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Water Quality Dynamics And Their Impact On Growth Performance Of Litopenaeus Vannamei In Semi-Intensive Farms Along Southeast Coast Of India

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Abstract
This study investigated the relationship between water quality parameters and production performance of Pacific white shrimp (Litopenaeus vannamei) in semi-intensive farming systems along the southeast coast of India. Water samples were collected from four commercial farms in Tamil Nadu and Andhra Pradesh during the summer season (February-June 2024) and analyzed for physico-chemical parameters following standard methods. Water quality parameters including dissolved oxygen (4.79-4.99 mg L^{-1}), temperature (28.9-29.4°C), salinity (23.4-33.3 ppt), and pH (8.06-8.25) were maintained within optimal ranges throughout the culture period. After 90-110 days of culture at uniform stocking density (50 PL m^{-2}), significant variations were observed in survival rates (68.0-97.6%), total yield (3859.6-6048.3 kg), and final average body weight (20.3-23.6 g) across farms. Correlation analysis revealed that dissolved oxygen had a strong positive association with average body weight ($r = 0.87$, $p < 0.05$), while water temperature showed a negative correlation with survival rate ($r = -0.72$, $p < 0.05$) and average daily growth ($r = -0.68$, $p < 0.05$). These findings suggest that implementation of Better Management Practices (BMPs) with particular attention to maintaining optimal water quality parameters, especially dissolved oxygen levels, and significantly enhances growth performance and production of L. vannamei in semi-intensive culture systems.

Key words: *Average body weight, Better management practices, Dissolved oxygen,* Litopenaeus vannamei, *Water quality.*

INTRODUCTION

Brackish water aquaculture stands among the fastest-growing food production sectors globally. Litopenaeus vannamei was first introduced to India in 2008 (CAA, 2010). This species, which contributed to global production of 5.7 million tons in 2023, represents one of the fastest-growing sectors in aquaculture (FAO, 2024). The Coastal Aquaculture Authority (CAA) of India has recognized, certified, and licensed brackish water aquaculture operations in several states including Andhra Pradesh, Tamil Nadu, Maharashtra, Gujarat, Orissa, Goa, and the Union Territories of Diu and Pondicherry. The majority of Indian farmers are adhering to higher stocking rates advised by the Coastal Aquaculture Authority of India (Rajkumar et al., 2022).

The most extensively cultivated euryhaline species in the world, L. vannamei has seen a substantial increase in value on the global market (Pratiwi et al., 2024; Li et al., 2023). Aquaculture is among the fastest-growing food production industries and plays an essential role in food and nutritional security, especially given the anticipated food crisis this century due to global population growth, climate change, shrinking landmasses, and depleted marine resources. The shrimp L. vannamei is characterized by its rapid growth, high survival rate even at high stocking densities, strong resistance to disease, and commercially significant euryhaline and eurythermic nature. These traits, combined with its lower dietary protein requirement and lower feed conversion ratio, contribute to a higher production rate compared to Penaeus monodon (Ahmadi et al., 2023).

L. vannamei is considered an excellent species for cultivation, especially in Western countries, and is known for its high survival rate across a broad range of salinity conditions, thriving in freshwater, brackish, marine, and estuarine environments (Zhou et al., 2023). L. vannamei is suitable species for intensive aquaculture system (Gunalan et al., 2023). The success of shrimp aquaculture largely depends on pond water quality. Salinity is an important factor affecting shrimp physiology, influencing food intake and growth (Ayaz et al., 2024). Although the Pacific white shrimp can tolerate a wide range of salinities, it thrives in a medium where the isosmotic point occurs at salinity comparable to the osmotic tolerance range of common shrimps (Shailender et al., 2023).

While euryhaline species can withstand harsh climatic conditions, they may exhibit worse growth performance, survival, and osmoregulation (Ye et al., 2023). L. vannamei can survive in a wide salinity range of 1-50 ppt and tolerate high temperatures, making it a preferred model species for researchers studying osmoregulation and salinity adaptation (Tseng et al., 2023). Currently, shrimp farmers face three primary challenges: climatic changes, environmental degradation, and new diseases. L. vannamei exhibits stable growth performance in many farms at salinities ranging from 5-35 ppt (Wang et al., 2023). Although Pacific white shrimp can tolerate a broad range of temperatures, like most other tropical and subtropical species, it grows best between 23 and 30°C.

Variations in water and soil pH significantly affect the health, survival, and growth of aquatic organisms. The overall water quality directly influences the performance and welfare of cultured aquatic species. According to Sharma et al. (2024), poor pond management practices, such as overstocking and excessive feeding, commonly result in reduced yields, disease outbreaks, and mass mortality. Estuaries serve as critical feeding grounds and habitats for many aquatic invertebrates, playing a vital role in regulating their osmoregulatory processes. Many shrimp farmers rely on bore water, which often contains elevated concentrations of calcium and magnesium. When absorbed by cultured shrimp, these ions can delay the shell-shedding process, leading to stunted growth and potentially causing mass mortality. The present study was conducted from February to June 2024 across four semi-intensive shrimp farms located in Tamil Nadu and Andhra Pradesh. The primary objective was to examine the relationship between water quality parameters and the growth performance of L. vannamei.

MATERIALS AND METHODS

Study area: This research was conducted during the summer season from February to June 2024. Four study sites were selected along the southeast coast of India: Tuticorin (8°39'51.94"N, 78°5'59.33"E), Ramnad (9°30'53.48"N, 78°54'53.25"E), Ponneri (13°19'38.94"N, 80°13'50.03"E), and Nellore (14°43'16.77"N, 80°7'37.06"E). All sites are located along the Bay of Bengal on India's east coast.

