Prospects and challenges of vannamei shrimp farming in low salinity environments with SWOT analysis

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Abstract. The cultivation of vannamei shrimp (*Litopenaeus vannamei*) is becoming increasingly important in the global aquaculture industry, especially in low salinity environments. This article examines the prospects and challenges of vannamei shrimp farming under such conditions using a SWOT analysis. Vannamei shrimp are known for their ability to adapt to various salinity levels, which allows for farming in non-coastal areas. Although it offers many advantages, such as geographic expansion and reduced disease risk, challenges, such as the need for strict water quality management and osmoregulation risks, remain. Through a SWOT analysis, it shows that strengths and opportunities fall into the positive area (quadrant 1), which describes a favorable condition for following up or maintaining shrimp farming in low salinity environments.

Key Words: aquaculture, low salinity, non-coastal area, swot, vannamei.

Introduction. Shrimp farming, particularly the vannamei shrimp (*Litopenaeus vannamei*), is crucial for the aquaculture industry worldwide. The rapid growth of this industry is driven by the high demand for shrimp as a source of animal protein, which increases with population growth and changes in consumption patterns (Durai et al 2022). According to Pinoargote et al (2018), 87% of the shrimp exported come from aquaculture. This study looked at how survival and the bacterial community composition of the aquaculture water and gastrointestinal tract of vannamei shrimp exposed to probiotic treatments after an induced infection of acute hepatopancreatic necrosis disease were affected. This shows that besides improving food security, shrimp farming also boosts the economies of producing countries, such as India and China, which have seen significant increases in shrimp production and exports (Alam 2024).

This species is known as an euryhaline organism, which allows them to survive and grow in a wide range of salinities, from freshwater to seawater with high salinity (Ismail et al 2021). This advantage makes vannamei shrimp the primary choice for farmers in various locations, including areas with low salinity, which often face challenges in cultivating other, more sensitive species. In addition, the ability of vannamei shrimp to quickly adapt to environmental changes, as well as their high survival rate, makes them a highly profitable commodity in intensive farming (Zebua et al 2023). However, despite having many advantages, the cultivation of vannamei shrimp also faces challenges, such as the increased risk of disease in low salinity conditions and the need for stricter water quality management (López-Téllez et al 2019). Therefore, a deep understanding of salinity tolerance and effective environmental management is crucial to maximizing the production potential of vannamei shrimp in aquaculture.

Vannamei shrimp farming in low salinity waters offers several advantages, including geographic expansion to non-coastal areas and rural economic diversification. However, significant challenges arise regarding the physiology of shrimp in those conditions, particularly in terms of osmoregulation. Vannamei shrimp require higher concentrations of potassium ions (K^+) and magnesium ions (Mg^{2+}) to maintain ion balance in their bodies in low-salinity environments (Roy et al 2007). Research shows that under low salinity conditions, shrimp have difficulty maintaining osmotic homeostasis, which can affect their growth and survival (Kaligis 2015). Therefore, it is important to carefully manage water quality, including the addition of necessary minerals to support the normal physiological functions of shrimp (Wafi et al 2020). With the right approach, shrimp farming in low salinity environments can become a sustainable and profitable alternative, although it requires special attention to the physiological needs of shrimp in the context of osmoregulation (Yunarty et al 2022). In addition to this potential, intensive cultivation in low-salinity environments also poses environmental threats. For example, there is a risk of soil salinization around the ponds and the pollution of freshwater used for agriculture and community needs. Therefore, it is essential to develop effective and sustainable aquaculture management techniques (Flaherty et al 2000).

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis approach provides a useful framework for understanding the prospects and challenges of shrimp farming in low salinity. Through this analysis, we can identify the strengths, weaknesses, opportunities, and threats faced by aquaculture enterprises in the context of shrimp farming in low salinity environments.

Material and method. This study uses the literature review method (2000-2024) as the basis for SWOT analysis. Various scientific journals, books, and technical reports discussing shrimp farming, particularly in low salinity environments, provided the data for this research. We chose the literature review approach because it encompasses a wide range of previous research findings that have identified various technical and environmental aspects of shrimp farming.

Data sources. The information sources come from databases of various references, such as research journals, journal reviews, annual reports, books, and data related to shrimp farming in low salinity environments (land-based), studies on shrimp osmoregulation physiology, and research on the environmental impacts of shrimp ponds published from 2000-2024.

Result and Discussion. SWOT analysis plays an important role in the advancement of shrimp farming, especially in low salinity environments. This analytical framework allows stakeholders to systematically evaluate the internal strengths and weaknesses of their operations along with external opportunities and threats. In the context of shrimp farming, especially in areas constrained by seawater resources, a comprehensive SWOT analysis can help farmers make the right decisions to enhance sustainability and productivity.

The strength of shrimp farming in low salinity conditions includes the potential to increase the growth rate and survival of species such as vannamei shrimp, which has shown excellent performance in low salinity environments (Abdelrahman et al 2018). The opportunities for growth in low-salinity shrimp farming are abundant, especially with the increasing global demand for shrimp products. The potential to develop innovative agricultural systems that utilize low-salinity water sources can attract investment and enhance market competitiveness (Lap et al 2021).

However, this sector has weaknesses, including inadequate infrastructure and limited access to technology that can optimize cultivation practices. For example, the lack of an effective water management system can exacerbate the challenges posed by salinity fluctuations, resulting in decreased shrimp yields. Moreover, reliance on traditional farming methods without integrating modern aquaculture techniques can hinder productivity and sustainability (Paul & Vogl 2011).

Therefore, conducting a SWOT analysis in the context of low-salinity shrimp farming is very important to identify strategic pathways that can lead to more sustainable and profitable practices. By leveraging strengths, overcoming weaknesses, seizing opportunities, and mitigating threats, stakeholders can enhance the feasibility of shrimp farming in challenging environmental conditions.

According to Table 1, the SWOT analysis on vannamei shrimp farming highlights several important points. Vannamei shrimp are very good at adjusting to different environments. This is because they are raised in systems that keep them healthy, like biofloc and recirculating aquaculture systems (RAS). These systems also enhance productivity and water use efficiency, making them a sustainable solution in shrimp farming. This emphasizes that vannamei shrimp farming has significant advantages in terms of productivity, efficiency, and risk management. However, the system needs to address several weaknesses. The challenges of osmoregulation and increased nitrogen toxicity frequently arise, especially in intensive systems. Additionally, the soil's absorption of minerals can lead to a reduction in nutrient availability, which is compounded by the high operational costs associated with systems such as RAS. Nitrogen waste management also requires a more complex approach to minimize environmental impact. Therefore, despite the effectiveness of this system, we need more efficient waste management and cost strategies to ensure sustainability.

