Effects of water quality parameters on growth performance of intensive shrimp pond (*Litopenaeus vannamei*)

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ABSTRACT

Currently, to monitor water quality, farmers in Vietnam need to analyze various indicators which increase production costs. In addition, the limitation of analytical facilities and techniques is a challenge. The objective of this experiment was to evaluate the influence of water quality parameters on shrimp growth rates and the seasonal fluctuation in water quality. A total of 4 modules were randomly selected and analyzed daily for 8 critical parameters during rainy and dry seasons. The SPSS ver.26 was used to evaluate the correlation between multi-parameters and their impact on the performance of shrimp ponds. The results showed that shrimp growth was influenced by salinity, nitrite (NO_2^-), alkalinity and pH about 80.4%, 75.6%, 67.8%, and 55.7%, respectively. Moreover, water quality fluctuated more during the rainy season than during the dry season. Some parameters that exhibited high fluctuation in ponds were dissolved oxygen (DO) and nitrite.

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1. Introduction

Water quality is an essential natural indicator for assessing the life cycle of shrimp pond ecosystems (Mahmudi et al., 2022; Ariadi et al., 2023). As the most sensitive spice Shrimp health is negatively impacted when the values of physical, chemical, and mineral parameters exceed defined limits (Boyd, 2017; Ariadi et al., 2019). Moreover, fluctuations in these parameters can adversely affect shrimp performance (Hukom et al., 2020). That's why, increasing understanding of the information on contamination and limiting its effect can reduce the death rate of shrimp by expressing the daily water quality data (Ma et al., 2013).

Along with water quality monitoring, shrimp growth rates are a crucial indicator of effective farm management. Early research showed that water quality parameters had different influences on the length of the shrimp culture period. (Ariadi et al., 2019; Chen et al., 2019) concluded that enhancing the water recirculation rate can lead to better water quality and stimulate shrimp growth. In detail, dissolved oxygen (DO) is an essential abiotic parameter for evaluating water quality in intensive whiteleg shrimp (*Litopenaeus vannamei*) farming systems and needs to be measured periodically (Madenjian, 1990; Supriatna et al., 2017; Osaka et al., 2022). The ideal average dissolved oxygen concentration for this process falls between 4 and 6 mg/L (Ferreira et al., 2011), and its solubility is greatly affected by salinity and water temperature (Boyd, 2017). When DO levels are low, the toxicity of ammonia gas can increase, making aquatic organisms more susceptible to stress (Sriyasak et al., 2015). Furthermore, physical parameters, such as temperature and salinity, have significant impacts on shrimp growth (Ponce-Palafox et al., 1997; Ren et al., 2021; Atikah & Hasibuan, 2023). In some studies, the fluctuation of alkalinity and hardness concentration affects shrimp production (Boyd, 2016; Boyd et al., 2016; Ge et al., 2023). Thus, farmers strive to avoid this in aquaculture ponds. Additionally, the value decreases could prevent shrimp growth in intensive farming ponds. Meanwhile, Phan et al. (2022) and Valencia-Castañeda et al. (2019) showed that high level of ammonia, nitrate and nitrite (NO_2^-) are toxics the survival of whiteleg shrimp. In general, poor water quality reduces shrimp growth and increases mortality rates due to ecosystem fluctuations (Anand et al., 2019; Kumar, 2023; Srinivas & Venkatrayulu, 2023). To evaluate immediately and more accurately the farming environment, several parameters should be monitored in shrimp cultivation. This can be a result of high cost and reduction in price competition in the new normal period (Nikolik et al., 2024). Furthermore, in the past, some researchers have conducted an investigation of water quality impacts on the shrimp culture system using the initial weight or final weight or simulation conditions in some experimental ponds. Thus, it cannot demonstrate the daily effectiveness of water characteristics on shrimp growth in real conditions.

In this study, the size of shrimp was collected more frequently than in previous studies. Together with daily water collection, 8 significant water parameters were selected. The purpose of determining the relationship between variations in dissolved oxygen parameters and water quality and their impact on shrimp growth rates in intensive farming cycles can be achieved. This helps farmers determine the most important indicator for a successful farming cycle and supports in making decisions.