System and experimental culture: All the experimental shrimp rearing ponds ranged from 0.48 to 0.58 ha, with an average depth of 1-1.8 m. Stocking density and pond management varied depending on the station. The intended purpose of the current research was to assess the relationship between shrimp production and water quality during the summer season. Pond design and water sources differed across all four stations, which helped in understanding the impact of water quality on shrimp production. L. vannamei (PL-10) was procured from a commercial shrimp hatchery after PCR testing for White spot syndrome virus. Stocking was carried out as per the standard procedure of acclimatization and progressive release of seeds into the rearing ponds. In all the experimental ponds, 50 seeds m^-2^ were stocked, specifically: Tuticorin - 2.6 lakhs; Ramnad - 2.5 lakhs; Ponneri - 2.4 lakhs; and Nellore - 2.9 lakhs.

A standard shrimp pellet feed was used throughout the culture period, initially twice daily (12-hr interval), then thrice daily (8-hr interval), and finally four times daily (6-hr interval). Check tray monitoring was carried out to assess feed intake after 30 days. Paddle wheel aerators were used to maintain dissolved oxygen levels in the rearing ponds. Cast net operations were conducted once every two weeks to regularly monitor the growth performance of shrimps in all four stations.

Procedure for collecting water samples: Every week, the physicochemical properties of the water in the control and test ponds were examined at three separate locations. Water samples were taken from a depth of 1-2 feet in the rearing ponds during the early morning hours (7-8 am) using clean 500 ml plastic bottles. These water samples were then transported to the laboratory for analysis. To remove any chemicals or suspended particles, water samples were filtered through a 0.45 µm membrane filter before examination. The samples were analyzed for various chemical parameters, including salinity, pH, total alkalinity, total hardness, calcium, magnesium, total ammonia, and dissolved oxygen, using standard techniques recommended by the American Public Health Association (APHA, 2023).
Dissolved oxygen (DO mg l^-1^) was measured four times daily (every six hours) in each pond. Temperature was measured using a standard Celsius thermometer (mercury bulb thermometer). Salinity, a crucial parameter in this study, was measured in situ using a portable hand-held optical refractometer (Atago, Japan), and pH was measured using an electronic pH pen (Erma, Japan). Dissolved oxygen was determined using a modified version of Winkler's method, as described by Talebian et al. (2023). Alkalinity was determined using a test kit (Merck, Germany) or following APHA guidelines (APHA, 2023), and total hardness was assessed using complexometric titration with EDTA (Biswas et al., 2024). Turbidity was measured using a Secchi disk (Boyd et al., 2023), and ammonia, calcium (Biotech Calcium Kit AA222), and magnesium were measured using a Merck kit and a complexometric titration technique, respectively.

Shrimp Growth and Survival: Random samples of L. vannamei were collected from each pond using a cast net to measure length, weight, and assess survival rates. A digital balance was used to weigh the shrimp for evaluating growth performance. Initial biomass (IB) and initial body weight (IBW) were recorded at the study's commencement. After 50 days, data collected included total number of shrimp (TNS), average body weight (ABW), total feed consumption (TFC), and feed conversion ratio (FCR). Final biomass, weight gain, growth rate, average daily growth, and survival percentage were documented at harvest. To monitor growth progression, experimental shrimp were sampled weekly and weighed using an electronic scale (A & D, GR 200) with 0.01 g precision. On day 49, shrimp were fasted for 24 hr before final weighing to determine growth parameters and calculate survival percentages. The formulae used to calculate final growth and survival rates followed methods described by Singh et al. (2024).
ADG (g) = (Present weight (g) - Previous weight (g)) / number of days
Weight increase (g) = final weight (g) - initial weight (g)
Feed conversion ratio (FCR) = Total feed consumed / Net wet weight of shrimp
Ratio of survival (%) = (Total number of shrimps survived / Total number of shrimps stocked) × 100
Statistical evaluation: To determine the significance of differences in growth parameters and water quality, one-way analysis of variance (ANOVA) was performed. All data sets are presented as means ± standard deviation and were subjected to ANOVA, with statistical significance set at $p < 0.05$. Duncan's multiple-range test (DMRT) was used for post-hoc analysis of mean differences. Additionally, Pearson correlation analysis was carried out to assess the strength and direction of linear relationships between growth parameters and water quality indicators, in order to identify possible associations.

Results and Discussion
The water quality at four experimental stations is documented in Table 1, with all parameters falling within the acceptable limits set by the Coastal Aquaculture Authority of India (CAA, 2024) for Litopenaeus vannamei cultivation. Changes in water quality in these areas were influenced by factors such as environment, weather, and anthropogenic activities, which varied over the seasons. The success of aquaculture operations and the growth performance of reared organisms largely depend on maintaining good water quality (Rasyidah et al., 2024). During the experiment, parameters like salinity, alkalinity, carbonate ($CaCO_3$), bicarbonate (HCO_3), total hardness, and magnesium did not show significant differences between treatments ($p > 0.05$). However, variations in salinity significantly impacted survival rates, weight gain, final weight, and feed conversion ratio (FCR). By the end of the production period,

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the average final weight, survival rate, and FCR varied across different stations, as detailed in Table 2. Overall, all water quality parameters in the study areas remained within the permissible limits for L. vannamei.

