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Analyze of production performance of vaname shrimp *Litopenaeus vannamei* culture and water quality on earthen pond and HDPE-lined pond

Analisis kinerja produksi budidaya udang *Litopenaeus vannamei* secara intensif dan kualitas air pada tambak tanah dan tambak berlapis HDPE

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ABSTRACT

Litopenaeus vannamei is a leading aquaculture commodity with high economic value. Efforts to enhance the production of *L. vannamei* shrimp can be achieved by selecting the type of pond. Culture ponds are crucial in controlling water quality and managing culture waste. Based on these conditions, selecting the appropriate type of pond is essential to improve the production performance of *L. vannamei* shrimp. This study aimed to analyze the effects of earthen ponds and high density polyethylene (HDPE)-lined ponds on production performance and water quality factors, identify key water quality parameters influencing shrimp yield, and conduct an economic analysis. This study was conducted with two types of ponds, earthen ponds and HDPE-lined ponds. Water quality factors were analyzed weekly using a composite sampling method. Meanwhile, shrimp weight sampling was conducted weekly after 35 days of culture using 30 shrimp for each pond. The results showed that shrimp production performance in HDPE-lined ponds was significantly higher than in earthen ponds. This enhanced production performance was attributed to the more optimal water quality parameters in HDPE-lined ponds, particularly the lower abundance of Cyanophyta. Furthermore, the soil quality in earthen ponds also reduces shrimp survival rates, leading to decreased pond productivity. Although the production costs for HDPE-lined ponds were 17.54% higher than earthen ponds, this investment increases farmers' total revenue by 57.20%. HDPE ponds produce high production performance and healthier water quality, thereby increasing farmers' income and proving economically viable.

Keywords: economic, growth, pond type, soil

ABSTRAK

Litopenaeus vannamei merupakan salah satu komoditas unggulan perikanan budidaya yang memiliki nilai ekonomis tinggi. Upaya untuk meningkatkan produksi udang *L. vannamei* dapat dilakukan dengan memilih jenis tambak. Tambak budidaya sangat penting dalam mengontrol kualitas air dan mengelola limbah budidaya. Berdasarkan kondisi tersebut, pemilihan jenis tambak yang tepat sangat penting untuk meningkatkan performa produksi udang *L. vannamei*. Penelitian ini bertujuan untuk menganalisis pengaruh tambak tanah dan tambak berlapis *high density polyethylene* (HDPE) terhadap kinerja produksi dan faktor kualitas air, mengidentifikasi parameter kualitas air utama yang mempengaruhi hasil panen udang, dan melakukan analisis ekonomi. Penelitian ini dilakukan dengan dua jenis tambak, yaitu tambak tanah dan tambak berlapis HDPE. Faktor kualitas air dianalisis setiap minggu dengan menggunakan metode pengambilan sampel komposit. Sementara itu, pengambilan sampel berat udang dilakukan setiap minggu setelah 35 hari budidaya dengan menggunakan 30 ekor udang untuk setiap tambak. Hasil penelitian menunjukkan bahwa kinerja produksi udang ditambak HDPE lebih tinggi dibandingkan tambak tanah. Tingginya kinerja produksi udang ini dikarenakan tambak HDPE memiliki parameter kualitas air yang lebih optimal dibandingkan dengan tambak tanah, terutama pada kelimpahan Cyanophyta yang lebih rendah. Selain itu, kualitas tanah di tambak tanah juga menurunkan tingkat kelangsungan hidup udang sehingga mengakibatkan rendahnya produktivitas tambak tanah. Meskipun biaya produksi untuk tambak yang dilapisi HDPE 17.54% lebih tinggi dibandingkan tambak tanah, namun biaya investasi ini dapat meningkatkan total pendapatan petambak sebesar 57.20%. Tambak HDPE menghasilkan kinerja produksi yang tinggi dan kualitas air yang lebih optimal, sehingga meningkatkan pendapatan petani dan terbukti layak secara ekonomi.

Kata kunci: ekonomi, pertumbuhan, tanah, tipe tambak

INTRODUCTION

Litopenaeus vannamei, commonly known as white-leg shrimp, is one of the most widely cultivated aquaculture commodities worldwide (Kamilia *et al.,* 2021). The *L. vannamei* shrimp has several advantages, such as tolerance for a wide range of salinity and temperature conditions (Landsman *et al.,* 2019), high survival rates (Lyu *et al.,* 2021), and suitability for high-density farming (Suwoyo & Hendrajat, 2021). In 2020, global production of *L. vannamei* reached 5.8 million tons, accounting for approximately 51.7% of total shrimp production (FAO, 2010). This volume is expected to rise due to increasing demand driven by population growth, rising incomes, and changing lifestyles of consumers (Lee *et al.,* 2021; Asmild *et al.,* 2024). These factors have encouraged the enhancement of shrimp production across various countries, including Indonesia.

In Indonesia, shrimp production is targeted to reach 2 million tons by 2024 (Suhana *et al.,* 2023). Therefore, effective management practice is necessary to ensure the success of this enhancement, one of which involves selecting the appropriate pond types. Ponds are vital in controlling water quality and managing waste from farming (Kilawati *et al.,* 2022). In Indonesia, shrimp farming predominantly uses two types of ponds, earthen ponds and HDPE-lined ponds (Ulumuddin *et al.,* 2018). Earthen ponds are generally more economical to construct and have less operational complexity (Satanwat *et al.,* 2023a; Nurussalam *et al.,* 2024).

Earthen ponds can support natural processes such as decomposition, mineral ions, and nutrient provision through soil interaction (Satanwat *et al.,* 2023b). The soil at the bottom of the pond also acts as a buffer to prevent drastic changes in water pH (Supriyono *et al.,* 2022). However, earthen ponds are prone to leaks and erosion of the pond walls (Saengrungruang & Boyd, 2014). Waste disposal in earthen ponds is also challenging, as the soil tends to be carried along with the wastewater when discharged. This process also increases water turbidity due to sediment stirring at the pond's bottom. Shrimp farming in earthen ponds is also highly dependent on soil and water quality, which can elevate the risk of crop failures (Hendrajat *et al.,* 2018).