Table 1

Key factors in SWOT analysis evaluation

No	*Parameter*	*Factor*	*References*
1	Strengths	Adaptability of vannamei shrimp	Hu et al (2015); Huang et al (2019); Camacho-Jiménez et al (2021); Kim et al (2024)
		Land use efficiency	Flaherty et al (2000)
		Disease risk reduction	Rahi et al (2021)
		RAS system water use efficiency	Miranda et al (2008); Suantika et al (2018)
		Biofloc system increases productivity	Ray & Lots (2017); Kumar et al (2018); Uawisetwathana et al (2021)
2	Weaknesses	Osmoregulation challenge	Roy et al (2010)
		Increased nitrogen toxicity	Valencia-Castañeda et al (2019)
		Mineral absorption by soil	Roy et al (2010)
		High operational cost	Flaherty et al (2000); Samocha et al (2002)
		Nitrogen waste management is more difficult	Valencia-Castañeda et al (2019)
3	Opportunities	Potential new markets in rural areas	Kaligis (2015)
		Use of RAS and biofloc systems for water efficiency	Kaligis (2015); Pinto et al (2020)
		Reduced dependence on coastal areas	Hilyana et al (2023)
		Innovations in automated water quality monitoring technologies	Kusrini et al (2016)
		Feed supplement innovation and water modification	Suantika et al (2018)
4	Threats	Risk of salinization of land and water sources	Flaherty et al (2000); Szuster & Flaherty (2002)
		Reliance on mineral supplements	Saoud et al (2007); Chitra et al (2017)
		Environmental impact of farm effluents	Valencia-Castañeda et al (2019)
		Competition with coastal farms	Wurmann et al (2004)
		Price fluctuations of mineral supplements	McNevin et al (2004)

In terms of opportunities, there is potential to expand the market in rural areas, especially by utilizing efficient technologies such as RAS systems and biofloc, which allow for cultivation in areas with water limitations. A lower dependence on coastal areas also presents a significant opportunity, supported by technological innovations in water quality monitoring as well as feed development and water modification. This paves the way for the development of more innovative, productive, and sustainable shrimp farming in the future. However, effective management of threats is also essential. The risk of soil and water source salinization, resulting from cultivation activities and reliance on mineral supplements, can escalate costs and negatively impact the environment. Waste from poorly managed ponds can damage the surrounding ecosystem, while competition with coastal ponds and fluctuations in supplement prices pose significant economic challenges. Thus, environmental sustainability and economic stability are keys to addressing these threats.

SWOT parameters analysis

Strengths

Adaptability of vannamei shrimp. Vannamei shrimp have the ability to adapt to low salinity environments through complex osmoregulatory mechanisms involving gene regulation related to ion transport and energy metabolism. This result is important for the development of aquaculture in inland areas, allowing shrimp farming far from coastal regions with adjustable salinity (Hu et al 2015). Vannamei shrimp rely on certain genes that regulate the expression of proteins involved in ion transport, such as Na^+/K^+-ATPase. This enzyme plays a crucial role in maintaining ion balance by pumping sodium out of the cell and potassium into the cell, which is essential in low salinity conditions (Kim et al 2024). Research by Camacho-Jiménez et al (2021) also shows that changes in environmental parameters such as salinity can affect the expression of genes related to shrimp health, highlighting the importance of these mechanisms in adapting to osmotic stress (Camacho-Jiménez et al 2021). Research by Huang et al (2019) shows that shrimp can adapt to low salinity despite experiencing increased oxygen consumption and changes in lipid metabolism, indicating that they expend more energy to maintain osmotic balance.

According to Figure 1, the weight gain and condition factor of prawns cultivated at 3 ppt were lower than those cultivated at 30 ppt. Even though in Figure 1, the condition factor values are very close between salinities of 3 ppt and 30 ppt, they are statistically different ($p < 0.01$). Nonetheless, there were no significant variations in prawn survival rates and hepatosomatic indices between the two salinity groups.

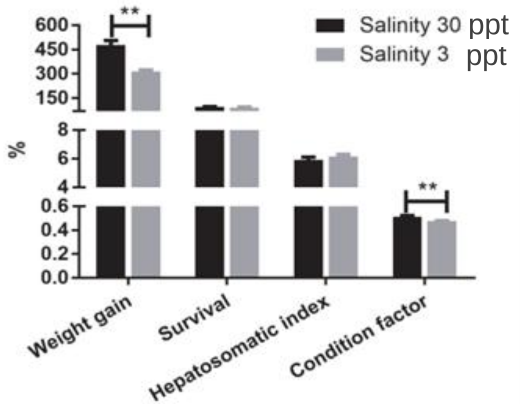

Figure 1. The weight gain (%), survival (%), hepatosomatic index (%), and condition factor (%) of *L. vannamei* at 30 and 3h salinity. Data are presented as the mean±SEM (n = 4). Two asterisks (**) indicate a highly significant difference ($p < 0.01$) between two salinities (source: Huang et al (2019)).

Land use efficiency. Cultivation in low salinity areas expands land use in inland regions, utilizing groundwater sources with low salt content, and the conversion of rice farming areas into shrimp farming ponds due to higher economic benefits (Flaherty et al 2000). The transition from rice farming to shrimp farming can provide higher economic benefits, especially in domestic and international markets. Vannamei shrimp are known to have a high market value, and the global demand for shrimp products continues to increase. By utilizing unproductive land, farmers can increase their crop yields and the profitability of their businesses.

Disease risk reduction. Previous research has shown that the white spot syndrome virus (WSSV), which is the cause of white spot disease, cannot spread efficiently in freshwater conditions because it does not thrive well in this environment. Therefore, shrimp farming in freshwater or low salinity can help minimize the risk of disease outbreaks that are detrimental to commercial shrimp farming (Rahi et al 2021). Considering that WSSV cannot thrive in freshwater, disease management strategies involving the maintenance of shrimp in low salinity conditions can help improve shrimp health and reduce economic losses due to disease outbreaks. This can also encourage innovation in aquaculture technology, such as the use of recirculating aquaculture systems (RAS) and biofloc, which can be more effective in maintaining water quality and shrimp health.

RAS system water use efficiency. The hybrid innovation of zero water discharge (ZWD) and RAS in the cultivation of vannamei shrimp in low salinity environments can enhance both water quality and productivity. This system successfully improved water usage efficiency, with a productivity of 2.7 kg m^{-3} and a survival rate of 78% at a density of 500 PL m^{-3} in the urban environment of Gresik, Indonesia (Suantika et al 2018). Additionally, according to the use of low-salinity shrimp pond wastewater, it can also be used for irrigating melon plants, yielding results comparable to freshwater irrigation. The efficient use of water reduces pH and increases the exchangeable sodium ratio (ESR) value in the soil, supporting sustainable agriculture in rural areas (Miranda et al 2008). Table 2 shows how RAS and the integration of aquaculture using low-salinity shrimp farming effluent can be used to improve water use efficiency and soil fertility with higher mineral content compared to irrigation water sources from rivers in rural or urban areas.