Dissolved Oxygen: Dissolved oxygen (DO) represents one of the most critical factors in shrimp farming as it reflects the overall environmental conditions throughout the cultivation period. Among the study sites, mean DO concentration was lowest in Nellore (4.79 ± 0.34^{a} mg l^-1^) and highest in Ramnad (4.99 ± 0.41 mg l^-1^), with Tuticorin and Ponneri recording 4.98 ± 0.53^{a} mg l^-1^ and 4.86 ± 0.39^{a} mg l^-1^, respectively. Statistical analysis revealed significant differences between stations ($p<0.05$), indicating a moderate effect of location on DO levels. Post-hoc tests confirmed that Nellore's mean DO concentrations were significantly lower than those of Ramnad ($p<0.001$) and Tuticorin ($p<0.05$), as shown in Table 1. These findings align with observations by Wu et al. (2023) in tropical aquatic ecosystems.
According to Global Aquaculture Alliance (GAA) guidelines, minimum acceptable DO values are 4 mg l^-1^ for general aquatic species and 3 mg l^-1^ specifically for marine shrimp farming (Yessy et al., 2024). The DO range recorded in this study (4.79 to 4.99 mg l^-1^) remained within safe limits according to these standards, though slightly below the 5.0 mg l^-1^ threshold recommended by Kır et al. (2023). For optimal shrimp production, DO levels between 3.5-2.75 mg l^-1^ are considered ideal. DO levels in aquatic environments provide valuable indicators of ecosystem processes including photosynthesis, bacterial activity, nutrient availability, and water stratification. As noted by Tseng et al. (2023), oxygen consumption in penaeid shrimp increases proportionally with temperature elevation from 20 to 30°C, demonstrating the temperature-dependent nature of oxygen requirements.

Temperature: In the present study, temperatures at all four stations ranged from 28.9°C to 29.4°C, as recorded in Table 1. This falls within the optimal temperature range for Litopenaeus vannamei, which is generally between 20°C and 33°C (Ayaz et al., 2024; Ariadi et al., 2023). The optimal temperature for L. vannamei can vary depending on factors like stocking density, with an ideal range of 29.3°C to 29.5°C (Liu et al., 2023). Temperature fluctuations during the rearing period can enhance shrimp growth, but extreme temperatures can have adverse effects. High temperatures accelerate metabolism, increase hunger, and reduce available oxygen, potentially leading to increased mortality and disease susceptibility (Nguyen et al., 2024; Wang et al., 2023). In this study, temperature showed a negative correlation with survival, Average Daily Growth (ADG), biomass, and conversion factor (CF), while it positively correlated with dissolved oxygen (DO), pH, and feed conversion ratio (FCR), and had no correlation with turbidity or salinity.

Turbidity: In the current study, turbidity levels varied across the four stations, with the highest recorded at Ponneri (26.75 cm) and the lowest at Tuticorin (21.25 cm). This variation can be attributed to factors such as dissolved organic matter, plankton blooms, and leftover feed, consistent with findings from tropical aquaculture systems by Zhou et al. (2023). The observed turbidity range falls within the broader context of marine shrimp production, which typically ranges from 21.25 to 38.75 cm, as noted by Sharifinia et al. (2023). However, optimal turbidity for shrimp culture is generally considered to be between 35 and 45 cm (Singh and Jain, 2023), with levels above 45 cm or below 25 cm potentially impacting shrimp growth and production negatively (Sharma et al., 2024; Wang et al., 2023).
pH: In the present study, mean pH values ranged from 8.06 at Tuticorin to 8.25 at Nellore. pH is considered a fundamental water parameter for optimal shrimp survival and growth, playing a critical role in metabolic and physiological processes while also helping manage soil acidity (Venkateswarlu et al., 2023). In aquaculture systems, pH fluctuates in response to various physical, chemical, and biological factors, including pond bottom soil characteristics, lime application, phytoplankton blooms, culture inputs (feeding, water source), temperature, and aeration regimes. For L. vannamei cultivation, researchers recommend maintaining pH within the range of 7.6-8.6 (Mishra et al., 2023). The pH values recorded in this study (8.06-8.25) align well with these recommendations (Rasyidah et al., 2024).

pH values below 7.0 have been shown to reduce growth and feed conversion efficiency in L. vannamei. Elevated pH values observed in our study suggest alterations in carbon dioxide and carbonate-bicarbonate equilibrium resulting from changes in physicochemical conditions. Daily pH fluctuations should be limited to 0.5 units, as values exceeding recommended ranges can inhibit shrimp growth or lead to mortality (Yessy et al., 2024). For biosecure shrimp production, maintaining stable pH through appropriate lime application is essential to standardize water quality parameters (Singh et al., 2024).

Salinity: Salinity represents a critical factor influencing growth and survival of aquatic species, especially within the Penaeidae family (Sharifinia et al., 2023). As euryhaline organisms, Pacific white shrimp can tolerate a remarkably wide salinity range from 1 to 50 g l^-1^ (Ye et al., 2023). In our study, L. vannamei demonstrated favorable growth across varying salinity conditions, with pond salinity ranging from a maximum of 33.30 ppt in Nellore to a minimum of 25.20 ppt in Ramnad (Figure 3). Previous research by Rahman et al. (2023) indicates that L. vannamei achieves optimal survival rates at salinities above 30-35 ppt, which corresponds with observations at our Tuticorin and Nellore sites. Jaffer et al. (2023) noted that elevated salinity may increase feed conversion ratio (FCR) in L. vannamei. Interestingly, L. vannamei also demonstrates considerable adaptability to lower salinity environments (8-22 ppt) as reported by Li et al. (2023), with some evidence suggesting accelerated growth under such conditions—a pattern observed at our Ramnad site. Variations in growth rate and survival across sites may also reflect differences in water sources (marine, brackish, or freshwater), as documented by Ahmed et al. (2023).