Studies have reported that shrimp production performance tends to decline in earthen ponds as they age. Due to reduced soil quality from the accumulation of organic matter and the presence of toxic compounds like ammonia, nitrite and hydrogen sulfide (Mustafakamal *et al.,* 2017; Sahadevan & Sureshkumar, 2020). Shrimp farming in HDPE-lined ponds also has its benefits and drawbacks. A major economic benefit of HDPE ponds is their more stable harvests, which provide farmers with a predictable income stream (Astiyani *et al.,* 2020). HDPE-lined ponds facilitate waste management at the pond bottom. These ponds are constructed with a central drain system connected to a hose, allowing waste to be removed from anywhere on the pond's bottom (Saengrungruang & Boyd, 2014; Fatalattof *et al.,* 2022).

Increases in ammonia and nitrite concentrations are also easier to anticipate and control, maintaining a healthy pond environment that does not negatively affect shrimp survival. However, HDPE-lined ponds have higher construction costs due to the need for HDPE material depending on the size of the pond (Saraswathy *et al.,* 2022). HDPE completely covers the soil, preventing soil-water interaction (Satanwat *et al.,* 2023b). This results in a higher demand for supplementation of mineral ions in the water, as there is no natural supply from the soil (Boyd & Queiroz, 2014). The presence of ions is crucial in shrimp farming because ions are needed for the metabolism and growth of shrimp, bacteria, and phytoplankton (Oliveira *et al.,* 2022; Pigmentel *et al.,* 2025; Sim *et al.,* 2025).

Studies have been conducted on the differences between pond types in shrimp farming. The results show that water in HDPE-lined ponds has lower total Vibrio and metabolite levels than earthen ponds (Ulumuddin *et al.,* 2018; Saraswathy *et al.,* 2022). However, previous research has focused on the differences in water quality dynamics and shrimp growth in extensive ponds. A more comprehensive analysis of pond-type differences in intensive farming systems is needed to expand our understanding. Improving productivity in intensive aquaculture remains a major challenge, especially under conditions of high stocking density and heavy artificial feed input.

Recent reports indicate that many intensive shrimp farms are shifting from earthen ponds to HDPE-lined ponds. However, the effects of different pond types in intensive shrimp farming systems still need to be better understood. Until now, no research has specifically addressed the impact of pond type differences on water quality factors that could directly influence shrimp survival rate, which is a critical strategy for improving shrimp production yields. This study aimed to analyze the effect of earthen and HDPE-lined ponds on shrimp production performance and water quality factors, to identify the relationship between water quality parameters that directly influenced survival rate, along with an economic analysis comparing the two pond types in intensive shrimp farming systems.

MATERIALS AND METHODS

Study area

This research was carried out at PT. Indonusa Yudha Perwita (IYP), West Java Province, Indonesia. Water quality analysis was conducted at the PT. IYP Laboratory and Aquaculture Environment Laboratory, Department of Aquaculture, IPB University. This location was selected because the facility cultivates shrimp using earthen and HDPE ponds with an average pond area of 2,500 m^2. Soil quality was measured to determine the soil profile in the earthen ponds (Table 1).

Table 1. Soil profile of earthen ponds used for *Litopenaeus vannamei* shrimp farming for 91 days.

Pond	Chemical soil quality	
	S (ppm)	ORP
D7	4,900	-121
E11	12,500	-191
F12	1,800	-109

Experimental design

The study was conducted in three earthen ponds and three HDPE-lined ponds. All ponds were stocked with *L. vannamei* PL 10 at a density of 95/m^2.

Water and shrimp sampling

Water samples were collected using a composite sampling method, which involved mixed samples taken from the inlet, outlet, and other points in the morning (Mutea *et al.,* 2021). The measured water quality parameters can be seen in Table 2. Thirty shrimp samples were randomly taken from each pond using a net. The weight of the shrimp was measured using a digital scale. Shrimp sampling was conducted weekly, starting from the day of culture (DOC) 35 until the end of the rearing period (harvest). Mortality was examined every day.

Observation of phytoplankton

Phytoplankton sampling was conducted in each pond using a passive method (Kurniawinata *et al.,* 2021). Approximately 50L of pond water was filtered using a plankton net with a mesh size of 25 µm. The filtered water was put into a dark sample bottle, and then eight drops of Lugol were added to preserve the plankton. Phytoplankton observation and identification were identified under microscope with 100× and 400× magnification, and their cell densities were evaluated using a hemocytometer. The abundance of phytoplankton was calculated using the formula by Katmoko *et al.* (2021).

Counting the number of bacteria

The abundance of the bacterial populations was determined by the total plate count (TPC) method every seven days. Water from the shrimp

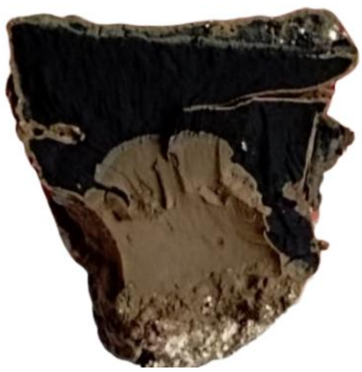

Figure 1. Soil of earthen ponds at the end of the rearing *Litopenaeus vannamei* shrimp farming for 91 days.

farming environment was diluted in a series and spread as much as 100 µL on culture media. Total vibrio count culture media used thiosulfate citrate bile salts sucrose (TCBS), while total bacterial count culture media used tryptone soya agar (TSA) with 2% NaCl added (Ariadi *et al.,* 2019). After incubated for 24 hours at a temperature of 28°C, the abundance of bacteria was calculated using the formula:

$$\frac{1}{\text{Dilution factor}} \times \frac{1}{\text{Sample volume}} \times \sum\text{colonies}$$

Production performance of shrimp

Productivity

Productivity is measured to determine the shrimp yield per hectare of the pond. Productivity was calculated using the formula by Akbar *et al.* (2020).

