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Water parameters correlated with the zootechnical performance of shrimp *Litopenaeus vannamei* grown in oligohaline waters

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ABSTRACT. The present study aimed to correlate the influence of water quality, cultivation time, area, and density of ponds on the zootechnical performance of shrimp *Litopenaeus vannamei* in oligohaline waters. It was demonstrated that, under the conditions of this research, better control of temperature, pH and water alkalinity can be employed. Ammonia levels were within the normal range and correlated positively with the growth rate ($\rho = 0.69859$) and production ($\rho = 0.66362$) of the ponds. There was also a positive correlation between cultivation time and pond density with shrimp weight (ρ = 0.75305 and 0.68933) and pond productivity (ρ = 0.74763 and 0.79367, respectively). Negative correlations were observed between: I) pH with shrimp survival ($\rho = -0.73238$) and pond production ($\rho = -0.68696$); II) alkalinity and pond production ($\rho = -0.66162$). The results show that the cultivation of shrimp *L. vannamei* in oligohaline waters is viable and there is potential for increased productivity associated with better hydrological monitoring and use of higher density and cultivation time by some producers.

Keywords: shrimp farming; aquaculture; aquatic environment; productivity.

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Introduction

Aquaculture is an important practice that has also been used as a solution to the problems generated by the overexploitation of fishing resources, requiring, however, the use of techniques that aim at practical and socio-environmental sustainability (Nascimento, Córdula, Benício, Oliveira, & Silva, 2015). Brazil has long been recognized as having ideal conditions for the development of shrimp farming as it possesses large areas of the coastal land, warm water temperatures year-round, an extensive agro-industrial base and an attractive domestic market (Cavalli et al., 2008). On the other hand, despite the dependence on an adequate water source, continental culture is an alternative that can generate income for local communities while it alleviates the pressure on coastal resources (Pinto et al., 2020), mitigating problems such as degradation of coastal waters, pond abandonment and destruction of mangrove forests (Galkanda-Arachchige, Roy, & Davis, 2020).

The Brazilian shrimp production in 2019 was 54.3 thousand tons, with over 99% of this production in the Northeast Region of the country (Instituto Brasileiro de Geografia e Estatística [IBGE], 2019). Shrimp farming is of great importance in this region, where most producers use semi-intensive methodology, with poor water quality control, according to the last survey carried out by the Brazilian Association of Shrimp Farmers and the Ministry of Fishing and Aquaculture of Brazil (Associação Brasileira dos Criadores de Camarão [ABCC], 2013). The state of Paraíba is the 3rd largest shrimp producer in the country, with an increase in production of almost five times between the years 2016-2019, reaching a total of 4.3 thousand tons (IBGE, 2019), with shrimp farming as a consolidated economic activity in two producer hubs: the coastal region and the Paraíba River valley. This is one of the most important rivers in the state due to the extension of its basin that covers about 38% of the state and its economic importance for cities and riverside populations. Along the basin, several properties are found, mostly from micro and small family farmers, in the municipalities of Mogeiro, Pilar, Salgado de São Félix, São Miguel de Taipú and Itabaiana using oligohaline water from the river itself, wells and reservoirs (Cavalheiro, Conceição, & Ribeiro, 2016). Shrimp production in ponds in the municipality of

Mogeiro, appeared in 2009 in the riparian zones of the Paraíba river, as an alternative to the agricultural decline due to soil exhaustion (Souza, Marques, Moura, & Silva, 2019).

The rapid expansion of shrimp farming brings about problems such as inadequate farming technology, disease outbreaks, water pollution and other problems related to environmental degradation (Zhao, Yao, Li, Zhang, & Aweya, 2020). A better understanding of the functioning of ecosystems, such as how their main elements are interrelated, allows the development of more efficient strategies for the sustainable use of local natural resources (Freeman, 1992). In this sense, it is necessary to identify the environmental aspects combined with the observation of cultures, which can promote subsidies to enable the generation of local income and employment through the production chains. The analysis of water quality, for example, allows to determine the influence that the environment has on shrimp, enabling the identification of unfavorable situations for its cultivation. In this way, the environmental parameters involved in the ecosystem must be constantly measured and monitored to avoid animal stress (Carbajal-Hernández, Sánchez-Fernández, Hernández-Bautista, & Hernández-López, 2017). Water quality affects reproduction, growth and survival of aquatic organisms, and its deterioration is a major factor that affects shrimp production performance (Ferreira, Bonetti, & Seiffert, 2011; Mohanty, Ambast, Panigrahi, & Mandal, 2018). In this way, monitoring of water quality parameters is important so that the producer can observe variations in these parameters and adapt their management practices (Jescovitch, Ullman, Rhodes, & Davis, 2018).