Total Alkalinity: The alkalinity in the current study varied from 163 to 223 mg l^-1^ across the four stations. Researchers worldwide cite different preferable alkalinity ranges, including 120-160 mg l^-1^ (Nguyen et al., 2024), 90-150 mg l^-1^ (Ariadi et al., 2023), and greater than 20 and less than 500 mg l^-1^ (Liu et al., 2023). Water alkalinity can be maintained by adding lime. Alkalinity is important because it can maintain a stable pH level, acting as a buffer against pH changes (Zhou et al., 2023). An optimum alkalinity of 80-120 mg l^-1^ stabilizes pH and promotes healthy development of primary producers. High alkalinity can inhibit shrimp molting due to excessive salt loss (Kumar et al., 2023). During this process, alkalinity is also lost, but sodium bicarbonate can act as a pH buffer and supply the inorganic carbon needed to promote nitrification (Kunwong et al., 2024). Alkalinity was statistically significant ($p < 0.05$) at the four locations. Because each of the four stations has a distinct water supply, the p-value ($p < 0.05$) was highly significant at various times during the culture process (Venkatrayulu et al., 2023).

Total hardness: Water hardness primarily derives from calcium and magnesium bicarbonates and is measured in ppm or mg l^-1^ (Truong et al., 2023). Seasonal variations in hardness levels have been documented across global shrimp farms, with distinct differences between summer and winter conditions (Rahman et al., 2023; Anna and Dinesh, 2023). Agricultural lime applications are commonly used to balance pond water hardness, providing essential elements for optimal shrimp production (Sipauba-Tavares et al., 2023; Biswas et al., 2024). In the present study, total hardness values ranged from 5196 to 6947 ppm, which aligns with findings reported by Singh et al. (2024) from L. vannamei farms in Gujarat.

Calcium: Calcium is the major ion which are responsible for shrimp metabolism, molting, reproduction, and growth by consumption of proteins/amino acids either directly or indirectly (Kumar et al., 2023). Calcium ions are taken up from the food and water and subsequently transported by the epidermis to the shell's cuticle. Depletion of calcium ions in shrimp leads to growth reduction, muscle cramping, whitening of the muscles and soft shell. Wang et al. (2023) stated that Calcium ions in shrimp farms ranges from 346 to 896.51 ppm and it was coincides with the Calcium ion content of the present study (Tuticorin 212 ppm < Nellore 466 ppm). Rahman et al. (2023), the level of Calcium was rich in high saline water than low saline water. Agricultural lime is typically used to augment calcium in shrimp farms.

Magnesium (Mg): Water hardness primarily derives from calcium and magnesium bicarbonates and is measured in ppm or mg l^-1^ (Truong et al., 2023). Seasonal variations in hardness levels have been documented across global shrimp farms, with distinct differences between summer and winter conditions (Venkateswarlu et al., 2023; Anna and Dinesh, 2023). Agricultural lime applications are commonly used to balance pond water hardness, providing essential elements for optimal shrimp production (Sipauba-Tavares et al., 2023; George et al., 2023). In the present study, total hardness values ranged from 5196 to 6947 ppm, which aligns with findings reported by Gunalan et al. (2023) from L. vannamei farms in South India.

Ammonia: According to Mishra et al. (2023), the optimal ammonia level in shrimp farms varies seasonally: 0.009 to 0.45 ppm in summer and 0.2 to 0.6 ppm in winter. Although shrimp are bottom dwellers, they are easily affected by ammonia, which can result from the decomposition of organic debris, excessive fertilizer use, molting shells, dead shellfish, and uneaten pellet feed. Elevated ammonia concentrations can retard shrimp growth and reduce survival rates (Singh et al., 2023; Ariadi et al., 2023). Ammonia levels increase with high stocking density and may decrease with low pH. Nkuba et al. (2023) found that ammonia and nitrite concentrations exceeding 1 mg l^-1^ can increase the occurrence of parasitic illnesses in shrimp ponds. In the current study, ammonia levels ranged from 0.012 to 0.051 mg l^-1^, and a regular survival rate was observed in the shrimp ponds.

Table 1: Mean water quality parameters (±SD) recorded in L. vannamei culture ponds across four stations in Southeast coast of India

