded at T3 and minimum value at T2. The present findings are consistent with previous research conducted by Godoy et al. [9] and da Silva et al. [6].

The turbidity, or the ability of the water to block sunlight, is determined by the amount of suspended matter in the water. Extreme turbidity affects the culture system ability to generate oxygen by restricting sunlight from penetrating the water (Lien and Giao, [18]).

The turbidity concentration in our research varied from 8.30 to 18.50 ppm (Figure 2f), and there were significant variations between (KW χ^2= 12.5; df = 2; P<0.05). The primary causes of increased turbidity could be attributed to phytoplankton, leftover food, and shrimp activities (Zhao et al., [37]). The average TSS concentration in the present investigation ranged from 109.50 to 254.60 ml/L for the various stocking density nursery culture systems (Figure 2e). Additionally, the statistical analysis showed a significant difference in the water TSS (KW χ^2= 12.5; df = 2; P<0.05). According to Vinatea et al. [35], turbidity and TSS concentration are closely associated because higher suspended particle concentrations make culture water more turbid and restrict light penetration. In this trial, turbidity tracked changes in TSS over the course of the experiment without showing any significant treatment differences. Furthermore, our research coincided with the findings of earlier reports conducted by Godoy et al. [9], Zhao et al. [35], and Huang et al. [12].

Chlorophyll a (Chl-a), constituting approximately 1% to 2% of the total dry weight of algae, assumes a pivotal role as a reliable metric for gauging the abundance of microalgae. Within the scope of the present study, the concentration of chlorophyll exhibited a discernible range, oscillating between 0.32 and 4.42µg/L. The conducted statistical analysis uncovered a significant disparity in chlorophyll levels when comparing biofloc and nursery culture conditions (KW χ^2= 0.42; df = 2; P>0.05; Figure 1e). In our investigation, Chl-a differed significantly between treatments. This might be varying of nutrient availability circumstances, which could result from uneaten feed that led to the growth of algae in the rearing tanks or from the breakdown of accumulated organic matter. According to Costa et al. [5], phytoplankton populations are expanding in response to rising phosphate and nitrogen concentrations. According to Shyne Anand et al. [29], phytoplankton supplements shrimp nutrition by recycling nutrients from the water column. Furthermore, the findings of the current study align with conclusions drawn in earlier research by Godoy et al. [9], Wasielesky et al. [36], and Panigrahi et al. [24].

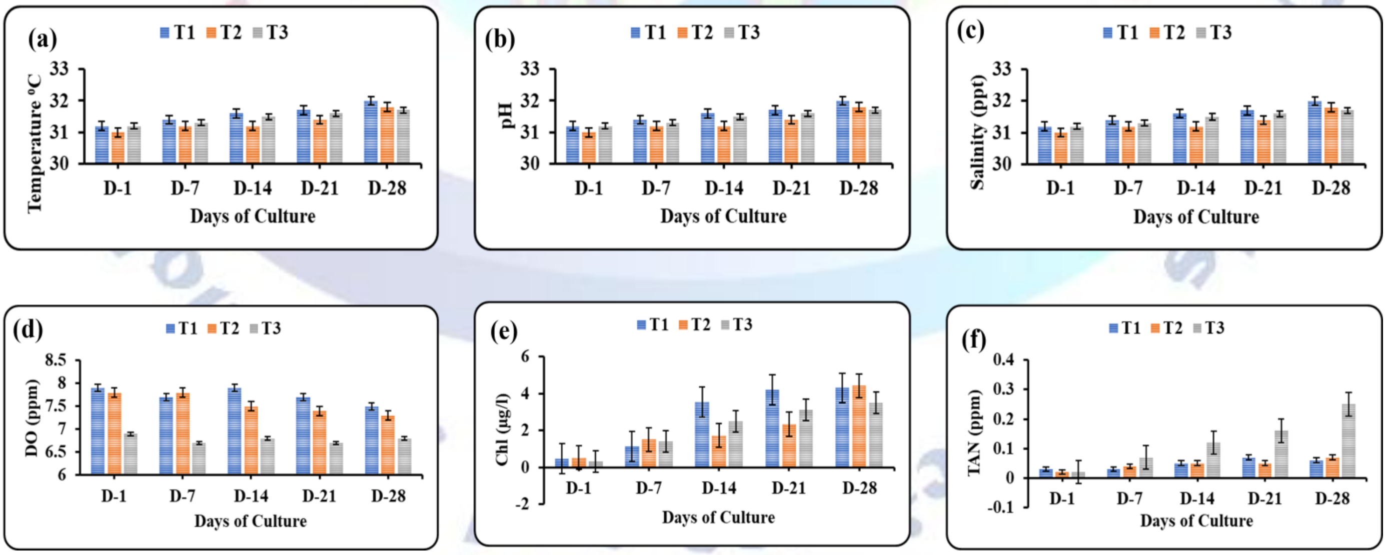

Figure 1. Physicochemical water quality parameters in the different stocking nursery culture system throughout a 30-days white leg shrimp rearing period (a) temperature, (b) pH, (c) salinity, (d) Dissolve oxygen, (e) Chlorophyll 'a', and (f) Total Ammonia Nitrogen.