In view of the scarcity of studies on water quality and productivity in family shrimp farming, as well as the potential of this economic activity for social and regional development, this work aims to evaluate the viability of the cultivation of marine shrimp *Litopenaeus vannamei* carried out by family producers from the municipality of Mogeiro, Agreste of Paraíba, Brazil. Based on the hypothesis that, due to the low use of technologies in farming systems, there are inappropriate water quality parameters for shrimp cultivation, limiting higher productivity, we seek to identify these parameters, to contribute to the improvement of these productive systems.

Material and methods

The study was conducted in the municipality of Mogeiro, where the Novo Mundo settlement is located, having approximately 40 family aquicultors. Mogeiro (Latitude: 07°17' S; Longitude: 35°28' W; Average altitude: 117 m; according to Francisco, Medeiros, & Santos, 2018) is part of the Brazilian Semiarid and is in the Agreste mesoregion of the state of Paraíba (Northeast of Brazil), microregion of Itabaiana, with a population of approximately 13,300 inhabitants (Instituto Brasileiro de Geografia e Estatística [IBGE], 2020), 110 km away from João Pessoa, the capital city of the state. Mogeiro's climate is hot and humid tropical (Koppen: *As*), according to Francisco and Santos (2017).

Data collection was carried out between June and September 2019, from ten *L. vannamei* shrimp ponds (area: 0.25-0.50 ha; densities: 50-80 animals m^{-3}) of 10 familiar producers (P1-P10), supplied with water from the Paraíba River (physicochemical characterization in Table 1; provided by a laboratory service provider), using post-larvae in the PL10 stage (approximately 10 d; obtained from commercial laboratories) to start the cultivation. The average temperature and the accumulated precipitation during the data collection period were 24.4°C and 40.7 mm, respectively (Figure 1). All ponds evaluated in the study are equipped with an aerator and commercial feed was used. Management prior to cultivation included liming, addition of sodium chloride and potassium chloride, depending on the producer. The maintenance of limnological conditions in the ponds was carried out using pumping programs that supply losses with evapotranspiration. The cultivation time varied between 77 and 98 days.

Water quality parameters of shrimp ponds were evaluated biweekly in triplicates according to recommendations of Boyd and Clay (2002). Biweekly measurement values were used to calculate average values and standard deviation during the cultivation cycle. The temperature measurements were carried out at the average depth, using a mercury thermometer with a resolution of 0.1°C. Salinity, pH, and dissolved oxygen were assessed using a refractometer, a portable digital pHmeter, and an oximeter, respectively. The Golterman, Clymo, and Ohnstad (1978) titulometric methods were used to measure alkalinity and water hardness. Nitrite and total ammonium concentrations were determined according to Mackereth, Heron, and Talling (1978) techniques.

Table 1. Physicochemical parameters of water (Paraíba River) used to supply shrimp ponds in Mogeiro, Agreste of Paraíba, Brazil.

Parameter	Unit	Value	Parameter	Unit	Value
pH	-	7.7	Iron	mg L^{-1}	0.0
Color (Pt-Co)	mg L^{-1}	0.0	Magnesium	mg L^{-1}	50.4
Turbidity	mg L^{-1}	0.0	Nitrate	mg L^{-1}	0.00
Alkalinity	mg $CaCO_3$ L^{-1}	60.0	Nitrite	mg L^{-1}	0.01
Total ammonium	mg L^{-1}	0.0	Potassium	mg L^{-1}	5.38
Calcium	mg L^{-1}	28.0	Redox Potential	mV	26
Chlorides	mg L^{-1}	178.5	Salinity	g L^{-1}	0.40
EC*	µS cm^{-1}	814	Sodium	mg L^{-1}	99.27
Density	mg L^{-1}	1.0	TDS**	mg L^{-1}	407
Hardness	mg $CaCO_3$ L^{-1}	280.0	Sulphates	mg L^{-1}	19.13

* EC = Electrical Conductivity; ** TDS = Total dissolved solids.