Survival rate (SR)

SR is the number of surviving shrimp at the end of the rearing period and is expressed as a percentage. SR was calculated using the formula by Kurniawinata *et al.* (2021).

Average daily growth (ADG)

ADG is the percentage of weight gain every day during the rearing period. The daily growth rate can be calculated using formula by Katmoko *et al.* (2021).

Feed conversion ratio (FCR)

FCR compares the feed given to produce 1 kg shrimp body live weight. FCR can be calculated using formula by NRC (2011).

Economic Analysis

The economic comparison between earthen ponds and HDPE ponds must be analyzed to determine which pond type is more feasible for development. The calculation of the operational cost structure and economic components such as investment costs (I), fixed costs (T), variable costs (V), total costs (TC), revenue (TR), and profits (P). The investment cost encompasses pond construction, HDPE lining, paddle wheels, and generators; fixed costs include pond preparation, electricity, labor, and depreciation; Variable costs include seeds, feed, vitamins and probiotics, agricultural supplies, and maintenance. The total costs represent the sum of fixed costs and variable costs. The economic analysis are undiscounted B/C ratio and incremental B/C ratio (Saraswathy *et al.,* 2022).

Undiscounted B/C ratio (UBCR)

UBCR is a ratio used in economic analysis to assess the feasibility of a project or investment. This ratio compares the project's profit or benefit to the costs incurred.

$$\text{UBCR} = \frac{\text{Profit}}{\text{Total costs}}$$

Table 2. Water quality parameter, measuring instruments, and measuring time of *Litopenaeus vannamei* shrimp farming for 91 days between earthen and HDPE ponds.

No	Parameter	Unit	Instuments/Method	Measuring time
1.	Temperature	°C	Thermometer	Daily
2.	pH	-	pH meter	Daily
3.	Salinity	psu	Refractometer	Daily
4.	Dissolved Oxygen (DO)	mg/L	DO meter	Daily
5.	Alkalinity	mg/L	Volumetric	Every 1 weeks
6.	Total Organic Matter (TOM)	mg/L	Volumetric	Every 1 weeks
7.	Hardness	mg/L	Volumetric	Every 1 weeks
8.	Biological Oxygen Demand (BOD)	mg/L	DO meter	Every 1 weeks
9.	Oxidation-Reduction Potential (ORP)	mV	ORP meter	Every 1 weeks
10.	Phosphate	mg/L	Ascorbic acid method	Every 1 weeks
11.	Nitrite	mg/L	Sulfanilamide method	Every 1 weeks
12.	Nitrate	mg/L	Brucine method	Every 1 weeks
13.	Total Ammonia Organic (TAN)	mg/L	Phenate method	Every 1 weeks
14.	Total Vibrio Count (TVC)	CFU/mL	Total Plate Count	Every 1 weeks
15.	Total Bacterial Count (TBC)	CFU/mL	Total Plate Count	Every 1 weeks
16.	Phytoplankton	Cell/mL	Microscope	Every 1 weeks

Interpretation of results is as follows, UBCR >1: the project is economically feasible because the total benefits generated exceed the costs incurred. UBCR=1, the project is at a break-even point where the total benefits generated equal the costs incurred, resulting in neither profit nor loss. UBCR <1, the project is considered not economically feasible as the total costs incurred are more significant than the total benefits generated, indicating that each unit of cost yields less than one benefit.

Incremental benefit-cost ratio (IBCR)

IBCR compares the additional benefits (incremental benefits) with the incremental costs of two or more alternative projects or investments. This ratio helps select the most efficient project or the one that provides the best-added value when there are several investment options.

$$\text{IBCR} = \frac{\text{Profit earthen pond} - \text{Profit HDPE pond}}{\text{Total costs earthen pond} - \text{Total costs HDPE pond}}$$

The calculation results can be grouped as follows, IBCR>1: Project B's additional benefits exceed the costs required. It means that Project B is more profitable than Project A. IBCR<1: The additional benefits of Project B are less than the additional costs required. It means that Project A is more profitable or efficient than Project B. IBCR = 1: Additional benefits equal additional costs. It means that both projects provide the same added value per unit of additional cost.

Analysis data

Data from each pond with a normal distribution were analyzed using a T-test. In contrast, data with a non-normal distribution were analyzed using the Mann-Whitney test to compare water quality factors. The results are expressed as the mean ± standard deviation (mean ± SD, n = 42), with a significance level of (P<0.05). Pearson correlation analysis is used to obtain relationships and patterns of connection between production performance and water quality. Data processing was carried out using R Studio version 4.3.1.

RESULTS AND DISCUSSION

Result

Effect of earthen and HDPE pond on the production performance

The results showed that the production performance of *L. vannamei* was significantly affected by the different pond types (Table 3). First, the productivity of HDPE ponds was significantly higher than that of earthen ponds (P<0.05). Second, the survival rate of HDPE ponds was significantly higher than that of earthen ponds (P<0.05). In contrast, the ADG, and FCR of earthen ponds were significantly higher than that of HDPE ponds (P<0.05). Overall, HDPE ponds resulted in the best production performance. HDPE ponds recorded 133% higher productivity and survival rate than earthen ponds. The FCR of HDPE ponds was 24% lower than that of earthen ponds.

Effect of different pond types on water quality parameters

There were significant differences (P<0.05) in water quality factors (temperature, pH, salinity, DO, alkalinity, hardness, TOM, nitrite, TBC, and phytoplankton) among the two ponds (Table 4). The temperature was higher in earthen ponds when compared to HDPE ponds. The pH was higher in earthen ponds when compared to HDPE ponds. The lowest salinity was observed in the earthen ponds (21.93 psu) compared to the HDPE ponds (25.07 psu). The lowest levels of DO were observed in the earthen ponds (4.56 mg/L) compared to the HDPE ponds (5.03 mg/L).