2. Materials and Methods

2.1. Study area

This research collected actual farming activities data at Minh Phu - Loc An Aquaculture Ltd, a 300-ha intensive shrimp farm in Vietnam, situated at Ba Ria- Vung Tau province, the southeast delta of Vietnam (Figure 1). Seawater is directly collected by a 20 km seawater pipeline supply for shrimp ponds. Each module includes 10 post-larvae ponds, 20 growing ponds and individual water treatment systems. Each post-larvae pond had 232 m^2 and the growing pond had 834 m^2 with 1.0 m water depths in both types. To ensure the required dissolved oxygen levels, paddlewheel aerators and bottom air diffusers were installed in each tank. Before stocking, pH and alkalinity were tested at the settlement pond, and it was pumped into post-larvae ponds. Each module is controlled separately following the module manager. A two-stage farming method was applied. The nursery phase typically lasts 12 - 15 days, followed by the grow-out phase. Normally, there is no water exchange in post-larvae ponds. The water exchange rate in grow-out ponds is 10 - 12% depending on the module manager's decision.

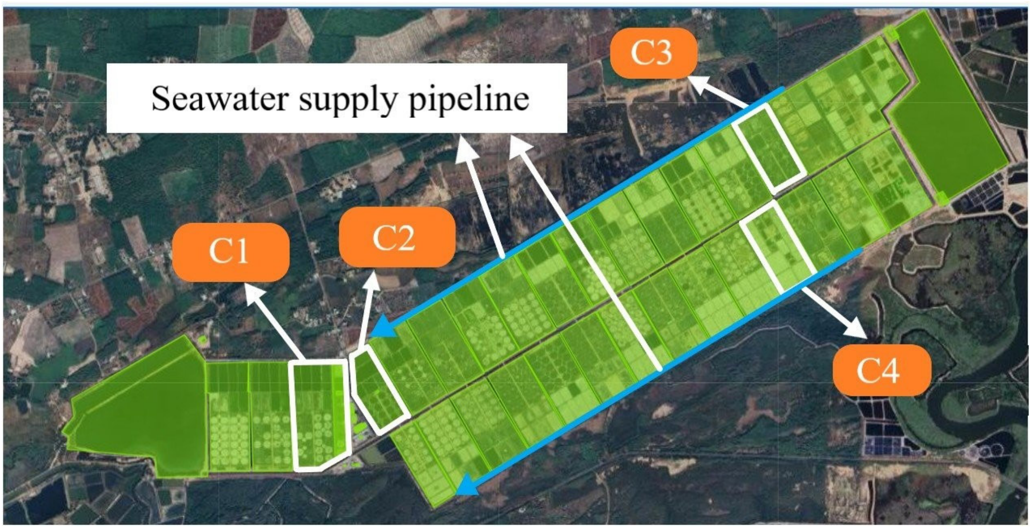

Figure 1. Map of the study area and sampling site at Minh Phu-Loc An Aquaculture Ltd, Dat do district, Ba Ria-Vung Tau province, Vietnam. C1 - C4: are denoted for shrimp modules taking water samples.

2.2. Experimental set-up

The method applied is an ex-post facto causal design, which implies analyzing the research objectives based on the existing natural phenomena in the field, over a period of a shrimp yield, with total a 8 ponds in 4 shrimp modules (2 ponds for each module) located downstream (C1 & C2) and upstream (C3 & C4) of seawater pipeline as Figure 1. In each preselected module, 2 ponds were randomly chosen. The quality parameters in the farming operations, including DO, pH, temperature, salinity, alkalinity, nitrite, phosphate, and total ammonia nitrogen (TAN), are determined on-site daily at 8 am. Because seasonal variation is considered an important natural factor influencing water quality, water samples were taken from the stocking day until harvesting day during dry and rainy seasons. Additionally, to examine how water quality affects the growth of shrimp, the size of shrimp (g/pcs) was monitored by request from post-larvae phase to grow-out phase. The module manager determined the optimal period for measuring shrimp size.

2.3. Water sampling and analysis

Based on the experimental set-up, a Van Dorn water sampler was used to take water samples daily. A total of 506 water samples were taken from 8 crops during the rainy and dry season. Water samples were taken in the 30 - 50 cm from the surface layer. Some physical parameters, such as DO, pH, temperature and salinity were measured directly using Aqua TROLL 500 Multiparameter Sonde (In-Situ Inc, Fort Collins, USA). An on-site laboratory was set up for the analysis of chemical parameters, such as alkalinity, nitrite, phosphate, and TAN. These parameters were determined as SMEWW by using HI801-02 (iris Visible Spectrophotometer, Hanna Instruments Inc, Woonsocket, RI, USA).