Parameters	Tuticorin	Ramnad	Ponneri	Nellore	F	Sig
DO_2	4.98 ± 0.53^a	4.99 ± 0.41^a	4.86 ± 0.39^a	4.79 ± 0.34^a	0.510	0.678
Temp	28.90 ± 0.99^a	29.00 ± 0.81^a	29.30 ± 0.82^a	29.40 ± 0.51^a	0.872	0.465
Tur	38.50 ± 18.42^a	30.50 ± 10.65^a	34.50 ± 11.89^a	36.00 ± 13.90^a	0.570	0.638
pH	8.06 ± 0.16^a	8.08 ± 0.34^a	8.13 ± 0.45^a	8.25 ± 0.09^a	0.806	0.499
PPT	31.40 ± 6.93^a	25.20 ± 4.70^b	23.40 ± 7.29^b	33.30 ± 2.21^a	7.092	**0.001****
Alk	182.50 ± 34.69^b	184.10 ± 23.32^b	223.00 ± 42.24^a	163.00 ± 24.51^b	8.605	**0.000****
CO_3	24.60 ± 11.08^b	32.50 ± 12.30^{ab}	42.00 ± 9.48^a	35.00 ± 10.80^{ab}	4.291	**0.011****
HCO_3	157.90 ± 33.65^b	151.60 ± 23.60^b	191.00 ± 43.32^a	128.00 ± 19.88^b	6.821	**0.001****
TH	6390.00 ± 1526.19^{ab}	5196.00 ± 1050.87^b	5552.00 ± 1868.43^b	6947.00 ± 1165.67^a	3.049	**0.041***
Ca^{++}	212.40 ± 48.24^c	336.80 ± 229.66^{bc}	625.20 ± 272.73^a	466.00 ± 74.33^{ab}	9.271	**0.000****
Mg^{++}	1423.20 ± 346.03^a	1072.90 ± 314.44^{ab}	968.90 ± 335.69^b	1408.60 ± 239.04^a	4.811	**0.006****
NH_3	0.02 ± 0.06^a	0.012 ± 0.01^a	0.013 ± 0.03^a	0.051 ± 0.06^a	1.334	0.279

Note: ** Highly significant; * Low significant. Remaining values are insignificant.

Abbreviations: DO_2 (Dissolved Oxygen); Temp (Temperature); Tur (Turbidity) PPT (Salinity); Alk (Alkalinity);TH (Total Hardness);Ca^{++} (Calcium; Mg^{++} (Magnesium); NH_3 (Ammonia)

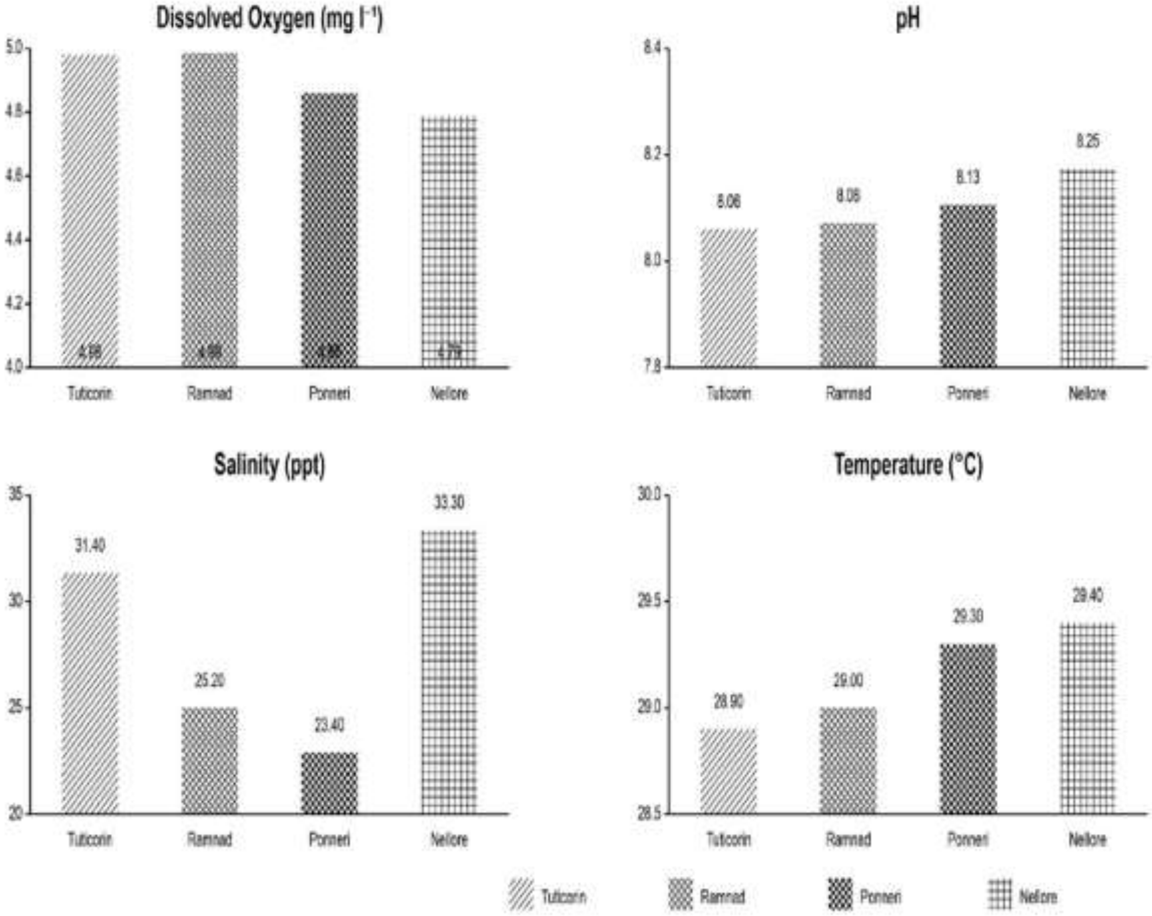

Figure 1: Comparison of Key Water Quality Parameters: This figure displays bar charts for four essential water quality parameters (dissolved oxygen, pH, salinity, and temperature) across the four study stations.

Growth performance: Monitoring of shrimp growth is essential for farm management as it provides basic tools such as periodic sampling which helps to assess the survival rate, length-weight, feed requirement, FCR and expected production rate (Hassan et al., 2023; Zhou et al., 2023). Statistical significance was examined among the four stations regarding the overall Shrimp Survival rate, Biomass, Cumulative feed and FCR (Table 2).