Mean hardness concentration was higher in HDPE ponds compared to earthen ponds. The TOM and nitrite were higher in HDPE ponds compared to earthen ponds. ORP was higher in earthen ponds when compared to HDPE ponds.

Table 3. Production performance (mean ±SD) of *Litopenaeus vannamei* shrimp farming for 91 days (one crop) between earthen and HDPE ponds.

Production performance	Earthen pond	HDPE pond
Productivity	3,929.31 ± 2,233.45	9,179.38 ± 611.37*
Survival Rate (SR)	27.32 ± 12.07	59.34 ± 10.6*
Average Daily Gain (ADG)	0.24 ± 0.02	0.14 ± 0.01*
Feed Conversion Ratio (FCR)	1.88 ± 0.21	1.43 ± 0.12*

Note: *Indicates the significance of difference (P<0.05) in earthen ponds compared to HDPE ponds.

The mean TBC was higher in HDPE ponds (14,228 CFU/mL) when compared to earthen ponds (8,923 CFU/mL).

Phytoplankton was higher in earthen ponds when compared to HDPE ponds. The phytoplankton abundance analysis identified four classes, Dinophyta, Cyanophyta, Bacillariophyta, and Chlorophyta (Figures 2 and 3). Chlorophyta dominated the phytoplankton abundance at the beginning of the rearing period in the earthen pond. However, as the rearing period increases (starting from day 56), the abundance of Cyanophyta is getting higher. In contrast, Chlorophyta dominated from the beginning of the rearing to the end of rearing in HDPE ponds.

The relationship between water quality factors and survival rate

The Pearson correlation test was conducted to analyze the relationship between each water quality parameter and shrimp survival rate. According to (Schober & Schwarte, 2018), correlation values can be categorized as follows, ±0.0–0.1 indicates negligible correlation, ±0.1–0.39 indicates a weak correlation, ±0.4–0.69 indicates a moderate correlation, ±0.7–0.89

Table 4. Comparison of water quality (mean ±SD) of *Litopenaeus vannamei* shrimp farming for 91 days between earthen and HDPE ponds.

Parameter	Earthen ponds	HDPE ponds	Tolerable range	
Temperature	28.86 ± 1.04 (26.2–30.5)	27.93 ± 1.02* (25.76–30)	25-32	(Ariadi *et al.,* 2023)
pH	8.21 ± 0.16 (7.85–8.55)	7.91 ± 0.21* (7.62–8.45)	7.5-8.5	(Venkateswarlu *et al.,* 2019)
Salinity	26.36 ± 2.15 (21.93–30.71)	29.34 ± 1.99* (25.07–32.3)	10-32	(SNI, 2014)
Dissolved Oxygen (DO)	5.25 ± 0.37 (4.56–6.07)	5.55 ± 0.32* (5.03–6.32)	>4	(Permen, 2016)
Alkalinity	177.11 ± 24.86 (130–232)	143.1 ± 21.66* (110–194.5)	<300	(Furtado *et al.,* 2015)
Total Organic Matter (TOM)	86.29 ± 13.12 (56.88–109.82)	102.92 ± 14.39* (61.28–124.75)	<90	(Permen, 2016)
Hardness	5,443.35 ± 868.73 (3,838.09–7,555.48)	6,070.29 ± 776.68* (4,645–7,548)	>1,000	(Venkateswarlu *et al.,* 2019)
Biological Oxygen Demand (BOD)	5.45 ± 1.99 (1–8.07)	5.59 ± 1.47 (1.77–7.36)	<10	(Hastuti *et al.,* 2023)
Oxidation-Reduction Potential (ORP)	235.52 ± 26.63 (187–289)	221.33 ± 33.89* (158–283)	>150	(Nghia *et al.,* 2021)
Phosphate	0.05 ± 0.02 (0.021–0.079)	0.05 ± 0.03 (0.01–0.13)	0.01 - 3	(Permen, 2016)
Nitrite	0.4 ± 0.26 (0.052–1.2)	0.72 ± 0.77* (0.1–3.08)	<1	(Satanwat *et al.,* 2023a)
Nitrate	0.43 ± 0.24 (0.158–0.874)	0.38 ± 0.22 (0.16–0.92)	0.1 – 4.5	(Mutea *et al.,* 2021)
Total Ammonia Organic (TAN)	0.55 ± 0.31 (0.07–1.33)	0.67 ± 0.63 (0.04–2.3)	<1	(Satanwat *et al.,* 2023a)
Total Vibrio Count (TVC)	860 ± 685 (0–2,550)	679 ± 530 (0–2,140)	$<10^3$	(Mutea *et al.,* 2021)
Total Bacterial Count (TBC)	8,923 ± 6,936 (2,400–33,000)	14,228 ± 11,844* (360–48,500)	$<10^6$	(Ariadi *et al.,* 2023)
Phytoplankton	748,729 ± 718,346 (161,111–4,244,444)	688,695 ± 8,888* (171,111–4,780,000)		

Note: Data correspond to the mean (n = 42) ± standard deviation (minimum – maximum). * Indicates the significance of difference (P<0.05) in earthen ponds compared to HDPE ponds.

indicates a strong correlation and ±0.9–1.00 indicates a very strong correlation. The Pearson correlation analysis for earthen ponds (Figure 4) showed no significant correlation between water quality and shrimp survival rate (P>0.05). Water quality exhibited only a weak correlation with shrimp survival, which may be attributed to two factors. First, water quality is not a singular factor affecting shrimp survival, as it interacts with other environmental parameters. Second, there may be other unmeasured factors in this study that significantly influence shrimp survival.