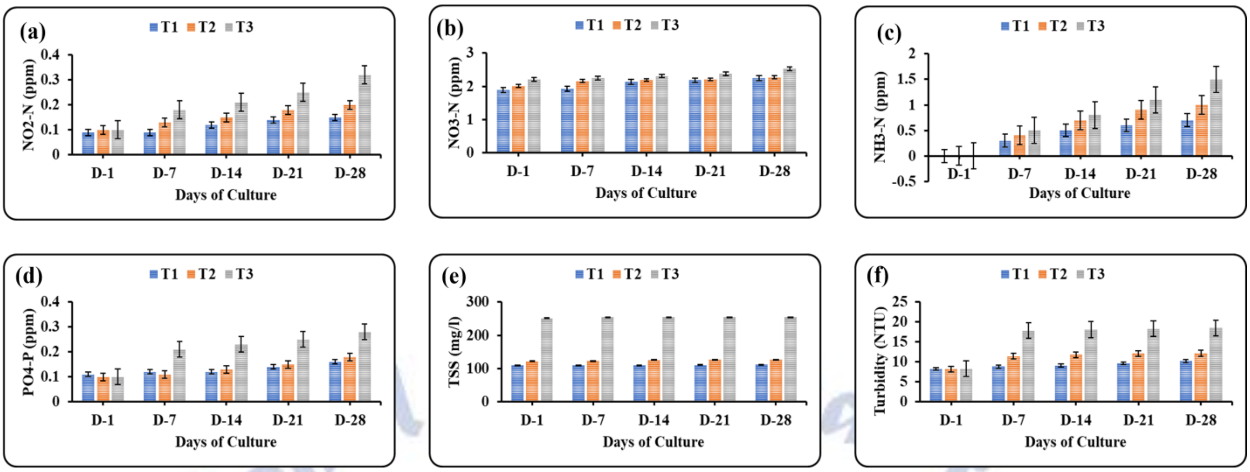

Figure 2. Physicochemical water quality parameters in the different stocking nursery culture system throughout a 30-days white leg shrimp rearing period (a) Nitrite-Nitrogen, (b) Nitrate-Nitrogen, (c) Ammonia-Nitrogen, (d) Phosphate-Phosphorus, (e) Total Suspended Solids and (f) Turbidity.

Pearson Correlation

Pearson correlations in a selected different stocking density nursery culture, the strength and direction of the linear relationship between the water qualities were evaluated. In T1 culture, the salinity was found to positively correlate with total nitrogen, nitrite, nitrate, ammonia, phosphate, TSS, and turbidity, with the exception of dissolved oxygen and chlorophyll. Total ammonia showed significant correlation with all the parameters except dissolved oxygen and chlorophyll (Figure 3). Similarly, T2 and T3 the salinity was found to positively correlate with total nitrogen, nitrite, nitrate, ammonia, phosphate, TSS, and turbidity, with the exception of dissolved oxygen (Figure 4 & 5). Statistics show that nutrition and other chemical components have an impact on shrimp growth and survival, according to research conducted by Mustafa et al. [21].

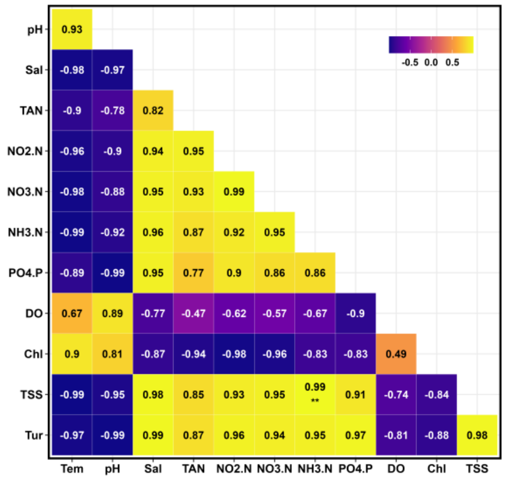

Figure 3. Pearson correlation coefficient between various physicochemical parameters in T1