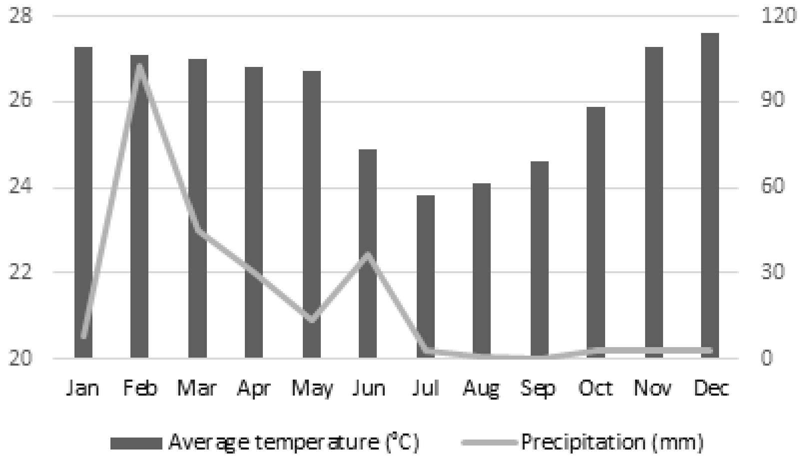

Figure 1. Average monthly temperature (°C) and precipitation (mm) for the year 2019 in the municipality of Mogeiro, Agreste of Paraíba, Brazil. The data collection period was from June to September.

Shrimps were evaluated for weight (average of 30 animals, caught with a fishing net, in triplicates) at 30-day intervals using semi-analytical balance, according to the following Equation 1:

$$\text{Average weight (g)} = \frac{\left(\frac{\text{P30R1}}{30}\right) + \left(\frac{\text{P30R2}}{30}\right) + \left(\frac{\text{P30R3}}{30}\right)}{3} \quad (1)$$

Where: P30 = weight of 30 animals from replicates 1 (R1), 2 (R2) and 3 (R3). The dynamics of weight gain was used to estimate the growth rate of shrimp. For this, the Equation 2 of weight (w) as a function of time (t) was used:

$$\text{w} = a\text{t} + b \quad (2)$$

Where the slope a was multiplied by 7 to obtain the growth rate in g $week^{-1}$. At the end of cultivation, the final average weight was measured, in addition to the survival of shrimp, production, and productivity of ponds, using the following Equations 3, 4 and 5:

$$\text{Survival (\%)} = \frac{\text{N}f \text{ x } 100}{\text{N}s} \quad (3)$$

Where: Nf = final number of post-larvae or adult shrimp; Ns = starting number of post-larvae.

$$\text{Production (kg)} = \text{final weighing of adult shrimp after harvesting} \quad (4)$$

$$\text{Productivity (kg ha}^{-1}\text{)} = \text{Production/Pond Area} \quad (5)$$

To assess the influence of cultivation time, pond area, pond density and water quality on parameters related to zootechnical performance (average weight, growth rate and survival of shrimps, production, and productivity of ponds), correlation analysis was performed. For this, the Shapiro-Wilk normality test was used. Correlations involving parameters with non-normal distribution were performed using the Spearman's coefficient, while those involving parameters with normal distribution were performed using Pearson's coefficient. Analyzes were performed using the PAST version 3.17 software (Hammer, Harper, & Ryan, 2001).

Results and discussion

The physicochemical analyzes of the water in the ponds during the cultivation of marine shrimp (Table 2) pointed out that most of the parameters showed normal results for use in shrimp farming, despite serious ionic imbalances in the water used to supply shrimp ponds (particularly sodium, potassium, calcium, magnesium, chlorides, and sulphates; Table 1) and management prior to cultivation is not guided by water analysis (with the exception of some producers who use their own instruments, such as oximeter and multiparameter).