The Pearson correlation analysis for HDPE ponds (Figure 5) showed a significant correlation between water quality and shrimp survival rate. Salinity and hardness were positively correlated with SR (P<0.01; r>0.50), but TAN and nitrite were negatively correlated with SR (P<0.01; r>-0.50). The parameters salinity, hardness, total ammonia nitrogen (TAN), and nitrite exhibited a moderate correlation with the survival rate (SR).

Economic analysis

The cost calculation was conducted for the operational expenses of intensive *L. vannamei* shrimp farming over one year. The earthen ponds had lower total costs compared to HDPE ponds (Table 5). However, average production in earthen ponds was lower than in HDPE ponds, resulting in lower revenues (Table 6). HDPE ponds had a 17.54 % higher total cost than earthen ponds but increased 57.20% higher farmers' revenue than earthen ponds. Based on the economic analysis, earthen ponds had an undiscounted BCR of 0.89, while HDPE ponds had a BCR of 1.72 (Table 7). This result indicates that earthen ponds were not economically feasible, whereas HDPE ponds were economically feasible because the profits exceeded the total costs. The incremental BCR of HDPE ponds was 5.67, indicating that for each additional unit of cost incurred using HDPE ponds instead of earthen ponds, a benefit of 5.67 units was obtained.

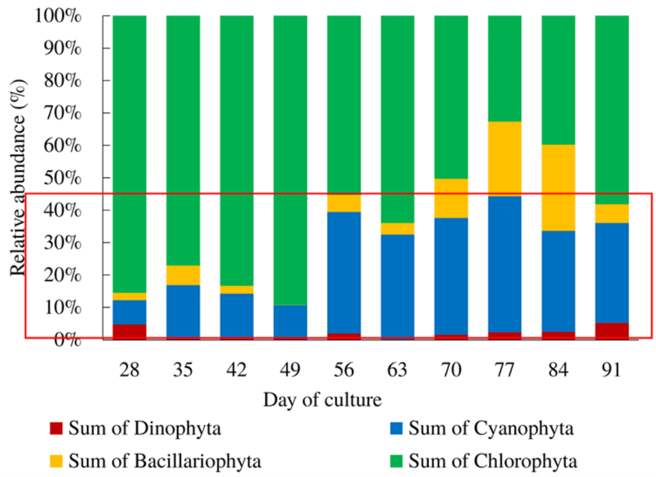

Figure 2. Phytoplankton abundance of *Litopenaeus vannamei* shrimp farming for 91 days in earthen ponds.

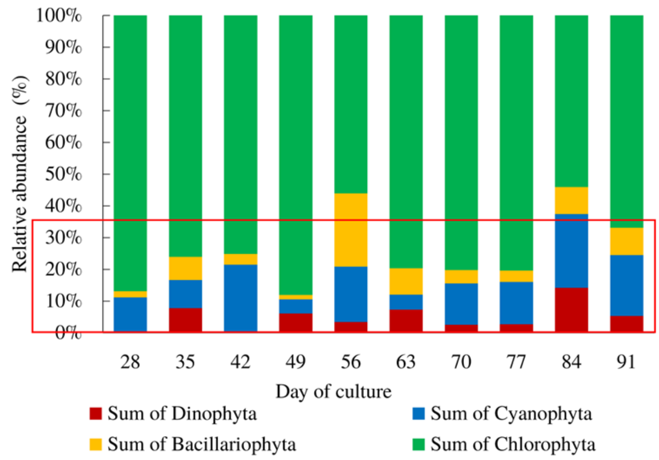

Figure 3. Phytoplankton abundance of *Litopenaeus vannamei* shrimp farming for 91 days in HDPE ponds.

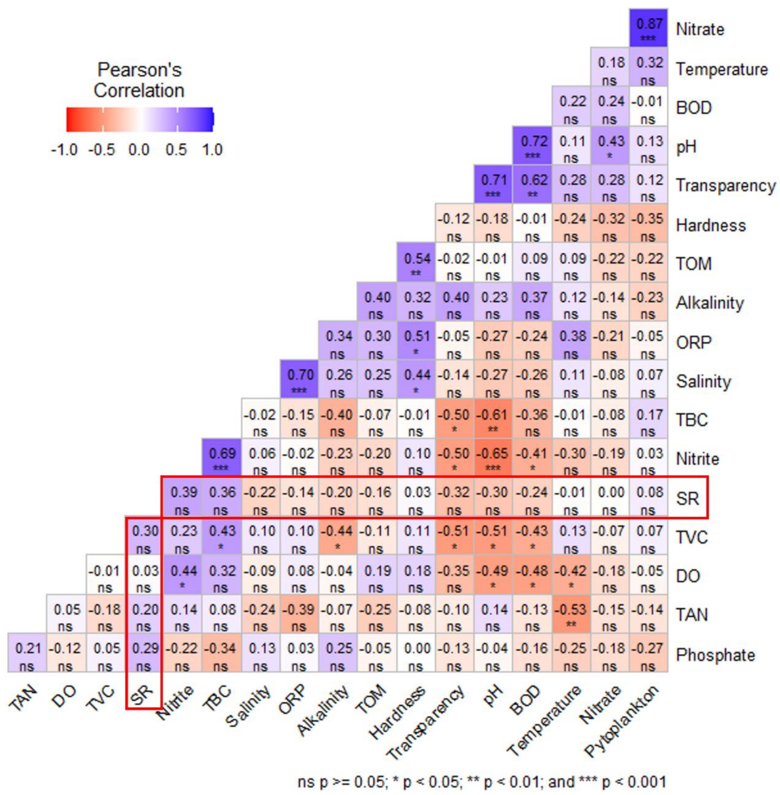

Figure 4. Pearson correlation between water quality factor and production performance of *Litopenaeus vannamei* shrimp farming for 91 days in earthen ponds. Description: DO = dissolved oxygen, TOM = total organic matter, BOD = biological oxygen demand, ORP = oxidation-reduction potential, TAN = total ammonia nitrogen, TVC = total vibrio count, TBC = total bacterial count, SR = survival rate.