Table 2 displays the mean values of the soil chemical properties measured both before (time 0) and after crop cultivation (time 1). With the exception of Ca at the 0-0.2 m soil layer and K, Ca, and ECe at the 0.2-0.4 m layer, there were no appreciable variations between plots in terms of the soil chemical parameters measured prior to crop planting. These variations were thought to be intrinsic to soil spatial variability because irrigation had not yet been implemented. Following crop harvest (time 1), the soil irrigated with the effluent had significantly lower levels of Mg ($p < 0.05$) at the 0-0.2 m layer and significantly higher levels of Na ($p < 0.01$), organic matter ($p < 0.05$), ECe ($p < 0.01$), and ESR ($p < 0.05$) than the soil irrigated with river water. The Ca content in the 0-0.2 m soil layer was found to have significantly dropped when the effluent was utilized as the water source, as it was no longer different between the two treatments. There was no discernible difference between the two treatments at the 0.2-0.4 soil layer, where the Ca content rose in the river water treatment and fell in the effluent treatment.

In both treatments, ECe and ESR rose throughout the crop cycle in relation to soil salinity, primarily at the 0-0.2 m soil layer. ECe and ESR rose more in the river water treatment than in the effluent treatment at the 0.2-0.4 m soil layer. Table 2 displays the variations in the tracked soil chemical values for each treatment from time 0 to time 1. The soil layer between 0 and 0.2 meters showed the most notable alterations. Using both water sources, there were significant increases in P and K levels ($p < 0.05$), which were most likely brought on by fertilization above crop nutrient requirements.

In the 0-0.2 m soil layer, Ca, Mg, and pH levels dramatically ($p < 0.05$) dropped in the shrimp effluent treatment but not in the river water treatment. The levels of Na, ECe, and ESR rose significant ($p < 0.05$) for both treatments in the 0-0.2 m soil layer during the course of the crop cycle. The ESR level rose 50% more in the effluent treatment than in the river water treatment, in contrast to the Na and ECe levels, which grew similarly in both treatments. That resulted from the wastewater treatment's observed reductions in Ca and Mg. However, Pizarro (1978) asserts that even after the crop. When harvested, the soil could still be categorized as normal because it showed ESR < 7% and ECe < 2 dSm1, indicating that soil salinity had virtually no detrimental influence on crop output for either treatment.

Table 2

Soil chemical characteristics before (time 0) and after (time 1) melon cultivation using shrimp effluent low salinity (E) and river (R) as irrigation water source (adapted from Miranda et al (2008))

Depth (m)	*Time*	*Treatment*	*pH*	*P (mg dm⁻³)*	*S (mg dm⁻³)*	*K mmolc (mg dm⁻³)*	*Ca mmolc (mg dm⁻³)*	*Mg mmolc (mg dm⁻³)*	*Na mmolc (mg dm⁻³)*	*OM (g dm⁻³)*	*EC_e (dS m⁻¹)*	*ESR (%)*
0-0.2	0	E	6.6	52.3	8.0	2.5	123.7	81.1	4.9	10.2	0.6	2.1
		R	6.5	45.7	6.8	2.2	100.1	76.2	3.7	10.5	0.5	1.9
		(E-R)	0.1	6.6	1.2	0.3	23.6	4.9	1.2	-0.3	0.1	0.2
0-0.2	1	E	6.4	219.2	11.4	3.6	93.7	50.0	8.3	16.6	1.1	5.0
		R	6.4	251.6	13.9	3.1	99.6	68.9	7.2	15.5	0.9	3.8
		(E-R)	0.0	-32.4	-2.5	0.5	-5.9	-18.9	1.1	1.1	0.2	1.2
0.2-0.4	0	E	6.9	28.3	6.6	2.0	103.5	74.3	6.6	7.1	0.6	3.3
		R	6.8	28.0	4.5	1.6	90.1	63.6	4.4	6.9	0.3	2.6
		(E-R)	0.1	0.3	2.1	0.4	13.4	10.7	2.2	0.2	0.3	0.7
0.2-0.4	1	E	6.8	54.8	3.8	2.1	100.5	77.2	6.3	9.2	0.7	3.4
		R	6.8	59.4	7.1	1.9	97.5	68.2	5.9	9.8	0.7	3.2
		(E-R)	0.0	-4.6	-3.3	0.2	3.0	9.0	0.4	-0.6	0.0	0.2

Note: OM = organic matter; EC_e = electrical conductivity; ESR = exchangable sodium ratio.

Biofloc system increases productivity. Ray & Lotz (2017) tested for commercial-scale biofloc shrimp production at three different salinities (10, 20, and 30‰). The results of shrimp testing at low salinity (10‰) showed a reduction in salt use of up to 50%. This significant cost saving is a significant benefit to the production facility. This study shows that biofloc aquaculture systems are effective at various salinity levels for shrimp production, with no significant differences in growth or feed efficiency. However, operating at lower salinity (10‰) significantly reduces salt consumption, lowering production costs while maintaining comparable shrimp yields. This highlights the economic and environmental potential of low-salinity biofloc systems for sustainable inland shrimp aquaculture. Table 3 shows that biofloc improves water quality and reduces ammonia by decreasing harmful nitrogen, as well as enhancing the growth and survival of shrimp. The use of biofloc can lower the concentration of nitrate and nitrite, making shrimp farming more environmentally friendly (Kumar et al 2018). According to Uawisetwathana et al (2021), adding ex-situ biofloc to the feed boosts the weight and survival of shrimp in a zero-water discharge system with low salinity. Biofloc also improves water quality by reducing ammonium and nitrite and enhances the nutritional value of the shrimp.

Table 3

Water quality parameters during the 8 week shrimp production experiment

Parameter	*Treatment*		
	Low salinity	*Medium salinity*	*High salinity*
Temperature (°C)			
AM	29±0.0 (26.5-29.6)	29.1±0.0 (26.3-29.6)	28.8±0.1 (26.1-29.5)
PM	29.1±0.0 (27.6-30.1)	29.2±0.0 (27.7-30.0)	29.0±0.0 (27.5-30.0)
Dissolved oxygen (mg L^{-1})			
AM	8.6±0.1 (6.7-11.1)	8.7±0.1 (6.6-12.5)	8.9±0.1 (6.0-12.9)
PM	7.9±0.1 (5.8-10.8)	7.7±0.1 (5.2-10.0)	8.0±0.1 (4.5-15.0)
pH			
AM	7.9±0.0 (7.7-8.2)	7.8±0.0 (7.6-8.0)	7.7±0.0 (7.4-8.0)
PM	7.9±0.0 (7.1 8.3)	7.7±0.0 (7.4-8.2)	7.7±0.0 (7.3-8.1)
Salinity (‰)	10.3±0.0 (9.2-11.0)	20.2±0.0 (18.2-21.2)	30.2±0.0 (27.1-31.9)
Ammonia (mg TAN L^{-1})	0.8±0.2 (0.0-4.0)	1.2±0.4 (0.0-8.0)	0.7±0.3 (0.0-4.4)
Nitrite (mg NO_2-N L^{-1})	0.3±0.1 (0.0-3.4)	0.4±0.2 (0.0-3.5)	0.6±0.2 (0.0-3.3)
Nitrate (mg NO_3-N L^{-1})	1.4±1.0 (0.0-8.7)	0.3±0.2 (0.0-2.0)	0.6±0.3 (0.0-1.5)
Phosphate (mg PO_4 L^{-1})	2.4±0.3 (0.6-3.8)	2.6±0.3 (1.4-44)	2.0±0.2 (0.8-3.3)
Alkalinity (mg $CaCO_3$ L^{-1})	310±15 (207-442)	320±19 (200-509)	322±25 (205-500)
BOD_5 (mg L^{-1})	180±12 (72-243)	164±9 (87-211)	171±17 (65-238)
Chlorophyll-*a* (ug L^{-1})	80±16 (24-200)	85±18 (24-240)	84±16 (40-240)
TSS (mg L^{-1})	263±14 (185-500)	286±19 (175-510)	330±30 (210-645)
VSS (mg L^{-1})	198±14 (95-460)	189±20 (35-370)	191±24 (90-490)
Turbidity (NTU)	74±7 (49-211)	64±4 (35-126)	61±6 (41-127)
Settleable solids (mL L^{-1})	7±1 (3-18)	9±1 (4-21)	9±1 (4-21)