Normally, shrimp size is the most suitable indicator in a batch. Previously, these assessments were only done manually on the harvesting day (Smith et al., 2002; Chen et al., 2019; Amalia et al., 2022). In this article, the artificial intelligence sizing machine S3 (Otanics Technology Jsc, Vietnam) was used to determine the shrimp body weight. With S3, we collected more data of the growth rate in a crop than in other studies because the growth rate of post-larvae phase can be easily measured by S3 than before. Furthermore, using S3 helps to keep the shrimp alive after sizing and protects the survival rate of the shrimp.

2.4. Statistical analysis

The collected data are analyzed by using SPSS ver.26 software to analyze the impact of observed parameters on shrimp growth rates. The seasonal fluctuations in water quality throughout the year are also described to understand the reflection of climate change.

The energy consumption required to maintain the desired DO levels is significant in a farming cycle. Therefore, assessing the dynamics of water quality parameters with DO levels is extremely important. The mentioned software was also used to demonstrate this relation.

3. Results and Discussion

3.1. The dynamics of water quality parameters with DO

The fluctuating values of DO concentration in a whiteleg shrimp farming cycle are presented in Figure 2. The lowest concentration point occurs at 60 days of farming on the harvesting day of module C4 at 4.73 mg/L, while the highest concentration value is observed on the first day (7.41 mg/L). The DO decrease may occur due to the retaining feeding rate after dusk. The food surplus can potentially increase synthesis and cause changes in DO. Similarly, DO consumption levels decrease along with the increase in feed input, due to the biosynthesis process of waste and other organic materials, align with Ma et al. (2013), Mirzaei et al. (2019) and Wafi et al. (2021). Our results are consistent with Ullman et al. (2019) and Weldon et al. (2021), who reported that higher feed amounts used generally lead to higher DO consumption in the water. Other reasons for the decrease at certain times include abiotic factors such as water temperature, pH, and salinity. This was reported by Boyd & Tucker (2012), Cao et al. (2019) and Rozario & Devarajan (2021).

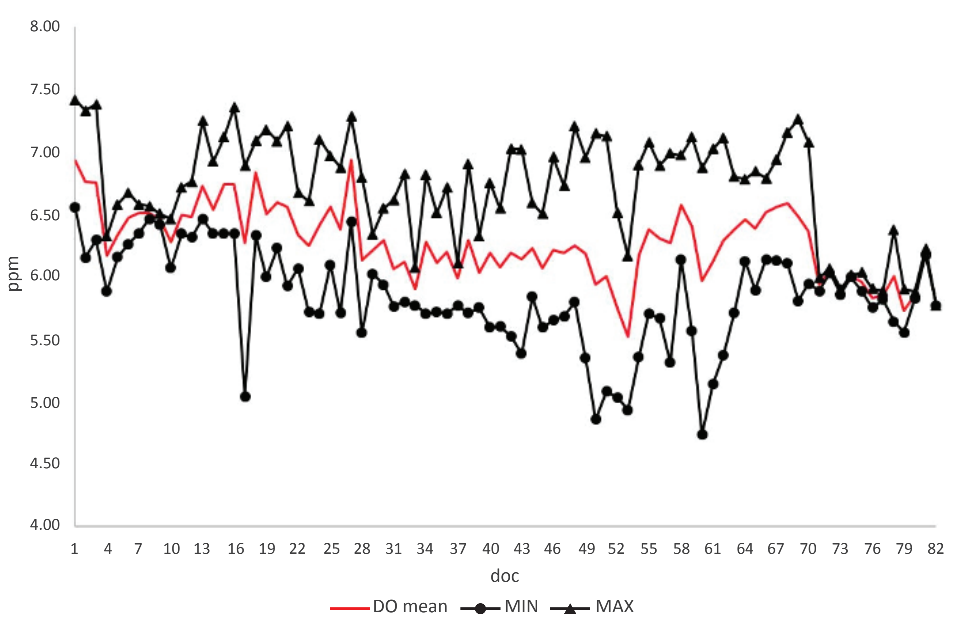

Figure 2. The fluctuation of dissolved oxygen levels during the shrimp farming period. MIN: minimum value; DO: dissolved oxygen; MAX: maximum value; doc: days of culture.