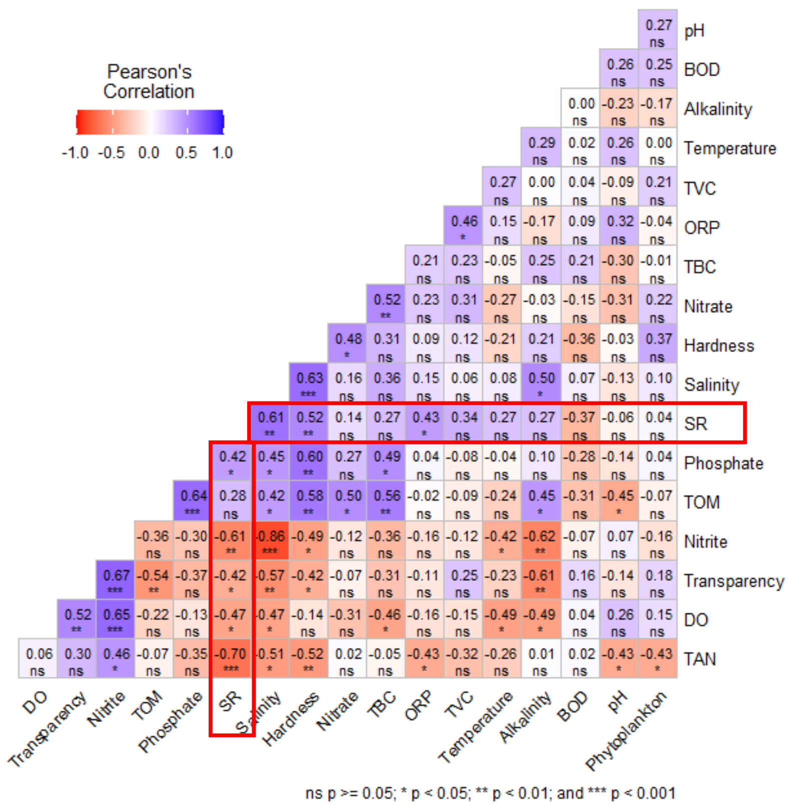

Figure 5. Correlation analysis between water quality factor and production performance of *Litopenaeus vannamei* shrimp farming for 91 days in HDPE ponds. Description: DO = dissolved oxygen, TOM = total organic matter, BOD = biological oxygen demand, ORP = oxidation-reduction potential, TAN = total ammonia nitrogen, TVC = total vibrio count, TBC = total bacterial count, SR = survival rate.

Discussion

Effect of earthen and HDPE pond on the production performance

The difference in pond types, whether earthen or HDPE-lined, significantly influenced production performance in this study. As shown in Table 3, HDPE-lined ponds demonstrated higher productivity, reaching 9.3 tons/ha, compared to 3.92 tons/ha in earthen ponds. Productivity in shrimp farming is closely related to the survival rate, where a higher survival rate results in a greater number of shrimp reaching harvest size. In HDPE-lined ponds, shrimp exhibited a higher survival rate, whereas the

Table 5. Operational cost structure of *Litopenaeus vannamei* shrimp farming for 91 days (one crop) between earthen and HDPE ponds.

Item	Earthen ponds	HDPE ponds
Investment cost (I)		
Pond	150,000,000 (9,685.54)	150,000,000 (9,685.54)
HDPE Liner	-	80,000,000 (5,165.62)
Paddlewheel	60,000,000 (3,874.22)	60,000,000 (3,874.22)
Generator	15,000,000 (968.55)	15,000,000 (968.55)
Fixed cost (T)		
Pond preparation	17,700,000 (1,142.89)	6,000,000 (387.42)
Electricity	51,613,270 (3,332.68)	51,613,270 (3,332.68)
Labor	31,748,572 (2,050.01)	31,748,572 (2,050.01)
Depreciation	8,580,000 (554.01)	12,530,000 (809.07)
Variable cost (V)		
Seed	23,750,000 (1,533.54)	23,750,000 (1,533.54)
Feed	60,389,274 (3,899.35)	97,713,898 (6,309.41)
Vitamin, Probiotic	16,000,000 (1,033.12)	5,138,000 (331.76)
Agricultural supplies	9,758,000 (630.08)	23,058,000 (1,488.86)
Maintenance	82,140,860 (5,303.86)	82,140,860 (5,303.86)
Total cost (TC)	526,679,976 (34,007.88)	638,692,600 (41,240.56)

Note: Average per hectare per year; (): US Dollar equivalent.

Table 6. Total production and total revenue of *Litopenaeus vannamei* shrimp farming for one year between earthen and HDPE ponds.

	Earthen ponds	HDPE ponds
Average Production (kg/ha/year)	7,858	18,358
Average Price (Rp)	60,000 (3.87)	60,000 (3.87)
Total Revenue (TR)	471,480,000 (30,443.60)	1,101,480,000 (71,122.88)

Note: Average per hectare per year; (): US Dollar equivalent.

Table 7. Economic analysis of *Litopenaeus vannamei* shrimp farming for one year between earthen and HDPE ponds.

Economic analysis	**Earthen ponds**	**HDPE ponds**
Total cost (TC)	526,679,976 (34,007.88)	638,692,600 (41,240.56)
Total revenue (TR)	471,480,000 (30,443.59)	1,101,480,000 (71,122.88)
Profit (P)	-55,199,976 (-3,564.28)	462,787,400 (29,882.31)
Undiscounted B/C ratio	0.89	1.72
Incremental B/C ratio		5.62

Note: Average per hectare per year; (): US Dollar equivalent.

shrimp cultured in earthen ponds had a notably low survival rate of only 27.32%. According to Suryadi & Merdekawati (2021), low productivity and survival rates in shrimp farming are generally attributed to disease outbreaks, which may explain the poorer performance observed in earthen ponds.