Data are presented as mean SEM (range) and different superscript letters in row indicate significant differences.
Source: Ray & Lotz (2017).

The levels of ammonia, nitrite, nitrate, and phosphate in the biofloc-supplemented treatments were lower than in the control (100%C) (Figure 2a-d). The concentrations of ammonia, nitrite, nitrate, and phosphate in 100%C significantly escalated during the culture duration, but those in 95%C+BF and 90%C+BF exhibited a small increase until week 4, followed by stabilisation. Ammonium concentrations in biofloc-supplemented groups were significantly reduced compared to the control group ($p < 0.05$) at week 4 (Figure 2a). Nitrite and nitrate levels in biofloc-supplemented groups were markedly reduced compared to the control group ($p < 0.05$) at week 5 (Figure 2b, c). The phosphate concentration in the biofloc-supplemented groups was considerably lower than that of the control group ($p < 0.05$) at week 2 (Figure 2d). The findings indicated that the microbial community in the ex-situ biofloc may contribute to the management and stabilisation of inorganic nitrogen and phosphate compounds in prawn cultivation.

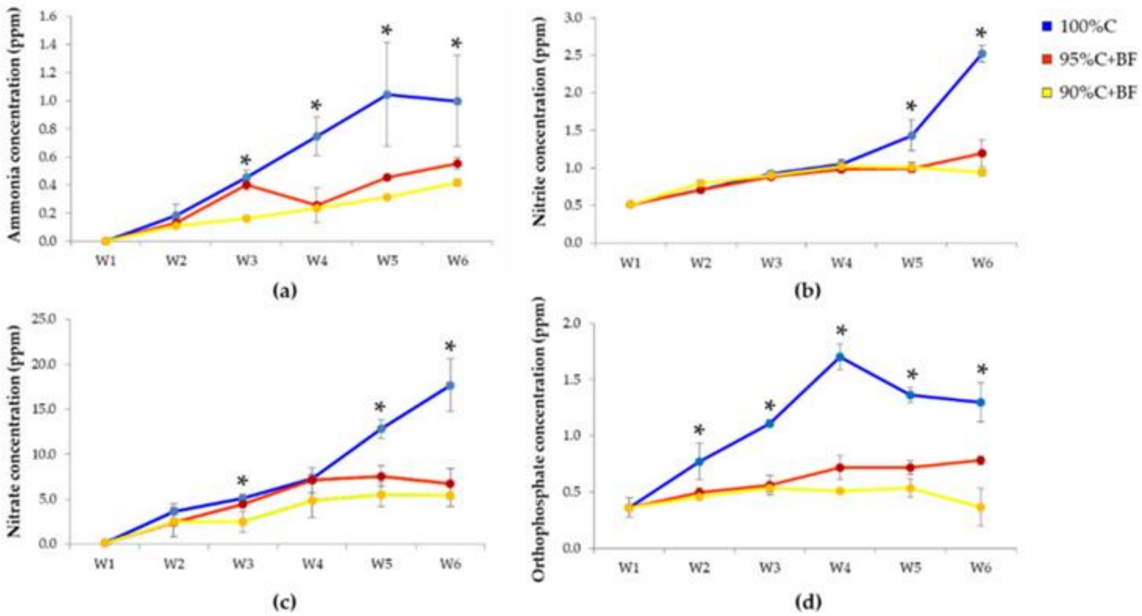

Figure 2. Concentrations of ammonia (a), nitrite (b), nitrate (c) and orthophosphate (d) concentrations during 6 weeks (W1-W6) of experiment using commercial pellet treatment without biofloc supplementation (100%C; blue), 5% (w/w) feed reduction supplemented with 0.3% (v/v) biofloc (95%C+BF; red) and 10% (w/w) feed reduction supplemented with 0.3% (v/v) biofloc (90%C+BF; yellow) (source: Uawisetwathana et al (2021)).

Weaknesses

Osmoregulation challenge. Shrimp need mineral supplements such as potassium and magnesium to maintain ion balance in low salinity water. The decrease in mineral levels can affect growth and survival (Roy et al 2010). Shrimp, as aquatic organisms, must maintain the proper ion balance to cope with the salinity differences between their bodies and the surrounding environment. Potassium (K^+) and magnesium (Mg^{2+}) are two ions that are crucial in the osmoregulation process. Potassium functions in maintaining the membrane potential of cells and supporting nerve function, while magnesium plays a role in activating various enzymes involved in energy metabolism. In low salinity conditions, shrimp tend to lose ions through the process of osmosis. To cope with this loss, they need to absorb ions from the environment or through their diet. If the levels of potassium and magnesium in the water are low, shrimp cannot maintain the necessary ion balance, which can lead to osmotic stress. This stress can disrupt physiological functions, reduce growth, and increase susceptibility to disease.

Increased nitrogen toxicity. Ammonia and nitrite become more toxic in low salinity conditions, which can threaten the survival of shrimp if water management is not properly conducted (Valencia-Castañeda et al 2019). Shrimp metabolism and leftover feed produce ammonia in two forms: free (NH_3) and NH_4^+. Under certain pH and salinity conditions, the proportion of free ammonia can become very toxic to shrimp. At low salinity, the proportion of free ammonia tends to increase, which can cause death in shrimp (Pariakan & Rahim 2021). Therefore, effective water quality management is essential to keep the concentration within safe limits. Free ammonia is highly toxic to shrimp, and under low salinity conditions, this proportion can increase. Research shows that increased levels of free ammonia can cause osmotic stress, disruption of physiological functions, and even death in shrimp. Therefore, it is important to monitor and manage ammonia levels in the water to ensure the health of the shrimp. Besides ammonia, nitrite is also a compound that is harmful to shrimp. Nitrite can interfere with the ability of shrimp to transport oxygen in the blood, which can lead to methemoglobinemia. In low salinity conditions, nitrite concentrations can increase, potentially causing toxicity.