The average DO concentration is presented in Table 1. The average DO concentration is 6.33 ± 0.39 mg/L, with a minimum of 4.73 mg/L and a maximum of 7.41 mg/L. This satisfied the requirement of maintaining a DO level above 4.5 mg/L in shrimp farming during culture time, as mentioned in studies of Simbeye & Yang (2014) and Adetunji et al. (2022). The normal DO level in our study was higher than the optimal value for shrimp farming ranging between 4 - 5 mg/L as reported by Islam et al. (2004). The optimal value is crucial for changes in pond water quality and is an important parameter for aerobic respiration and redox processes in water and pond sediments (Boyd, 2017).

The data on water quality parameters for each module are presented in Table 1. The pH values of C1, C2, C3, and C4 are 7.65 ± 0.34, 7.62 ± 0.31, 7.99 ± 0.14 and 7.96 ± 0.12, respectively. Daily pH measurements for 4 modules yielded an average value of 7.8 ± 0.23. The difference of the salinity of the water in downstream (C1 & C2) modules and upstream (C3 & C4) modules was observed in Table 1. The average value of this parameter in this study area is 30.29 ppt. The distinction of module manager's decision about daily water exchange rate may be the reason of salinity change. The DO level has an average value of 6.33 mg/L. The optimal pH range for whiteleg shrimp farming is 7.5 - 8.5, with a fluctuation range of 0.5, algin with Reddy & Mounika (2018). The obtained salinity value in this study is 30.29 ppt. Meanwhile, the optimal range is approximately 20 - 25 ppt (Ferreira et al., 2011). On the other hand, shrimp can naturally thrive within a salinity range of 0 to 40 ppt due to their osmoregulatory system (Ponce-Palafox et al., 1997; Jaffer et al., 2020; Khanjani et al., 2020). The average temperature obtained in the study is 27.53°C, optimal for shrimp development. This was reported by Wyban et al. (1995) and Madusari et al. (2022), where the optimal range is 27 - 30°C. It can be affirmed that DO concentration, pH, salinity, and temperature during the shrimp farming period all fall within optimal ranges.

Similar to salinity, there are discrepancies between downstream and upstream modules of TAN, NO_2^- and PO_4^{3-} value (in Table 1). The average values of these three parameters in C1 and C2 are higher than in C3 and C4. The interaction of stocking density and farming condition influenced the variation of water quality was also proposed in studies of Biao et al. (2004) and Esparza-Leal et al. (2020). In fact, each region employs different aquaculture practices and the farmers rely on their individual experience to make decision. This was mentioned early by Kautsky et al. (2000). Minh Phu-Loc An Aquaculture Ltd, each module is operated by different groups of farmers so that each module works as separate farm. Consequently, the water characteristics were dramatically changed. Especially, extremely high nitrite values were detected in C1 and C2. While Samocha (2019) declared that a good survival of shrimp has been demonstrated when exposed to high nitrite concentration in 8 days, this study found that the tolerance threshold of shrimp survival can be up to than 50 mg/L. The effect of unusually peak level of NO_2^- was not evaluated because this situation happened when there was no water exchange on the last days of the crops to rise the color of shrimp and the feeding rate still remained.

Table 1. Average values of water quality parameters during the shrimp farming period