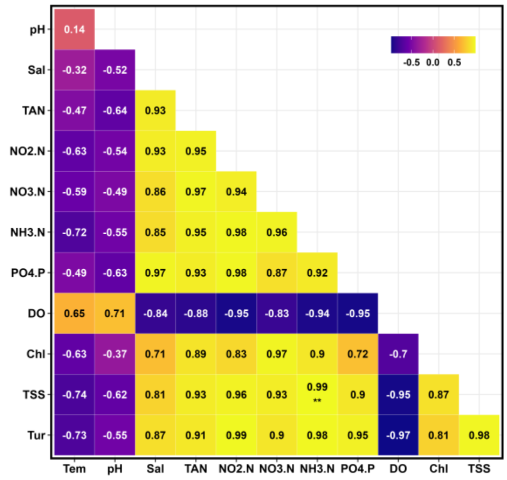

Figure 4. Pearson correlation coefficient between various physicochemical parameters in T2

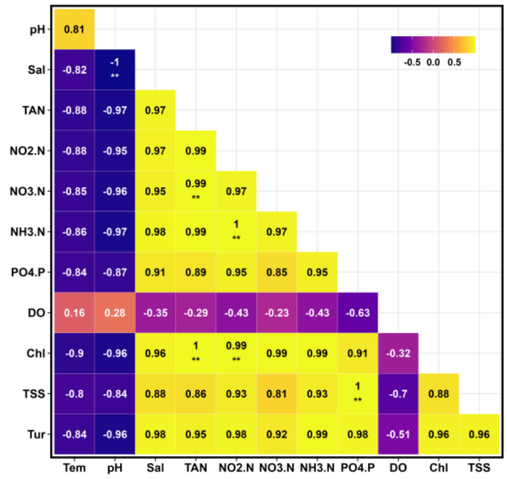

Figure 5. Pearson correlation coefficient between various physicochemical parameters in T3

Principal Component Analysis

Principal component analysis was used to compare various stocking density cultures and evaluate the water quality. With components 1 and 2 accounting for 66.29% and 22.07% of the total variation, respectively, the first two components explained 88.36% of the variation (Figure 6). The T1 and T2 was found to be positively correlated with pH, dissolved oxygen, chlorophyll; on the other hand, the T3 was found to be negatively correlated with environmental parameters like temperature, salinity, nitrite nitrogen, nitrate nitrogen, total ammonia nitrogen, ammonia nitrogen, phosphate nitrogen, turbidity, and total suspended solids. The factors, that mainly affect shrimp productions are physicochemical and nutrients (Nguyen et al., [23]). The results of this investigation agree with previous research conducted by Mustafa et al. [21].

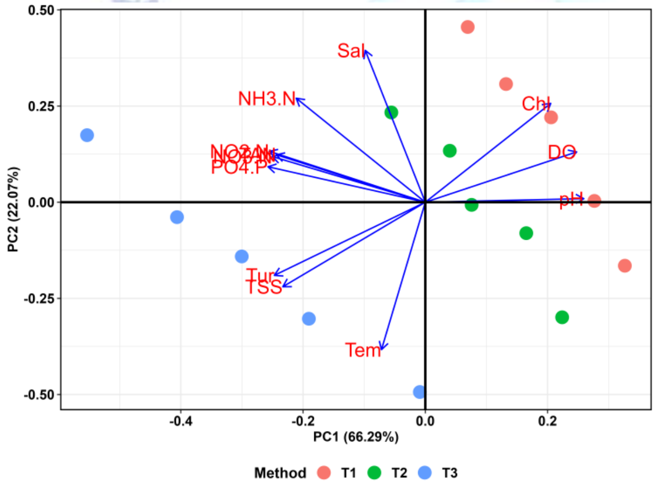

Figure 6. Principal component analysis drawn for the relationship between environmental parameters and culture methods

The growth, survival and feed conversion ratio in white shrimp

In all the treatment, the effect of different stocking density on weight gain, specific growth rate (SGR), average daily growth (ADG) and food conversion ratio (FCR) was assessed. The growth of *L. vannamei* was measured at weekly interval for 30 days of nursery culture. Few animals from each pond were collected by cast net and average body weight was calculated at each weekly interval. Average daily growth (ADG), specific growth rate (SGR), and food conversion ratio (FCR), in all the three treatments were measured at the end of experiment. The initial weight of post larvae (PL) was 0.001g in all the treatments during stocking.