Table 4 shows that well water has an average salinity of 3.70 ppt, while pond water has an average salinity of 2.56 ppt. Well water has higher concentrations of salinity, total alkalinity, chloride, calcium, and sodium ($p < 0.05$) and lower concentrations of sulfate ($p < 0.05$) than initial pond water. Well water and pond water do not differ in magnesium and potassium concentrations ($p > 0.05$). Carbonate precipitation, ion exchange between the substrate and water, and dilution from rainfall and runoff contribute to the compositional differences between well water and pond water. Meanwhile, the concentration of major ions in normal seawater diluted to 2.56 ppt has much higher values of potassium, magnesium, and sulfate compared to well and pond water. This indicates that the pond's substrate can absorb minerals such as potassium and magnesium, making the addition of these minerals to shrimp farming pond water ineffective.

Table 4

Concentrations of salinity, total alkalinity and major ions in well water used to supply ponds at an inland shrimp farm in Alabama and the concentrations of those variables in pond water at this farm in late April before potassium and magnesium salts were applied (adapted from McNevin et al (2004))

Variable	*Well water (n = 4)*	*Pond water (n = 5)*	*Seawater diluted to 2.56 g L^{-1} salinity*
Salinity (g L^{-1})	3.70±0.34[a]	2.56±0.51[b]	2.56
Total alkalinity (mg L^{-1} as $CaCO_3$)	272.6±30[a]	1 19.9±55.7[b]	10.52
Chloride (mg L^{-1})	1982±177[a]	1460±117[b]	1410
Sulfate (mg $^{L-1}$)	0.46±0.56[a]	33.8±18.7[b]	200
Calcium (mg L^{-1})	118.2±5.6[a]	59.8±5.1[b]	29.7
Magnesium (mg L^{-1})	5.46±0.92[a]	4.61±1.18[a]	100
Potassium (mg $^{L-1}$)	11.6 ± 1.8[a]	6.25±2.44[a]	27.4
Sodium (mg L^{-1})	1402±110[a]	971±208[b]	77.9

Values with different superscripts on the same row are significantly different ($p < 0.05$).

Table 5 presents data on the toxic concentrations of various nitrogen compounds (TAN, NO_2-N, NO_3-N) at various exposure durations (24, 48, 72, and 96 hours) against the tested organisms. The TU_{50} (Toxic Unit 50) equivalent concentration for TAN tends to decrease over time, going from 24.2 at 24 hours to 9.6 at 96 hours. The same applies to the concentrations of NO_2-N and NO_3-N, which also show a decreasing trend. LC_{50}, or the concentration that is lethal for 50% of the population, also decreases over time. For TAN, the initial LC_{50} value was 116.0 mg L^{-1} at 24 hours and decreased to 29.0 mg L^{-1} at 96 hours. A similar pattern occurred with NO_2-N, with the LC_{50} value decreasing from 58.5 to 10.6 mg L^{-1}, and NO_3-N from 4874 to 900 mg L^{-1}. This information shows that nitrogen compounds become more harmful over time, as shown by the fact that TU_{50} and LC_{50} values for TAN, NO_2-N, and NO_3-N go down.

Table 5

Equivalent concentration of TU50 of the mixture TAN/NO_2-N/NO_3-N and single LC_{50} of juveniles of *L. vannamei* exposed at a salinity of 3 g L^{-1} (adapted from Valencia-Castañeda et al (2019))

Time (h)	*TU_{50} equivalent concentration*				*LC_{50} single*		
	TU	*TAN*	*NO_2-N*	*NO_3-N*	*TAN*	*NO_2-N*	*NO_3-N*
24	2.5 (2.0, 3.1)	24.2	4.1	1125	116.0	58.5	4874
48	1.2 (1.1, 1.3)	11.3	1.9	351	44.6	15.4	2254
72	1.1 (1.0, 1.2)	10.0	1.8	336	39.6	12.4	1091
96	1.0 (0.9, 1.1)	9.6	1.6	297	29.0	10.6	900

Mineral absorption by soil. The pond's bottom soil can absorb minerals like potassium and magnesium, rendering the addition of these minerals to shrimp farming pond water ineffective. Several factors, including soil type, pH, and salinity, can influence the process of mineral absorption by the pond's bottom soil. Soil that is rich in organic matter or has a high cation exchange capacity tends to absorb more minerals, thereby reducing the amount of minerals available in the water. This causes the concentration of minerals in the water to decrease, making it insufficient to meet the physiological needs of shrimp. Research by Roy et al (2010) shows that to ensure optimal mineral availability, periodic reapplication of minerals is necessary.

High operational cost. The main constraint in shrimp farming in low salinity environments is the high costs associated with soil and water management to maintain ion balance. In this context, the addition of minerals such as potassium and magnesium becomes crucial to support the osmoregulation of shrimp. However, the cost of these additional minerals can be a significant burden for farmers. According to Flaherty et al (2000), in Thailand, the costs incurred for additional minerals significantly increase operational costs. Several factors, such as the need for periodic reapplication of minerals absorbed by the pond's bottom soil and the need for more intensive water quality monitoring and management, contribute to this.

The study by Samocha et al (2002) highlights the economic challenges faced in shrimp farming using high-intensity closed systems, especially in inland areas. One of the main issues identified is the high construction and operational costs, which can be a barrier to the sustainability of the system. In a closed system, water quality management becomes very important, especially in low salinity conditions where deficiencies of essential ions such as potassium and magnesium often occur. The addition of these minerals is necessary to support the osmoregulation of shrimp, but it also increases the operational cost burden. Limitations in resources and infrastructure in rural areas can exacerbate this situation, thereby increasing doubts about the financial viability of a closed system.

Nitrogen waste management is more difficult. A study by Valencia-Castañeda et al (2019) revealed that under low salinity water conditions, the toxicity of nitrogen compounds such as ammonia, nitrite, and nitrate increases, contributing to higher mortality rates in shrimp. This indicates that nitrogen waste management poses a significant challenge in shrimp farming in low salinity environments. The toxicity of nitrogen compounds can have detrimental effects on shrimp health, as the accumulation of ammonia and nitrite can disrupt physiological functions, including osmoregulation and oxygen transport. In low salinity conditions, the shrimp's ability to cope with osmotic stress becomes more difficult, thereby increasing their vulnerability to the toxic effects of nitrogen compounds. Therefore, effective nitrogen waste management is crucial in maintaining water quality and shrimp health. Practices such as regular water replacement, the use of biofloc systems, RAS, and the implementation of water quality monitoring technology can help reduce the accumulation of nitrogen compounds and improve the survival and productivity of shrimp.

Opportunities

Potential new markets in rural areas. Low salinity aquaculture opens up opportunities for shrimp farmers, providing flexibility for fish farmers to develop their businesses in more diverse land areas (Kaligis 2015). Moreover, with the increasing awareness of the importance of sustainability in farming practices, low-salinity shrimp farming can become an attractive alternative for farmers, especially in the context of climate change and environmental degradation where one of the advantages of vannamei shrimp is its ability to adapt to varying environmental salinity changes due to its efficient osmoregulation capability (Bückle et al 2006).