Survival%: Shrimp survival rate has an inverse relationship with the stocking density, when stocking density increases survival decreases. Cannibalism in crustaceans during the molting process may be the cause of decreased survival with high stocking density (Sharma et al., 2024). Highest survival rate can be achieved by good seed quality, proper feed proportion and regular monitoring of water quality parameters. In the present study all the shrimp ponds were evenly stocked (50 PL m^-2^) and survival rate has been calculated at the termination of the culture. Highest survival was recorded in Tuticorin (97.62%), queue up by Ramnad (88.99%), Nellore (68.29%) and lowest in Ponneri (68%). Several researchers reported that white leg shrimps show high growth rate at 35 ppt when compared to 40 and above ppt (Ayaz et al., 2024) it is consistent with our present study. Several research reports states that the survival and growth of L. vannamei varies with stocking densities (Gunalan et al., 2023).

ABW: Singh et al. (2023) and Nguyen et al. (2024), states that shrimp weekly weight gain, survival rate varies among ponds which mainly depends on the water quality management. In the present study we observe different ABW in four stations with utmost average weight gain at 90 DOC in Tuticorin (23.67 g) followed by Ramnad (23.50 g), Ponneri (22.66 g), and stumpy growth in Nellore (20.33 g). The ability of Pacific white shrimp to utilize natural productivity and its effect on enhancing shrimp growth is well documented (Pratiwi et al., 2024; Rahman et al., 2023). Shrimp growth rate is determined by water temperatures (Liu et al., 2023) and salinity. Fluctuation in water temperature greatly affects daily weight gain, an average pond water temperature has been maintained by regular water exchange with routine water quality management (Zhou et al., 2023; Li et al., 2023).

Average Daily Growth (ADG): The ADG (g day^-1^) of the present study varied with water source (Creek, Direct Sea, Backwater, Bore well), maximum in Tuticorin (0.27 g day^-1^) and minimum in Ponneri (0.23 g day^-1^). Statistical analysis revealed that all stations were significantly different (P<0.05). This ADG of our study was consistent with the results of an intensive farming system. L. vannamei exhibit better ADG, and thrive well when they are reared in low salinity 28 ppt (Singh et al., 2023; Kumar et al., 2023).

Biomass (kg): A maximum harvest (Biomass Production) was observed in Tuticorin (6048.33 kg) and minimum in Ponneri (3533.33 kg) after 90 days of culture during the present study. Several researchers reported that biomass proliferations when stocking density increases (Ahmadi et al., 2023). L. vannamei exhibit an elevated biomass, survival rate by ideal water quality managements (Pratiwi et al., 2024). The above observations are in concurrence with the results of present study. Vannamei shrimp growth performance is closely related to water quality. According to the study's findings, the dynamics of water quality have an impact on growth performance in weekly sampling, and the final harvest shows a survival rate with harvest biomass (Ye et al., 2023).

FCR: Feed Conversion Ratio (FCR) is a prime alarm for shrimp farmers to assess production and input ratio of feed. Several water quality factors such as Temperature, pH, Salinity, Hardness, etc., have an impact on shrimp feed consumption with slow feed consumption during low temperature compared to high temperatures. The water stability of commercial shrimp pellet feed plays a vital role in FCR and growth performance of shrimps in rearing ponds. More feeding frequencies, quality pellet feed and 3 hr water stability boost the FCR level in the present study. Pratiwi et al. (2024) states that shrimp growth and FCR are determined by regular sampling. Several reports (Wang et al., 2023), state that high stocking density, feed quality, farm management practices boost FCR level in intensive culture systems. In the present study maximum feed intake and high FCR was recorded in station Tuticorin (1.07) followed by Ramnad (1.22), Ponneri (1.34), and Nellore (1.35), respectively (Table 2). The contribution of nutritional compounds originating from the natural food supply has been reviewed. Singh et al. (2024) have reported mean FCR (1.31-1.33), survival (70.8-81%), production cycle duration (90-110 days), harvest size (59-85 shrimp kg^-1^) values parallel in range for the production parameters reported in the present study.

Table 2: Growth parameters of L. vannamei cultured in different stations along southeast coast of India

Parameters	Tuticorin	Ramnad	Ponneri	Nellore	F	Sig
Sur	97.62 ± 3.06[a]	88.99 ± 6.35[a]	68.00 ± 4.92[b]	68.29 ± 8.70[b]	17.915	**0.001****
ABW	23.67 ± 1.53[a]	23.50 ± 1.50[a]	22.66 ± 1.53[ab]	20.33 ± 1.53[b]	3.060	0.091
ADG	0.27 ± 0.02[a]	0.26 ± 0.02[a]	0.25 ± 0.02[a]	0.23 ± 0.01[a]	2.348	0.149
Biom	6048.33 ± 70.06[a]	4985.00 ± 532.61[b]	3533.33 ± 125.83[c]	3859.66 ± 115.37[c]	49.496	**0.000****
CF	6443.00 ± 86.12[a]	6083.33 ± 301.39[b]	4800.00 ± 100.00[d]	5184.00 ± 60.83[c]	62.680	**0.000****

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FCR	1.07 ± 0.002[c]	1.22 ± 0.12[b]	1.35 ± 0.02[a]	1.34 ± 0.03[ab]	13.397	**0.002****

Note: ** Highly significant;Remaining values are insignificant.
Abbreviations: Sur. (survival);ABW (average body weight);ADG(average daily growth); CF (cumulative feed); FCR(feed conversion ratio).