Quality parameter		Module				Average value of study area
		C1	C2	C3	C4	
DO (mg/L)	Mean	5.99 ± 0.41	5.95 ± 0.44	6.70 ± 0.38	6.67 ± 0.34	6.33 ± 0.39
	Range	4.86 - 7.08	4.73 - 7.28	5.55 - 738	5.77 - 7.41	
pH	Mean	7.65 ± 0.34	7.62 ± 0.31	7.99 ± 0.14	7.96 ± 0.12	7.8 ± 0.23
	Range	7.10 - 8.38	6.97 - 8.31	7.73 - 8.52	7.81 - 8.49	
Sal (ppt)	Mean	24.64 ± 4.13	24.87 ± 4.5	36.66 ± 0.53	36.83 ± 0.35	30.29 ± 0.39
	Range	16.51 - 31.04	16.37 - 30.96	34,71 - 37,38	35,89 - 37.61	
T (^{0}C)	Mean	28.53 ± 0.84	28.44 ± 0.78	26.42 ± 0.72	26.1 ± 0.82	27.53 ± 0.09
	Range	26.65 - 30.98	26.79 - 30.49	24.88 - 27.81	24.88 - 27.81	
Alk (mg/L)	Mean	144.95 ± 28.62	145.67 ± 33.86	167.04 ± 23.2	159.66 ± 23.99	153.64 ± 1.69
	Range	79 - 193	57 - 193	123 - 215	125 - 210	
TAN (mg/L)	Mean	4.03 ± 4.38	5.93 ± 4,8	2.61 ± 1.51	2.3 ± 1.32	3.67 ± 0.21
	Range	0.15 - 17.5	0.18 - 22.1	0 - 7.68	0 - 5.8	
NO_2^- (mg/L)	Mean	9.62 ± 1.335	7.81 ± 11.25	0.74 ± 0.64	0.91 ± 1.06	4.70 ± 0.58
	Range	0 - 57.6	0 - 41.6	0 - 2.90	0 - 6.65	
PO_4^{3-} (mg/L)	Mean	3.71 ± 3.76	4.10 ± 4.5	0.74 ± 0.64	0.91 ± 1.06	2.48 ± 0.20
	Range	0 - 17.7	0 - 20.4	0 - 2.90	0 - 6.65	

Note: DO - dissolved oxygen; Sal - salinity; T - temperature; Alk - alkalinity; TAN - total ammonia nitrogen.

Based on the correlation test results, the DO concentration in aquaculture ponds is related to water quality parameters, and its correlation with the physico-chemical data is presented in Table 3. The data indicates an inverse relationship with the physico-chemical parameters including phosphate, temperature, nitrite, and TAN, while there was a positive relationship with pH, salinity, and alkalinity. This finding was consistent with the results in the research of Vinatea et al. (2009) and Esparza-Leal et al. (2020). This finding also highlights the issue that high DO concentration not only wastes energy but also changes the stability of pH level in tank.

Table 2. The correlation between DO and the physico-chemical parameters of water

	Parameter	pH	Sal	T	Alk	PO_4^{3-}	NO_2^-	TAN
DO	Pearson correlation	0.729**	0.396**	-0.525**	0.300**	-0.457**	-0.365**	-0.371**
	Sig (2-tailed)	0.000	0.000	0.000	0.006	0.000	0.001	0.001
	N	82	82	82	82	82	82	82

*Note: * - correlation is significant at the 0.05 level; ** - correlation is significant at the 0.01 level; DO - dissolved oxygen; Sal - salinity; T - temperature; Alk - alkalinity; TAN - total ammonia nitrogen.*

3.2. Effects of water quality on shrimp growth rate

Based on correlation tests and descriptive analysis, nitrite concentration fluctuates at values higher than the water quality standards for intensive shrimp farming. The variation in water quality parameters is closely related and indirectly affects shrimp growth rate and aquaculture productivity (Chen et al., 2019). The impact of DO, nitrite, salinity, alkalinity, and other parameters on shrimp growth rate can be partly seen in Figure 3. The effect of DO fluctuations on shrimp growth rate in ponds can be described by the regression formula with the following equation:

$$y = -26.49 - 5.854x \ (R^2 = 0.037)$$

This means that fluctuations in DO content in the pond affect the shrimp growth rate by approximately 3.7%, while the rest is influenced by other factors. Although, it was recommended that the DO content surveyed in the shrimp ponds is always at the optimal level, and the farmers usually keep this level higher than required, it can increase the operation cost. Moreover, when analyzing the correlation between DO and shrimp growth, it does not show a strong interaction

The impact of nitrite (NO_2^-) on shrimp growth rate during the farming period can be described by the following equation:

$$y = 3.099 + 0.874x \ (R^2 = 0.756)$$

Nitrite affects the shrimp growth rate by up to 75.6%. High nitrite levels adversely affect water quality parameters and shrimp development (Ma et al., 2018; Valencia-Castañeda et al., 2019; Phan et al., 2022). High nitrite concentrations (NO_2^{-}) also affect feed intake, increase oxygen consumption, interfere with the ammonia excretion system, and cause moderate mortality (Valencia-Castañeda et al., 2019). Overall, increased nitrite levels in ponds are caused by environmental fluctuations in the aquaculture ecosystem (Soares et al., 2020).