Use of RAS and biofloc systems for water efficiency. The opportunity of the RAS can be used for better water quality management by filtering and processing water sustainably. In low salinity shrimp farming, water quality becomes a critical factor that affects the health and growth of the shrimp. This system effectively monitors and manages parameters such as ammonia, nitrite, and dissolved oxygen, thereby reducing the risk of poisoning due to the accumulation of harmful compounds (Kaligis 2015). Additionally, the design of RAS significantly reduces water usage by recycling processed water. This is crucial in areas with limited water resources. Similarly, the biofloc system provides innovative solutions to improve water quality and reduce water usage in low salinity aquaculture (Pinto et al 2020). Three test treatments (T1, T2, and T3) and one control treatment (CT) were part of the experimental design. Various mixes of commercial (CS) and inexpensively made salt mixture (PS) at 20 g L^{-1} were tested: CT = 20:0, T1 = 10:10, T2 = 5:15, and T3 = 0:20 (CS g L^{-1}:PS g L^{-1}). The results show that the water quality and ion balance in all treatments remain suitable for the species. T1 produced the highest productivity, while T2 was more cost-effective. Conversely, T3 was not technically feasible for use. Nutritional composition analysis confirms that this model does not reduce the nutritional quality of the shrimp.

Table 6 shows how well vannamei shrimp farms did with four different artificial salinity treatments (CT, T1, T2, and T3). It shows things like the number of shrimp that survived, their average final weight, their growth rate, their yield, and their feed conversion ratio (FCR). In the CT (20:0) and T1 (10:10) treatments, the survival rates were very good with values of 81.7±1.8% and 82.0±2.9%, respectively, which were not significantly different. The T2 (5:15) treatment had a lower survival rate (56.0±7.9%), while T3 (0:20) showed the lowest survival rate (12.0±1.5%). The highest average final weight was achieved in the T2 treatment (12.8±0.3 g), followed by T1 (11.2±0.2 g) and CT (10.5± 0.3 g), while T3 showed the lowest value (4.3±0.4 g). The growth rate showed a similar pattern, with T2 recording the highest growth (1.3±0.0 g $week^{-1}$), followed by T1 (1.1± 0.0 g $week^{-1}$) and CT (1.0±0.0 g $week^{-1}$), while T3 was the lowest (0.4±0.0 g $week^{-1}$). The T1 (10:10) treatment provided the best overall results in terms of FCR, survival, mean final weight, growth rate, and production yield, making it the most viable option for shrimp farming with artificial salinity water. Treatment 3 (0:20) underperformed in all parameters and has the opposite performance to T1 (10:10).

Table 6

Litopenaus vannamei shrimp performance in a biofloc technology culture system for 63 days using freshwater artificially salinized from different salt mixture compositions (adapted from Pinto et al (2020))

Parameter	*CT*	*T1*	*T2*	*T3*
Survival (%)	81.7±1.8^a	82.0±2.9^a	56.0±7.9^b	12.0±1.5^c
Mean final weight (g)	10.5±0.3^b	11.2±0.2^b	12.8±0.3^a	4.3±0.4^c
Growth rate (g $week^{-1}$)	1.0±0.0^b	1.1±0.0^b	1.3±0.0^a	0.4±0.0^c
Yield (kg m^{-3})	2.2±0.0^b	2.4±0.1^a	1.8±0.2^c	0.2±0.0^d
Feed conversion rate	1.8±0.0^a	1.7±0.1^a	2.4±0.3^b	16.4±3.7^c

Reduced dependence on coastal areas. One of the main advantages of shrimp farming in low salinity is the ability of vannamei shrimp to thrive in such conditions. Vanname shrimp have euryhaline properties, allowing them to survive in a wide range of salinities, including freshwater (Hilyana et al 2023). By transitioning to land-based farming, farmers can mitigate the risk of pollution commonly found in coastal ponds, including pollution from domestic and agricultural waste, and the potential effects of climate change on water quality in coastal areas (Lestantun et al 2022). In addition, low salinity aquaculture can help maintain healthier coastal ecosystems while also increasing the productivity and sustainability of shrimp farming operations.

Innovations in automated water quality monitoring technologies. One promising approach is the use of Internet of Things (IoT) technology in water quality monitoring. IoT-based monitoring systems can reduce reliance on manual monitoring methods, which are often time-consuming and inefficient. With the Android-based application, farmers can monitor water quality from a distance, thereby saving time and resources (Kusrini et al 2016).

Feed supplement innovation and water modification. Innovation in mineral supplements in feed and the addition of minerals to aquaculture water is a strategic step to enhance the survival and growth of shrimp, especially in low salinity conditions. Research by Suantika et al (2018) shows that the addition of essential minerals such as potassium, magnesium, and calcium can help shrimp maintain ion balance and support the crucial osmoregulation process for their health. In low salinity environments, shrimp often experience osmotic stress due to the loss of essential ions. By providing mineral supplements in the feed, farmers can ensure that the shrimp receive the necessary nutrients to support their growth and immune system. Furthermore, the addition of minerals to the aquaculture water helps maintain optimal ion concentrations, which are crucial for the survival of shrimp. This innovation not only contributes to the improvement of shrimp health and growth but also has the potential to enhance overall production efficiency.

Threats

Risk of salinization of land and water sources. Salinization of land and water around shrimp farms can disrupt the local ecosystem, especially when wastewater is not properly managed (Braatan & Flaherty 2001). The transition to low-salinity shrimp farming in inland areas previously used for agriculture (such as rice) can cause agricultural land to lose its fertility due to salinization. This results in a long-term decline in agricultural yields, as reported in a study in Thailand (Flaherty et al 2000). The accumulation of salt in groundwater can reduce the quality of water typically used for irrigation or human consumption. Use of high salinity contaminated water in agriculture can impact crop yields and induce salinity stress in plants with lower salt tolerance (Szuster & Flaherty 2002).

Reliance on mineral supplements. The dependence on mineral supplementation, such as potassium, calcium, and magnesium, to address mineral deficiencies in low-salinity water in vannamei shrimp ponds has become a necessity. Mineral supplements can enhance the growth and survival of shrimp. This shows that mineral supplementation is effective in improving shrimp farming performance at low salinity, although it requires additional operational costs (Saoud et al 2007). According to Chitra et al (2017), the release of minerals from commercial mineral mixtures into low-salinity pond water, such as calcium, magnesium, and potassium, increases with salinity, indicating that proper management and monitoring of mineral supplementation are crucial in low-salinity shrimp farming (Chitra et al 2017).

Environmental impact of farm effluents. According to Valencia-Castañeda et al (2019), in low salinity environments, nitrogen compounds such as ammonia, nitrite, and nitrate are more toxic compared to high salinity environments. The accumulation of nitrogen in shrimp pond waste has the potential to increase environmental toxicity and threaten the survival of shrimp if not managed properly (Valencia-Castañeda et al 2019).