The provided table offers a detailed overview of a *L. vannamei* nursery experiment, presenting growth parameters across distinct treatments (T1, T2, and T3). This study provides valuable insights into the performance of the shrimp under diverse experimental conditions. The growth parameters encompass initial weight, final body weight, specific growth rate (SGR), survival percentage, and feed conversion ratio (FCR). In T1, characterized by an initial weight of 0.01±0.00 grams, a substantial growth was observed, with the final body weight reaching 1.02±0.01 grams. This growth was reflected in the specific growth rate (SGR) of 3.36±0.01%, indicating a robust daily growth rate. Additionally, T1 exhibited a high survival rate of 92.1±0.2%, and an efficient feed conversion ratio (FCR) of 0.68±0.1, underscoring effective feed utilization. Conversely, T2 and T3 displayed variations in the initial and final weights, SGR, survival, and FCR, with both treatments exhibiting decreasing trends across these parameters (Table 2). These results imply that the different experimental conditions significantly influenced the growth and survival metrics of the *L.vannamei* shrimp. The outcomes of this study emphasize the pivotal role of experimental conditions in shaping the performance of these organisms, particularly in the context of aquaculture or similar research endeavors. The observed variations in growth parameters underscore the importance of optimizing conditions to enhance the overall productivity and sustainability of shrimp farming practices. According to Sandifer et al. [28], feed conversion efficiency decreased with increasing stocking density. Growth performance in aquaculture is directly impacted by the density of shrimp populations in nursery culture system. However, if it is not designed appropriately, increasing a shrimp culture density might result in health problems and delayed shrimp growth. Many authors have reported on the survival and growth of *L. vannamei* stocked in different density in culture tank (Samocha, [27]; Eid et al., [7]; Rodríguez-Olague et al., [26]).

Table 2. Growth characteristic of *L. vannamei* seeds in the different stocking density nursery culture systems

Growth Parameters	T1	T2	T3
Initial weight (g)	0.01±0.00	0.01±0.00	0.01±00
Final body weight (g)	1.02±0.01	0.68±0.01	0.41±0.01
SGR (% growth day^{-1})	3.36±0.01	2.23±0.01	1.33±0.01
Survival (%)	92.1±0.2	84.5±0.1	68.2±0.3
FCR	0.68±0.1	0.91±0.1	1.26±0.1

The impact of stocking density on aquaculture outcomes is a critical consideration with far-reaching implications for productivity, growth, and survival rates. High stocking densities, characterized by an increased number of organisms within a given cultivation area, can exert significant stress on the aquatic environment and the cultured species. One of the notable effects of high stocking density is the elevated nutrient load in the water. As more organisms coexist in a confined space, the accumulation of waste products, such as feces and uneaten feed, increases. This excess organic matter can lead to deteriorating water quality, potentially resulting in a rise in ammonia and nitrite levels. Poor water quality, in turn, negatively influences the health and growth of the cultured species. The growth rate of organisms in high-density stocking environments often experiences a decline. The competition for resources, such as food and space, becomes intense, limiting the individual access and uptake of essential nutrients. This competition-induced stress can manifest in reduced growth rates among the cultured species. Survival rates are also adversely affected in high-density stocking scenarios. The heightened competition for resources, coupled with the compromised water quality, can weaken the overall resilience of the population. Increased susceptibility to diseases and elevated stress levels can contribute to higher mortality rates among the cultured organisms. Additionally, the Feed Conversion Ratio (FCR), a key indicator of the efficiency with which feed is converted into biomass, tends to be adversely impacted by high stocking densities. The intensified competition for feed resources can lead to inefficient feed utilization, ultimately resulting in higher FCR values. This inefficiency is a concern as it not only affects the economic aspects of aquaculture but also raises environmental considerations regarding the sustainable use of feed resources. As a result, variations in stocking density play a pivotal role in determining the overall success of aquaculture operations. High stocking densities can lead to increased nutrient loads, diminished growth rates, reduced survival rates, and higher FCR. Therefore, careful consideration and management of stocking densities are essential for achieving sustainable and productive aquaculture practices.

4. CONCLUSIONS

The findings of this study highlight the superiority of the T1 treatment, demonstrating significantly greater biomass production compared to all other treatments. Interestingly, doubling the shrimp density in the high-density treatments did not yield significant differences in survival, growth rate, or shrimp weight. The comprehensive evaluation based on growth performance, feed utilization, and economic assessment led to a conclusive recommendation: stocking white shrimp at a density of 400,000 individuals per 100 tons tank emerged as the most effective strategy under the experimental conditions. The implications of this conclusion extend beyond the confines of the study, offering valuable insights for both farmers and biologists involved in white shrimp production within nursery culture systems. By identifying the optimal stocking density, this research provides practical guidance that can enhance the efficiency and profitability of shrimp cultivation. The significance of these results lies not only in the immediate operational benefits for farmers but also in contributing to the broader understanding of sustainable and effective practices in aquaculture. As such, the study serves as a valuable resource for decision-making in the aquaculture industry, promoting informed choices for optimizing white shrimp production in nursery culture systems.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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