Water temperature in the ponds varied between 24.20 (P4) and 25.67°C (P3), being below the recommended range for shrimp farming (28 to 32°C) according to Van Wyk and Scarpa (1999). Although average temperatures between 23 and 30°C are considered normal for tropical waters species by some authors (Tenório, Souza-Filho, Ramos, & Alves, 2015), this can be an important factor preventing greater productivity of the ponds, particularly in the winter period, when the present study was carried out (Figure 1). Results obtained by Bórquez-Lopez, Casillas-Hernández, López-Elías, Barraza-Guardado, and Martínez-Córdova (2018) show that a reduction in temperature from 30 to 26°C causes a reduction in food consumption of 11.56%. It has also been reported that growth rates are significantly reduced when temperatures drop below 26°C (Van Wyk, Davis-Hodgkins, Laramore, Main, & Scarpa, 1999). In the study carried out by Boyd and Clay (2002), the water temperature of the ponds varied between 23 and 32.5°C, being a major factor influencing shrimp growth. Possible solutions to this problem involve heating water, which would also result in higher production costs.

Table 2. Water analysis of shrimp ponds in Mogeiro, Agreste of Paraíba, Brazil.

Parameters	Mean	Standard Deviation	Minimum	Maximum
Temperature (°C)	25.00	0.42	24.20	25.67
pH	8.31	0.06	8.22	8.42
Salinity (g L^{-1})	2.61	0.17	2.33	2.83
Alkalinity (mg $CaCO_3$ L^{-1})	107.2	8.7	91.0	119.8
Dissolved oxygen (mg L^{-1})	5.63	0.17	5.38	5.84
Nitrite (mg L^{-1})	0.011	0.004	0.009	0.022
Total ammonium (mg L^{-1})	0.29	0.04	0.23	0.37
Hardness (mg $CaCO_3$ L^{-1})	294.9	23.0	257.5	342.4

The pH of the water ranged between 8.22 (P3) and 8.42 (P8). These values are within the range considered appropriate (6.5-9.0) for *L. vannamei* (Van Wyk & Scarpa, 1999; Carbajal-Hernández et al., 2017), however, they are above the optimal range (7.2-7.8) according to Van Wyk and Scarpa (1999). The pH is an important indicator of water environment affecting the life and survival of shrimp (Duan, Wang, Liu, Zhang, & Xiong, 2019), affecting many physiological functions (such as oxidative stress, immune suppression, and pathogen susceptibility) when at low or high levels (Han et al., 2018a; 2018b; Duan et al., 2019).

L. vannamei is considered one of the most suitable shrimp species for cultivation inland, due to its high tolerance to low salinity (Jayasankar et al., 2009). In the present study, salinity ranged from 2.33 (P2) to 2.83 g L^{-1} (P3), above the minimum required (0.5 g L^{-1}) for the cultivation of this species (Van Wyk & Scarpa, 1999). In an experiment conducted by Jaffer et al. (2020), using 100 L oval tanks, starting cultivation with juveniles, and using acclimatization scheme with initial salinity of 25 g L^{-1} (lowering by 0.5 g L^{-1}/2h; maximum rate of 5 g L^{-1} day^{-1} salinity change), *L. vannamei* growth and survival rates were not affected by salinities ranging from 1 to 25 g L^{-1}. According to these authors, if the acclimation process is followed properly, the species has excellent potential in inland waters at salinity as low as 1 g L^{-1}. On the other hand, Cavalheiro et al. (2016) verified a 40 % superiority in the daily weight gain of the shrimps grown in the Cariri region of Paraíba, using effluent from the desalination of a mineral water factory (~4.4 g L^{-1}), in comparison with the traditional cultivation carried out in the Paraíba River valley (~1.5 g L^{-1} salinity).

The lowest alkalinity observed was 91.0 (P1) and the highest was 119.8 mg $CaCO_3$ L^{-1} (P8), with most ponds (P2-P10) showing values above the recommended minimum alkalinity (100 mg $CaCO_3$ L^{-1}), whereas water hardness varied from 257.5 (P1) to 342.4 mg $CaCO_3$ L^{-1} (P10), with acceptable ranges ($\geqslant$ 150 mg $CaCO_3$ L^{-1}) according to Van Wyk and Scarpa (1999).

Dissolved oxygen varied between 5.38 (P8 and P10) and 5.84 mg L^{-1} (P4), above the minimum concentrations required (5.0 mg L^{-1}) to maintain acceptable shrimp survival, feed, and growth rates (Carbajal-Hernández et al., 2017). Decreased levels of dissolved oxygen caused by the deficiency of water quality and linked to the inadequate number of aerators, can lead the shrimp population to deep stress, leaving them subject to contamination by pathogenic microorganisms present in the water and sediments of the ponds (Associação Brasileira dos Criadores de Camarão [ABCC], 2005).