Competition with coastal farms. Shrimp farming in low salinity faces competition from production in coastal areas with naturally higher and more stable salinity to support productivity. Wurmann et al (2004) highlighted the fierce competition in the global shrimp market between coastal farms and inland farms. In Latin America, inland shrimp farms face challenges from more established coastal shrimp farms, particularly regarding access to export markets. This competition is intensifying along with the decline in global shrimp prices and the need to improve production efficiency and product quality.

Price fluctuations of mineral supplements. High dependence on the addition of minerals such as potassium and magnesium to maintain ion balance increases operational costs and risks if the supply of these minerals is disrupted. McNevin et al (2004) discussed how the use of mineral supplements in low-salinity ponds increases shrimp productivity but still requires careful cost management because reliance on these additional minerals can increase operational costs.

***SWOT analysis quadrant plot**.* Based on the SWOT analysis above, here is the interpretation of the results for each category.

Strengths (3.55). The main strength in shrimp farming at low salinity lies in the adaptability of vannamei shrimp to this environment. This adaptability allows the shrimp to grow well even in varying salinity conditions. In addition, the potential for geographical expansion provides opportunities for farmers to diversify land in inland areas, which were previously unused for shrimp farming. The reduction of marine disease risk is also a significant added value in this practice, as terrestrial environments tend to have a lower mortality risk compared to coastal ponds. This can improve the survival of shrimp and overall productivity.

Weaknesses (3.20). The main weakness in this cultivation is the additional mineral requirements such as potassium and magnesium needed to maintain ion balance. The availability of these minerals is crucial for the health and growth of shrimp, but it can significantly increase operational costs, and the rise in ammonia and nitrite toxicity in low salinity conditions requires careful management. This weakness highlights the need for effective management strategies to reduce the risks and costs associated with cultivation.

Opportunities (3.50). The opportunity for shrimp farming in low salinity is very promising. The large market potential in rural or urban areas provides opportunities for farmers to develop their businesses. The use of RAS can increase water use efficiency and reduce environmental impact, while reducing dependence on coastal aquaculture opens up new opportunities for diversification. Innovation in technology and cultivation practices can enhance competitiveness and productivity, making this sector more attractive to investors and farmers.

Threats (3.25). The most significant threats in shrimp farming at low salinity include land salinization and dependence on mineral supplements. Salinization can reduce soil fertility and affect shrimp growth. Furthermore, relying on mineral supplements can escalate operational expenses and introduce risk in the event of a disruption in the mineral supply. Environmental risks, such as pollution from poorly managed shrimp farms, are also a concern. Therefore, it is important to develop effective management strategies to address this threat and ensure the long-term sustainability of shrimp farming.

According to Table 7, the vannamei shrimp farming system in low salinity water exhibits several key strengths, achieving a total score of 3.55. The vannamei shrimp's adaptability (weighted score of 1.2) and land use efficiency (weighted score of 1.0) stand out as the strongest points. This system also demonstrates advantages in reducing disease risk, water use efficiency with the RAS system, and productivity improvement through the biofloc system. From the opportunity side, with a total score of 3.5, this system opens up new market potential in rural areas (weighted score of 1.2) and provides solutions for water use efficiency (weighted score of 0.75). Innovation in automatic water quality monitoring technology and the development of feed supplementation systems also present promising opportunities. However, this system also faces several weaknesses, as indicated by its overall score of 3.2. Osmoregulation challenges are the main weakness (weighted score of 1.2), followed by increased nitrogen toxicity and soil mineral absorption issues. We also need to address high operational costs and more complex nitrogen management. The main threats, with a total score of 3.25, include the risk of soil and water source salinization, which has a weighted score of 1.4, and the dependence on mineral supplements (weighted score of 0.75). We also need to anticipate the environmental impact of agricultural waste, competition with coastal agriculture, and fluctuations in mineral supplement prices.

Table 7

Weighting, rating, and scoring in SWOT analysis

Strengths	*Weight*	*Rating*	*Weighted score*	*Opportunities*	*Weight*	*Rating*	*Weighted score*
Adaptability of vannamei shrimp	0.3	4	1.2	Potential new markets in rural areas	0.3	4	1.2
Land use efficiency	0.25	4	1	Use of RAS systems for water efficiency	0.25	3	0.75
Disease risk reduction	0.2	3	0.6	Reduced dependence on coastal areas	0.2	4	0.8
RAS system water use efficiency	0.15	3	0.45	Innovations in automated water quality monitoring technologies	0.15	3	0.45
Biofloc system increases productivity	0.1	3	0.3	Feed supplement innovation and water modification	0.1	3	0.3
Total score for Strengths: 3.55				Total score for Opportunities: 3.5			
Weaknesses	*Weight*	*Rating*	*Weighted score*	*Threats*	*Weight*	*Rating*	*Weighted score*
Osmoregulation challenge	0.3	4	1.2	Risk of salinization of land and water sources	0.35	4	1.4
Increased nitrogen toxicity	0.25	3	0.75	Reliance on mineral supplements	0.25	3	0.75
Mineral absorption by soil	0.2	3	0.6	Environmental impact of farm effluents	0.2	3	0.6
High operational cost	0.15	3	0.45	Competition with coastal farms	0.1	3	0.3
Nitrogen waste management is more difficult	0.1	2	0.2	Price fluctuations of mineral supplements	0.1	2	0.2
Total score for Weaknesses: 3.2				Total score for Threats: 3.25			

The SWOT analysis plot in Figure 3 reveals that strengths and opportunities fall into the positive area (quadrant 1), indicating a good condition where there is a combination of strengths and opportunities. The strategy in this quadrant focuses on leveraging existing strengths to seize available opportunities. If a business or project is in this quadrant, it indicates a good condition and proactive development is needed to maximize its potential. The recommended strategies are: (1) further development of the business by utilizing technology and effective cultivation practices; (2) maximizing market opportunities by increasing production and efficiency; (3) utilizing internal resources to achieve greater potential in the low-salinity shrimp farming industry.

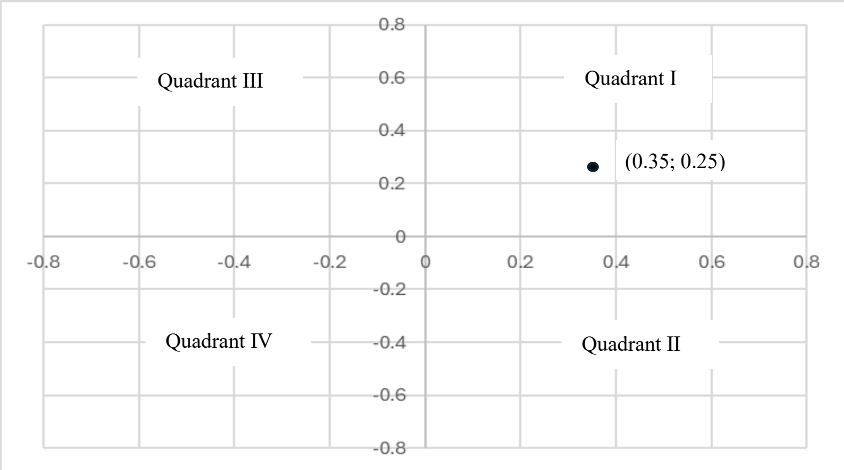

Figure 3. SWOT analysis quadrant plot.