As illustrated in Fig. 2, growth performance parameters of L. vannamei varied significantly across the four study stations. Survival rate was highest in Tuticorin (97.62%) followed by Ramnad (88.99%), while both Ponneri and Nellore showed considerably lower survival rates (68.00% and 68.29%, respectively). Similarly, average body weight (ABW) at harvest was greatest in Tuticorin (23.67 g) and Ramnad (23.50 g), with moderate growth in Ponneri (22.66 g) and lowest in Nellore (20.33 g). Biomass production followed a similar pattern, with Tuticorin yielding the highest production (6048.33 kg), followed by Ramnad (4985.00 kg), Nellore (3859.66 kg), and Ponneri (3533.33 kg). Feed conversion ratio (FCR) was most efficient in Tuticorin (1.07), progressively increasing in Ramnad (1.22), and reaching highest values in Ponneri (1.35) and Nellore (1.34), indicating less efficient feed utilization at these stations.

Correlation analysis (Fig. 3) revealed distinct relationships between water quality parameters and growth performance. A strong positive correlation (r = 0.87) was observed between dissolved oxygen and average body weight, with higher DO levels associated with greater shrimp growth. In contrast, water temperature demonstrated significant negative correlations with both survival rate (r = -0.91) and average daily growth (r = -0.95). These findings suggest that even small temperature variations within the range of 28.9-29.4°C can substantially impact growth performance and survival of L. vannamei under semi-intensive farming conditions, with cooler temperatures within this range promoting better outcomes.

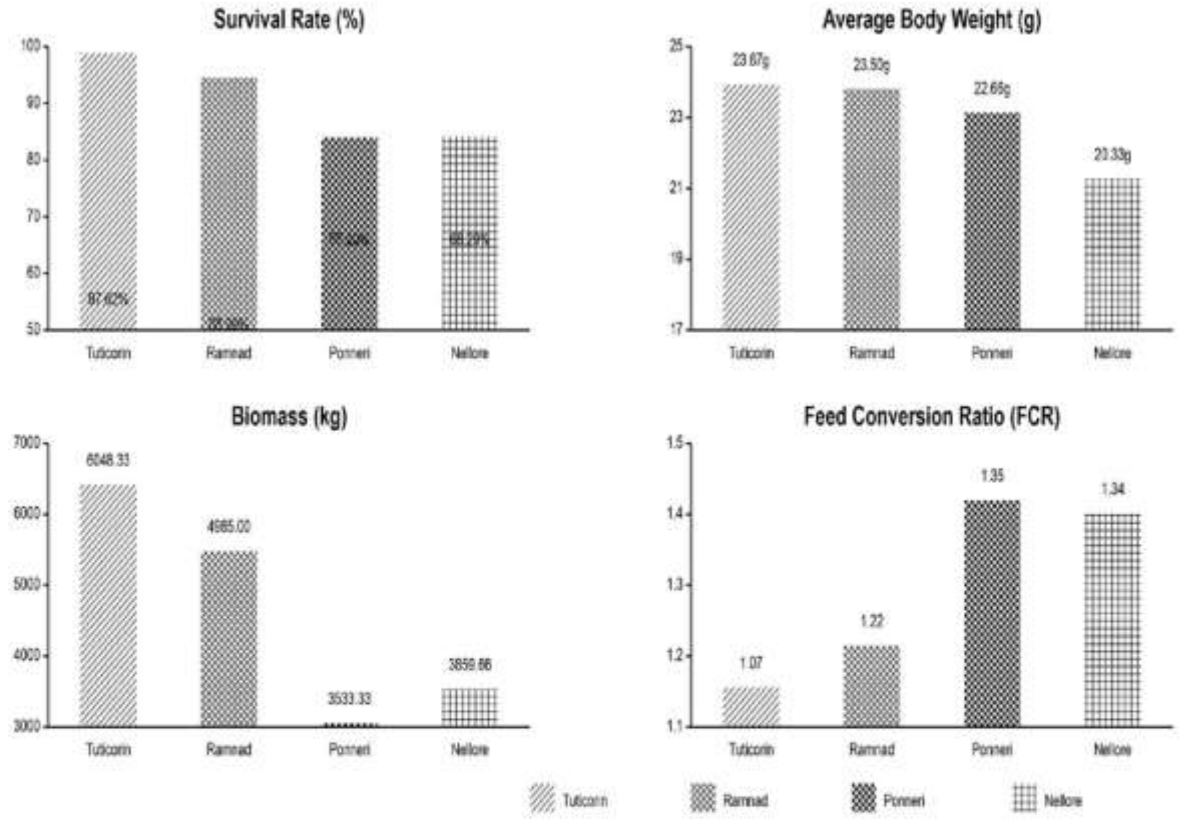

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Figure 2: Growth Performance Parameters of L. vannamei: This figure illustrates the growth performance metrics (survival rate, average body weight, biomass, and FCR) across all stations.