Nitrite concentration ranged from 0.009 (P7-P10) to 0.022 mg L^{-1} (P3), whereas the lowest total ammonium concentration was observed in P8 and P10 (0.23 mg L^{-1}) and the highest in P1 (0.37 mg L^{-1}). The concentration of both nitrogenous residues in the culture water was shown to be in accordance with the values recommended by Valencia-Castañeda et al (2018). These authors investigated the effects of nitrogen compounds toxicity on *L. vannamei* in low salinity waters, indicating that, for salinities 1 and 3 g L^{-1}, safe levels are up to 0.17 and 0.25 mg L^{-1} for nitrite, and 0.54 and 0.81 mg L^{-1} for total ammonia, respectively.

The average weight of the shrimp varied between 6.84 (P9) and 9.85 g (P1), with growth rates from 0.51 (P8 and P9) to 0.85 g $week^{-1}$ (P1), according to Table 3. Lower shrimp production was observed in P9 (460 kg), which also showed lower productivity (1150 kg ha^{-1}), while the highest production was in P1 (1280 kg), with the highest productivity (3200 kg ha^{-1}). The values of these productive parameters (except for ponds P8 and P9) were similar to those obtained by Cavalheiro et al. (2016) in Agreste of Paraíba, Brazil, also in a semi-intensive production system. Ponds with better productivity, particularly P1, showed growth rate and final weight of *L. vannamei* close to values in the biofloc technology culture system using artificially salinized freshwater (Pinto et al., 2020) and using seawater in an aquaponic system (Pinheiro et al., 2017). Shrimp survival ranged between 30.2 (P9) and 62.2% (P4), with values close to the average survival rates (44.83%) observed in oligohaline waters by Spanghero et al. (2008), but lower than the results previously obtained in Agreste of Paraíba (~85.5%) by Cavalheiro et al. (2016). These differences may be related to the lowest winter temperatures observed in the present study, as well as other water quality parameters, such as pH.

Table 3. Zootechnical performance and cultivation conditions of shrimp ponds in Mogeiro, Agreste of Paraíba, Brazil.

Zootechnical performance and cultivation conditions	Mean	Standard Deviation	Minimum	Maximum
Average weight (g)	8.84	0.97	6.84	9.85
Growth rate (g $week^{-1}$)	0.70	0.11	0.51	0.85
Survival (%)	48.8	10.5	30.2	62.2
Production (kg)	838	249	460	1,280
Productivity (kg ha^{-1})	2,513	665	1,150	3,200
Cultivation Time (d)	89	8	77	98
Density (shrimp m^{-2})	64	12	50	80
Pond area (ha)	0.34	0.07	0.25	0.50

As shown in Table 4, there was a positive correlation between total ammonia with shrimp growth rate (ρ = 0.69859) and pond production (ρ = 0.66362). Total ammonium is found in the ponds water as a product of the metabolism of the shrimp and by decomposition of organic matter, such as unconsumed food and feces (Maia, Gálvez, & Silva, 2011; Chang, Chiang, Cheng, & Chang, 2015). While optimal ammonia levels are a good source of nitrogen for marine phytoplankton that increases the level of dissolved oxygen in water and serves as food for shrimp, high levels of ammonia are harmful to shrimp (Zhao et al., 2020), causing large detrimental effects, such as increasing the sensitivity to pathogens and molting frequency, decreasing osmoregulatory capacity, as well as affecting animal growth and survival (Lu et al., 2016; Qiu et al., 2018). Since the ammonia concentrations observed in the present study were within the acceptable range for shrimp cultivation, not reaching toxic levels that compromise productivity, it is possible that the positive correlations between total ammonia and some parameters of zootechnical performance are associated with a better food availability and it is also possible that a higher concentration of ammonia is a consequence of the higher growth rates of the shrimp, resulting in a greater release of this residue in the aquatic environment.