The FCR in earthen ponds was higher than in HDPE-lined ponds, reaching 1.88. This value exceeded the optimal limit for intensive shrimp farming, which is <1.5 as specified by SNI (2014). A high FCR indicates inefficient feed utilization, often resulting from reduced shrimp appetite (anorexia). Anorexia is a common clinical sign of stress caused by disease infection in shrimp. This finding aligns with Jithendran *et al.* (2021), who reported that shrimp ponds in India infected with Enterocytozoon hepatopenaei (EHP) exhibited clinical signs, including an elevated FCR of up to 2.2.

Disease is a major issue that can reduce production performance and lead to economic losses. The occurrence of disease in shrimp is influenced by the interaction between the host, pathogen, and environmental stressors (Snieszko, 1974). Among these factors, the environment plays a crucial role in supporting shrimp survival, as water quality directly affects their health and overall culture conditions (Amien *et al.,* 2022).

Effect of earthen and HDPE-lined pond on the water quality factor

The difference in pond substrates led to variations in water quality factors in the water column. This variation was strongly influenced by the interaction between soil sediments and water, whereas such interaction did not occur in HDPE ponds (Boyd & Queiroz, 2014). Based on the water quality measurements in Table 3, the concentration of water quality parameters in both types of ponds was generally similar, as they remained within the tolerance range for *Litopenaeus vannamei* farming, except for the parameters of total TOM, TAN and nitrite. Furthermore, there was a notable difference in the composition of phytoplankton abundance between the types of pond, with Cyanophyta exhibiting a significantly higher abundance in earthen ponds compared to HDPE-lined ponds.

Total organic matter (TOM) refers to the accumulation of organic content in water, originating from uneaten feed and shrimp waste. TOM in HDPE-lined ponds were higher than earthen ponds, and exceeded the tolerable limit for intensive shrimp culture, which is 90 mg/L (Permen, 2016). The high TOM levels in HDPE-lined ponds may be attributed to the accumulation of waste generated from culture inputs as the rearing period progresses. Additionally, the presence of the HDPE liner restricts interactions between soil and water, preventing the absorption of organic matter by the soil and consequently leading to elevated organic content in the water. In contrast, in earthen ponds, organic matter is absorbed and retained within the soil pores, resulting in lower TOM concentrations in the water.

According to Saraswathy *et al.* (2022), bacterial populations in soil typically range from 10^6-10^{12}, whereas in water, it range from 10^3-10^9. TOM levels below 100 mg/L are commonly found in shrimp ponds and are often maintained, particularly during the rainy season. During this period, water dilution may lead to a reduction in available nutrients for phytoplankton and bacteria, potentially causing cell lysis and disrupting the nutrient cycle balance in the pond ecosystem. This is in line with the finding of Yuspita *et al.* (2018), who stated that high TOM levels create favorable environmental conditions for bacterial proliferation, leading to an increase in bacterial abundance. In shrimp ponds, the presence of bacteria is crucial as they play a key role in the decomposition of organic matter.

TBC in HDPE-lined ponds accelerates the nitrification process. Nitrification involves two processes, namely organic matter decomposition and oxidation into ammonium and nitrite. Nitrite will be oxidized into nitrate as the final form (Supriyono *et al.,* 2021; Hastuti *et al.,* 2023). This process leads to increased concentrations of TAN and nitrite in HDPE-lined ponds. A significant portion of organic matter in earthen pond is absorbed into soil pores and accumulates at the pond bottom. This accumulation originates not only from the ongoing production cycle but also from previous cycles. Consequently, the pond bottom experiences a high nutrient loading (Cole *et al.,* 2018).

Nitrogen and phosphorus are essential nutrients required to promote phytoplankton growth. The ratio of nutrient load in aquatic environments plays a crucial roles in selectively shaping phytoplankton community composition (Campos *et al.,* 2021). The phytoplankton composition in earthen ponds differs from that in

HDPE-lined ponds, with earthen ponds exhibiting a higher abundance of cyanophyta (Figure 2 and 3). The higher abundance of cyanophyta was suspected due to low N:P ratio (Hoa & Nhi, 2020). In older earthen ponds, a deficiency of trace minerals often occurs, which can hinder bacterial decomposition of organic matter. As a result, nitrogen availability in the water column becomes limited, restricting the growth of most phytoplankton species. However, Cyanophyta possess an adaptive advantage due to the presence of heterocyst cells, which enable the cyanophyta to bind N from free air, allowing cyanophyta to proliferate more rapidly than other phytoplankton groups (Kurniawinata *et al.,* 2021). This condition support an environment that favors Cyanophyta growth, leading to their significant proliferation in earthen ponds.

Effect of water quality factors on survival rate

Changes in water quality parameters, including physical, chemical, and biological aspects, can influence the physiological processes of shrimp. Water quality parameters that exceed or below the tolerable limits can induce stress, increase susceptibility to diseases, and at certain concentrations directly cause mortality (Boyd, 2017)but more often, it stresses aquatic animals making them more susceptible to infectious diseases. The effort required for maintaining homeostasis by aquatic animals exposed to suboptimal water quality also diverts energy from growth. Survival and growth of aquatic animals in culture systems decline as the quality of water deteriorates. Most of the problems with water quality in aquaculture result from less than optimal quality of the water supply and fertilizer- and feed-waste effects on water quality.

The major water-quality stressors are suboptimal levels or concentrations of the following water temperature, salinity, and cation imbalance (usually site- or source water-related. Therefore, maintaining optimal water quality is crucial in shrimp farming, as it significantly affects shrimp growth and survival rate. In this study, the high concentrations of TAN and nitrite in HDPE-lined ponds exceeded the tolerable range for shrimp farming, potentially leading to a decline in water quality. However, despite the higher concentrations of TAN and nitrite in HDPE-lined ponds, their productivity remained higher than that of earthen ponds. This phenomenon may be attributed to the fact that water quality is not determined by a single factor.