The impact of alkalinity (Alk) on shrimp growth rate during the farming period can be described by the following equation:

$$y = 32.302 - 0.159x \ (R^2 = 0.678)$$

This means that fluctuations in alkalinity content in the pond affect the shrimp growth rate by approximately 67.8%, while the rest is influenced by other factors.

The impact of salinity (Sal) on shrimp growth rate during the farming period can be described by the following equation:

$$y = 35.792 - 0.94x \ (R^2 = 0.804)$$

This means that fluctuations in salinity content in the pond affect the shrimp growth rate by approximately 80.4%, while the rest is influenced by other factors.

The impact of temperature (T) on shrimp growth rate during the farming period can be described by the following equation:

$$y = -79.925 + 3.216x \ (R^2 = 0.166)$$

The impact of pH on shrimp growth rate during the farming period can be described by the following equation:

$$y = 241.811 - 30.413x \ (R^2 = 0.557)$$

The impact of total ammonia nitrogen (TAN) on shrimp growth rate during the farming period can be described by the following equation:

$$y = 8.199 + 0.257x \ (R^2 = 0.018)$$

The impact of phosphate (PO_4^{3-}) on shrimp growth rate during the farming period can be described by the following equation:

$$y = 7.628 + 0.485x \ (R^2 = 0.143)$$

This means the change of temperature, pH, TAN, and PO_4^{3-} level in the pond affect the shrimp growth rate by approximately 16,6%, 55,7%, 1,8%, and 14,3% respectively while the rest is influenced by other factors.

In this study, salinity was identified as the most influential parameter affecting the growth rate of shrimp. This factor significantly influences the productivity variations in shrimp farming ponds was also proposed in the study of Prapaiwong & Boyd (2012). Salinity plays a crucial role in shrimp development, directly impacting their physiological functions and nutrient absorption capabilities. Our study has shown that shrimp thrive best at salinity levels between 15 and 25 parts per thousand (ppt). Under optimal salinity conditions, shrimp not only grows faster but also exhibit better resistance to stress and diseases. Conversely, abrupt or unsuitable changes in salinity can reduce growth rates and overall health of the shrimp.