There was also a positive correlation of cultivation time with shrimp weight (ρ = 0.75305) and pond productivity (ρ = 0.74763), suggesting that a longer cultivation time could be employed by some producers, to obtain a greater final biomass of the shrimp and, consequently, greater production and productivity in the ponds. Producer 9, for example, who adopted the shortest cultivation time (77 days), obtained the shrimp with the lowest weight and the ponds with the lowest production and productivity. However, producers who adopted a cultivation time longer than 90 days obtained shrimp with a final average weight greater than 9.0 grams. Ruiz-Velazco, Estrada-Pérez, Hernandez-Llamas, Nieto-Navarro, and Peña-Messina (2013), employing stock models and multivariate analysis to predict shrimp production in commercial semi-intensive conditions, demonstrated that higher final shrimp weight was obtained when the duration of cultivation, as well as the temperature, increased. The density of ponds was also positively correlated with average weight of the shrimp (ρ = 0.68993) and productivity (ρ = 0.79367), which may be related to the type of commercial feed offered, since those used for high-density cultivation have a higher percentage of proteins.

Table 4. Correlations between water analysis parameters, pond area, cultivation time, pond density (first column) and zootechnical performance parameters (average weight, growth rate and survival of shrimps, production, and productivity of ponds) of Mogeiro, Agreste of Paraíba, Brazil.

	Average Weight**	Growth rate**	Survival	Production	Productivity
Temperature	0.40492	0.19310	-0.16716	-0.04118	0.22820
pH	-0.58537	-0.29574	-0.73238*	-0.68696*	-0.53421
Salinity	-0.02147	-0.34505	-0.00941	-0.34893	-0.11488
Dissolved Oxygen	-0.09756	0.16990	-0.03144	0.19555	-0.14989
Alkalinity	-0.26140	-0.40777	-0.12795	-0.66162*	-0.22580
Hardness	-0.12158	-0.26348	0.10773	-0.45219	0.02044
Total ammonium	0.52310	0.69859*	0.17224	0.66362*	0.45477
Nitrite**	0.46862	0.42438	0.48775	0.45766	0.18434
Pond area	-0.37657	-0.21979	0.11922	0.42013	-0.36165
Cultivation time	0.75305*	0.53800	0.25903	0.24757	0.74763*
Pond Density	0.68993*	0.61489	0.35950	0.29089	0.79367*

* Significant correlations ($p \leq 0.05$). ** Correlations are according to Spearman's coefficient. Other correlations (parameters with normal distribution) are according to Pearson's coefficient.

The water pH was negatively correlated with the shrimp survival (ρ = -0.73238) and pond production (ρ = -0.68696). These results confirm that the pH range (despite being short) observed in the present study is above the optimal values for the cultivation of *L. vannamei* and are in line with those observed by Han et al. (2018a), who observed that *L. vannamei* exhibited a moderate tolerance to gradual-low pH (6.65-8.20), compared to a gradual-high pH (8.20-9.81) during a 28-d experiment. Variations in pH, which result from photosynthetic and respiratory processes, can be minimized by maintaining adequate water buffering capacity, using certain compounds (buffers), capable of releasing hydrogen ions in water at high pH levels and removing hydrogen ions of water at low pH levels (Van Wyk & Scarpa, 1999).

Alkalinity was also negatively correlated with the pond production (ρ = -0.66162). These results are contrary to expectations, since according to Van Wyk and Scarpa (1999) alkalinity of water should be maintained above 100 mg $CaCO_3$ L^{-1} to minimize pH fluctuations and to provide a source of bicarbonate ions for the nitrifying bacteria. A possible explanation for this result may be related to the pH range observed in the ponds, since a higher alkalinity implies a higher concentration of exchangeable bases neutralizing acids released into the water, thus, the pH will tend to remain above the optimum levels. Furthermore, lower alkalinity can have indirect impacts on the primary productivity or growth of phytoplankton, since it can decrease the bioavailability of certain nutrients for primary producers and, consequently, for shrimp (Wurts, 2002).

Conclusion

Most of the evaluated parameters related to water quality showed normal results for use in shrimp farming. However, better control of temperature (particularly in winter), pH and alkalinity is needed. Ammonia levels were normal and correlated positively with shrimp growth rate and pond production, however, pH was negatively correlated with shrimp survival and pond production, while alkalinity was negatively correlated with production. Cultivation time and pond density were positively correlated with shrimp weight and pond productivity, indicating that a longer duration of cultivation and use of higher density (with hydrological monitoring and management of ponds) by some producers may contribute to greater productivity in the cultivation system.

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