Other water quality parameters were within optimal conditions, thereby mitigating the effects of elevated TAN and nitrite levels. This is in line with the findings of Ariadi *et al.* (2021), who stated that the water quality of an aquatic environment is determined by various interacting physical, chemical, and biological parameters that collectively influence the aquatic ecosystem. Interestingly, the overall water quality parameters in earthen ponds remain within the tolerance range that supports shrimp growth. Therefore, the measured water quality parameters are not the primary factors contributing to the low survival rate in earthen ponds. This finding is further supported by the results of Pearson correlation analysis, which indicate a weak correlation between water quality and shrimp survival rate. No water quality parameter was found to significantly influence the survival rate of shrimp in earthen ponds.

The abundance of phytoplankton in terms of quantity did not directly affect shrimp survival rates. However, this study revealed a notable difference in the relative composition of phytoplankton species. The relative abundance of *Cyanophyta* in earthen ponds was higher than in HDPE-lined ponds, and its abundance continued to increase as the rearing period progressed (Figure 2 and 3). *Cyanophyta* is a type of phytoplankton that produces toxins capable of attacking the hepatopancreatic tissue of shrimp, making it harmful and detrimental to shrimp farming. *Cyanophyta* contains *microcystins* at a concentration of approximately 45 µg/L (Smith *et al.,* 2008). These toxins function by damaging the structure and function of the hepatopancreas through enzyme inhibition, which triggers apoptosis.

Shrimp exposed to these toxins experienced metabolic stress, which ultimately led to mortality (Chen *et al.,* 2024). A study on the effects of *Cyanophyta* on shrimp mortality was conducted by Zimba *et al.* (2006), who detected *microcystin-LR* toxins at a concentration of 55 µg/g of total shrimp weight in the hepatopancreatic tissue of deceased shrimp. In contrast, shrimp from ponds without mortality showed no detectable levels of this toxin in their hepatopancreatic tissue. Another common issue in earthen ponds is the decline in soil quality, which is suspected to be a contributing factor to the low production performance of these ponds. Shrimp are benthic organisms that spend most of their time in the water-sediment interface zone; therefore, pond sediment conditions play a crucial role in maintaining their physiological balance.

Soil quality can be assessed using the oxidation-reduction potential (ORP) parameter, which reflects the oxidation or reduction level in the chemical system and identifies anaerobic conditions in pond soil. The ORP tolerance threshold for shrimp farming is +50 mV (SNI, 2006). In this study, the soil ORP values ranged from -191 to -109 mV (Table 1), which is classified as highly reduced according to ORP value categorization by Wiyoto *et al.* (2016). Highly reduced sediment indicates the presence of extensive anaerobic zones at the pond bottom. Additionally, sulfur (S) concentrations in earthen ponds were relatively high, with the highest recorded value reaching 12,500 ppm, leading to reduction processes. The black coloration of the sediment (Figure 1) indicates that sulfur has been reduced to hydrogen sulfide (H_2S).

H_2S is a toxic compound that can gradually cause shrimp mortality, particularly during nighttime, and is suspected to be another factor contributing to the low survival rate in earthen ponds. These findings align with the study by Tho *et al.* (2011), which reported that numerous shrimp farms in the Mekong region, Vietnam, went bankrupt following mass shrimp mortality at the end of 2008. The primary cause of this event was poor pond soil quality, with ORP values ranging from -105 to -422 mV and H_2S concentrations between 0 and 0.02 mg/L.

Economic Analysis of Earthen Ponds and HDPE Ponds

Shrimp farming is conducted in two cycles per year in both earthen and HDPE-lined ponds, with cost details shown in Table 5. HDPE ponds require a higher initial investment due to installing HDPE lining. Thus, the total cost of shrimp farming in these ponds is 17.54% higher compared to earthen ponds. However, HDPE ponds can increase harvest biomass, thereby increasing farmers' income by 57.20% annually. This outcome exceeds the findings of Saraswathy *et al.* (2022), who reported an 18% income increase due to an additional planting cycle per year.

Earthen pond requires only soil as the pond walls, resulting in lower investment costs. Additionally, the construction of earthen ponds utilizes simple technology, which contributes to the overall reduction in total production costs. However, in this study, earthen ponds demonstrated low productivity. The shrimp cultivated in these ponds exhibited a low survival rate, with only a small proportion reaching harvestable size. This condition negatively impacts farmers' income. The low Benefit-Cost Ratio (B/C ratio) of 0.89 indicates that shrimp farming in earthen ponds is not economically viable.

The incremental benefit-cost ratio (BCR) in this study was 5.67 for HDPE-lined ponds, indicating that the additional investment in HDPE ponds provides significantly higher economic benefits compared to earthen ponds. This high incremental BCR value demonstrates the economic feasibility of HDPE-lined ponds, with superior profitability despite requiring a higher initial investment. The increased profitability is likely attributed to improved water quality, higher shrimp survival rates, and greater productivity in HDPE ponds. These findings further reinforce the idea that adopting HDPE technology in shrimp farming is a highly beneficial long-term investment and contributing to the economic sustainability of farmers.

CONCLUSION

HDPE-lined ponds demonstrated higher production performance compared to earthen ponds due to their more optimal water quality, particularly indicated by the lower abundance of Cyanophyta. Cyanophyta is a potentially harmful phytoplankton species that produces toxins capable of reducing shrimp survival rates. Additionally, the low survival rate of shrimp in earthen ponds was also influenced by poor soil quality. Earthen pond with degraded soil quality is no longer economically viable. The use of HDPE-lined ponds can mitigate the negative effects of declining soil quality, thereby creating a more stable environment for shrimp growth. Although the production costs for intensive shrimp farming in HDPE-lined ponds were 17.54% higher than in earthen ponds, this investment was proven to increase farmers' total income by 57.20%. Thus, the adoption of HDPE-lined ponds not only enhances productivity but also contributes to the economic sustainability of shrimp farmers.

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