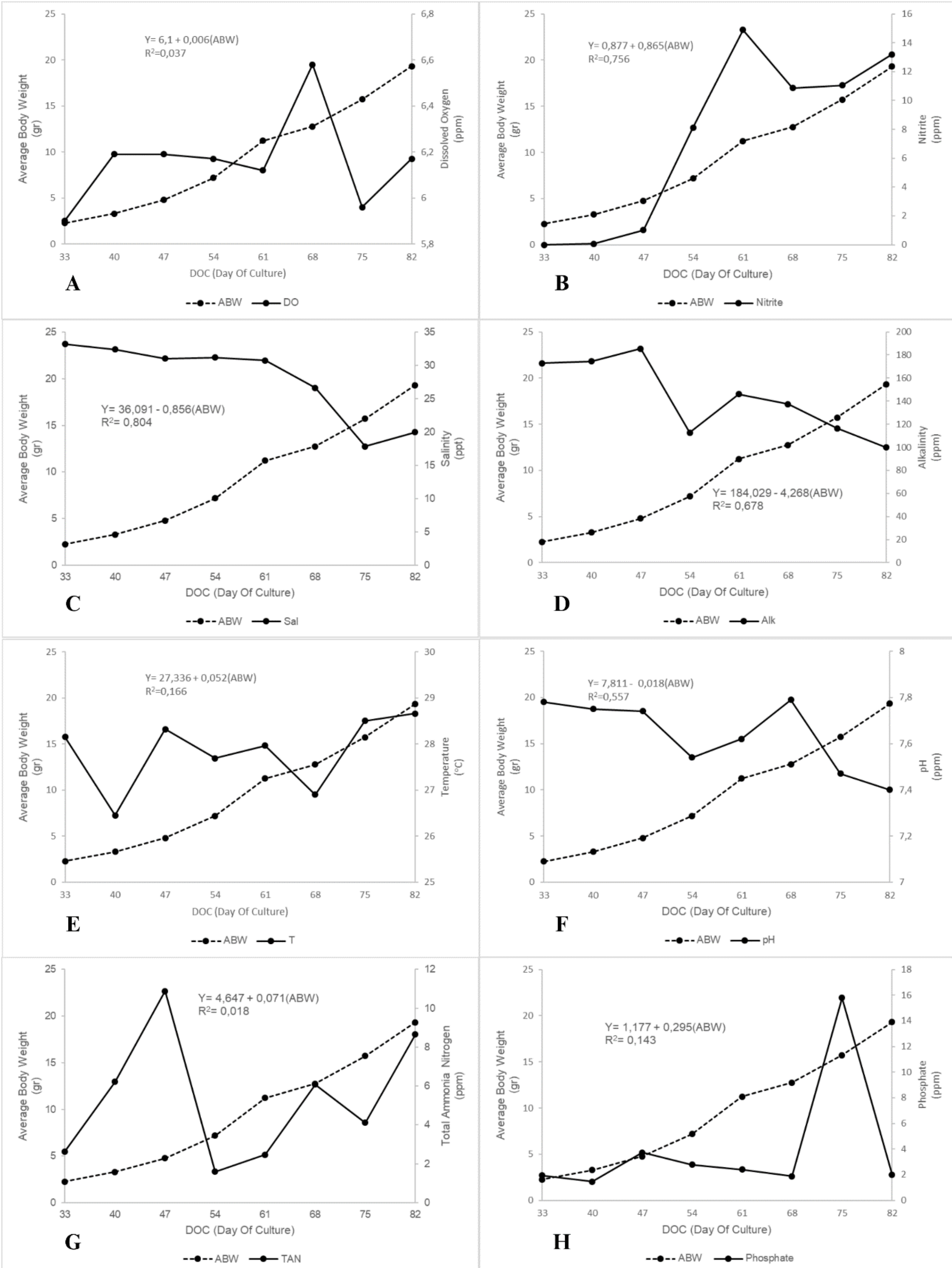

Figure 3. Effects of water quality on shrimp growth rate. ABW: average body weight; A: dissolved oxygen; B: nitrites; C: Salinity; D: Alkalinity; E: Temperature; F: pH; G: TAN; H: Phosphate.

3.3. Water quality assessment in season

In general, water quality tends to fluctuate significantly as shown in Figure 4. During the rainy season, water quality tended to fluctuate dynamically. Similar observations have been discussed in studies of Ariadi et al. (2023) that the main water quality parameters were stable in the dry season, and the rainy season has a greater negative impact on water quality source than droughts condition.