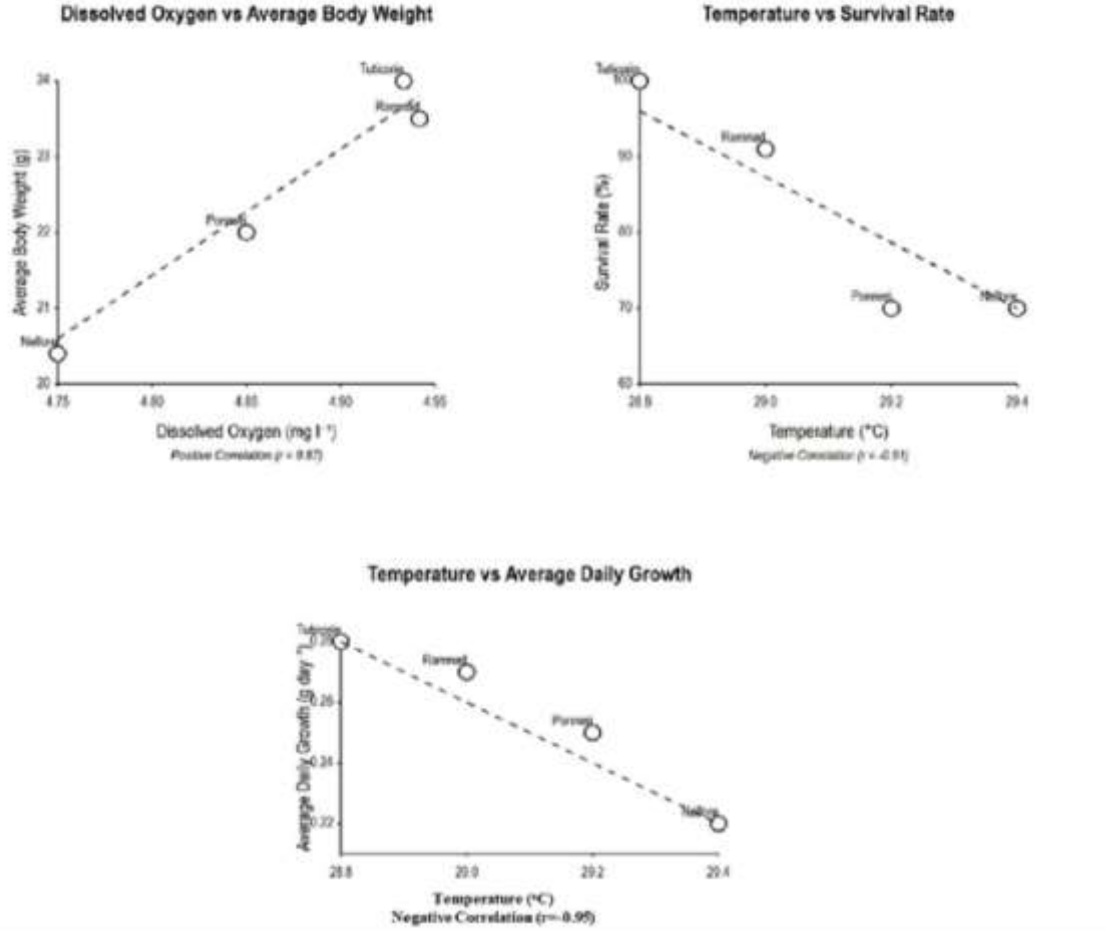

Figure 3: Correlation Between Water Quality and Growth Parameters
This scatter plot figure shows the three key correlations identified:

1. **The positive correlation between dissolved oxygen and average body weight**
2. **The negative correlation between temperature and survival rate**
3. **The negative correlation between temperature and average daily growth**

CONCLUSION

The research conducted on various environmental parameters affecting the survival, growth, and overall productivity of Litopenaeus vannamei (Pacific white shrimp) in semi-intensive culture farms in four stations showed that key water quality factors, such as dissolved oxygen (DO), temperature, turbidity, pH, salinity, alkalinity, total hardness, calcium, magnesium, and ammonia, play vital roles in shrimp health and development. DO in all the stations were above the optimum level (4 mg l^-1^), with the lowest DO level observed in Nellore. Temperature in the study period varied from 20-33°C and exhibited negative correlation with survival and other growth parameters. Turbidity in all the study stations was within the range (21.25-38.75 cm), enhancing primary productivity in the culture systems. pH levels varied within the recommended range and were seen as optimal for shrimp survival and growth. Stable salinity in Ramnad (Back water) resulted in better survival and growth, while least production was observed in Ponneri (Bore well) with lowest ppt.

A stable water quality was maintained in all the stations by addition of different available lime, while monitoring the alkalinity and total hardness. Highest calcium and magnesium levels were observed in Nellore which showed retarded shrimp growth, molting inhibition and enhanced excess primary productivity. Though the level of ammonia was within optimum level, we observed low survival and growth in Nellore and Ponneri. Based on the above observations we suggest that shrimp growth performance may be varied by some basic water parameters such as temperature, pH, salinity, ammonia and dissolved oxygen, which can be optimized by regular farming operations. The shrimp survival diverges in four stations may be due to the quality of shrimp seed, feed quality and variations in the water quality. This study highlights the importance of balancing stocking densities, water quality, and feed management to optimize shrimp survival and growth. High stocking densities, while increasing biomass production, negatively impacted survival and growth, as evidenced by lower survival rates and higher FCR values at Ponneri and Nellore. Conversely, maintaining optimal stocking densities in combination with effective water quality management, as seen in Tuticorin, resulted in the best overall performance in terms of survival, growth, and FCR. Scientific eco-friendly farming management, regular water quality monitoring, periodic sampling and assessment of shrimp growth with low FCR helps to produce large quantity of shrimp and boost our nation high in world market.

AUTHORSHIP & CONTRIBUTORSHIP

Authors' contributions: VS: Data curation, Formal analysis, Writing - original draft; **DSK**: Conceptualization, Methodology, Supervision; **NT**: Original draft, Validation; **DY**: Review and editing

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