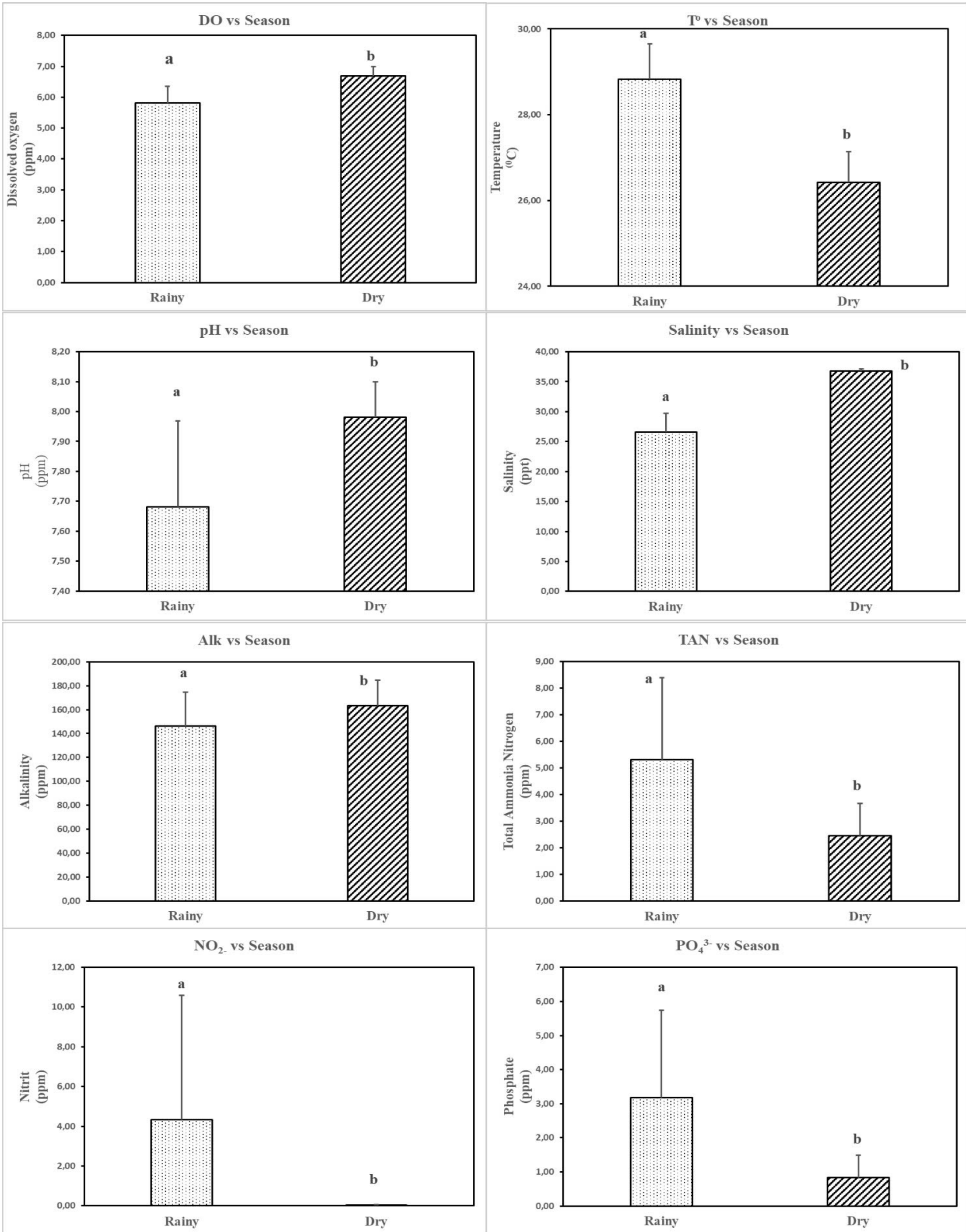

Figure 4. Water quality parameters in two seasons.

As observed in Figure 4, water parameters during the rainy season, generally have lower levels of dissolved oxygen, pH, salinity, and alkalinity compared to the dry season. Similarly, studies of Teichert-Coddington et al. (1996), Guerrero-galván et al. (1998) and Abdul et al. (2021) found the same situation of water quality change in a year. This is due to the large volume of rainwater diluting the substances in the water and reducing the concentration of mineral ions.

Conversely, the water temperature, and the levels of ammonia, nitrite, and phosphate are higher during the rainy season. This is because rainwater carries organic materials from the land, increasing decomposition processes and releasing these compounds into the water. In the dry season, the absence of diluting rainwater typically results in higher salinity and alkalinity, while the concentrations of organic materials and nitrogen-containing compounds such as ammonia and nitrite are generally lower. The evaporation process in the dry season further increases the concentration of mineral ions in the water, leading to more stable pH and salinity levels.

4. Conclusions

Previous studies have shown that pollutants stress shrimp, making them more susceptible to disease. Following this idea, on-time interpretation of water quality is an essential solution for farming environment control. Meanwhile, the more parameters are measured, the more operation costs will be paid. This study identifies the key indicators that impact shrimp growth. Thus, it helps farmers to customize the plan of water quality monitoring. From that, the cost–saving can be easily done.

As recent reports highlighted decreasing production cost is a must-be action for shrimp farmers. Table 3 shows the relationship between DO and other common quality parameters, thus the farm manager could predict the reduction of DO when some important pollutants as indicators of water quality are present. This opens up opportunities to reduce energy costs for maintaining DO when it is not necessary. Based on the results, the fluctuations in dissolved oxygen concentration during the shrimp farming period were characterized by normal levels of variation, with the highest concentration being 7.41 mg/L at 1 day old and the lowest concentration being 4.73 mg/L on day 60. Furthermore, dissolved oxygen (DO) in ponds generally correlates positively with salinity, pH, and alkalinity, and inversely with temperature, nitrite levels, photoperiod, and TAN.

There is a pronounced difference in water quality between the dry and rainy seasons. Water quality parameters during the rainy season tend to be more variable and less stable compared to the dry season. Therefore, a water quality control strategy is needed during the rainy season to minimize fluctuations in water quality.

Conflict of interest

The authors declare that they have no conflict of interest.

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