Conclusions. Vannamei shrimp farming in low salinity environments offers significant potential for economic diversification and production increase. The adaptability of these shrimps, along with innovations in aquaculture technology such as recirculating aquaculture systems and biofloc, can enhance the efficiency and sustainability of the business. However, we must address the challenges of mineral requirements for osmoregulation and water quality management with appropriate strategies. With an effective management approach, shrimp farming in low salinity can become a sustainable and profitable alternative, providing a positive contribution to food security and the local economy.

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References

Abdelrahman H. A., Abebe A., Boyd C. E., 2018 Influence of variation in water temperature on survival, growth and yield of Pacific white shrimp *Litopenaeus vannamei* in inland ponds for low-salinity culture. Aquaculture Research 50(2):658-672.
Alam S. M., 2024 Portraying the Bangladesh shrimp industry: a SWOT analysis. Sustainability 16(3):1290.
Braatan R. O., Flaherty M., 2001 Salt balances of inland shrimp ponds in Thailand: implications for land and water salinization. Environmental Conservation 28(4):357-367.
Bückle L. F., Barón B., Hernández M., 2006 Osmoregulatory capacity of the shrimp *Litopenaeus vannamei* at different temperatures and salinities, and optimal culture environment. Revista de Biologia Tropical 54(3):745-753.

Camacho-Jiménez L., Díaz F., Sanchez-Castrejón E., Montiel-Arzate A., Ponce-Rivas E., 2021 Dose-dependent effect of recombinant CHH-B1 on osmoregulatory capacity and Na^+/K^+-ATPase expression in bilaterally eyestalk-ablated shrimp *Litopenaeus vannamei*. Biotecnia 23(3):58-65.
Chitra V., Muralidhar M., Saraswathy R., Dayal J. S., Lalitha N., Thulasi D., Nagavel A., 2017 Mineral availability from commercial mineral mixtures for supplementation in aquaculture pond waters of varying salinity. International Journal of Fisheries and Aquatic Studies 5(4):430-434.
Durai V., Chrispin L. C., Bharathi S., Velselvi R., Karthy A., 2022 Factors determining the economic performance of *Litopenaeus vannamei* (whiteleg shrimp), aquaculture in Tamil Nadu, India. Aquaculture Research 53(13):4689-4696.
Flaherty M., Szuster B., Miller P., 2000 Low salinity inland shrimp farming in Thailand. Ambio 29(3):174-179.
Hilyana S., Amir S., Alim S., Scabra A. R., Muahiddah N., Diamahesa W. A., 2023 [Production and commercialization of low salinity vannamei shrimp in the Sokong Village, North Lombok]. Jurnal Abdi Insani 10(2):761-770. [in Indonesian]
Hu D., Pan L., Zhao Q., Ren Q., 2015 Transcriptomic response to low salinity stress in gills of the Pacific white shrimp, *Litopenaeus vannamei*. Marine Genomics 3:297-304.
Huang M., Dong Y., Zhang Y., Chen Q., Xie J., Xu C., Zhao Q., Li E., 2019 Growth and lipidomic response of juvenile Pacific white shrimp *Litopenaeus vannamei* to low salinity. Frontiers in Physiology 10:1087.
Ismail, Scabra A. R., Marzuki M., 2021 Effect of additioning phosphorus to cultivation media on the growth rate of vaname shrimp (*Litopenaeus vannamei*) French at salinity 0 ppt. Indonesian Journal of Aquaculture Medium 1(2):113-124.
Kaligis E., 2015 [Growth response of white shrimp (*Litopenaeus vannamei*) reared in low salinity medium, fed different protein and calcium levels]. Jurnal Ilmu Dan Teknologi Kelautan Tropis 7(1):225-234. [in Indonesian]
Kim C. W., Lee J. W., Kang S. W., Kang H. S., 2024 Study on ferritin gene expression to evaluate the health of white leg shrimp (*Litopenaeus vannamei*) postlarvae due to changes in water temperature, salinity, and pH. Water 16(11):1477.
Kumar V. S., Pandey P. K., Anand T., Bhuvaneswari G. R., Dhinakaran A., Kumar S., 2018 Biofloc improves water, effluent quality and growth parameters of *Penaeus vannamei* in an intensive culture system. Journal of Environmental Management 215:206-215.
Kusrini P., Wiranto G., Syamsu I., Hasanah L., 2016 [Online water quality monitoring system for shrimp aquaculture using android based applications]. Jurnal Elektronika dan Telekomunikasi 16(2):25-32. [in Indonesian]
Lap N. V., Phuong L. K., Oanh T. T. K., Thong T. D., Lan N. T., Quyen T. H., Tai L. T., 2021 The farming models adapting to climate change in the eastern coastal area of the Mekong River Delta, Vietnam. Ecology and Evolutionary Biology 6(1):1-7.
Lestantun A., Saputra I., Mursitorini E., 2022 [Saprobity index and phytoplankton community structure in aquaculture ponds of vannamei shrimp (*Litopenaeus vannamei*)]. Jurnal Kelautan dan Perikanan Terapan 5(2):117-125. [in Indonesian]
López-Téllez N. A, Corbala-Bermejo J. A., Bustamante-Unzueta M. L., Silva-Ledesma L. P., Vidal-Martínez M. V., Rodriguez-Canul R., 2019 History, impact and status of infectious diseases of the Pacific white shrimp *Penaeus vannamei* (Bonne, 1831) cultivated in Mexico. Journal of the World Aquaculture Society 51(2):334-345.
McNevin A. A., Boyd C. E., Silapajarn O., Silapajarn K., 2004 Ionic supplementation of pond waters for inland culture of marine shrimp. Journal of the World Aquaculture Society 35(4):460-467.
Miranda F. R., Lima R. N., Crisostomo L. A., Santana M. G., 2008 Reuse of inland low-salinity shrimp farm effluent for melon irrigation. Aquacultural Engineering 39(1):1-5.
Pariakana A., Rahim, 2021 [Characteristics of water quality and the presence of *Vibrio* sp. bacteria in traditional shrimp pond areas on the coast of Wundulako and Pomala Kolaka]. Journal of Fisheries and Marine Research 5(3):547-556. [in Indonesian]
Paul B. G., Vogl C. R., 2011 Impacts of shrimp farming in Bangladesh: challenges and alternatives. Ocean and Coastal Management 54(3):201-211.

Pinoargote G., Flores G., Cooper K., Ravishankar S., 2018 Effects on survival and bacterial community composition of the aquaculture water and gastrointestinal tract of shrimp (*Litopenaeus vannamei*) exposed to probiotic treatments after an induced infection of acute hepatopancreatic necrosis disease. Aquaculture Research 49(10):3270-3288.

Pinto P. H. O., Rocha J. L., Figueiredo J. P. d. V., Carneiro R. F. S., Damian C., de Oliveira L., Seiffert W. Q., 2020 Culture of marine shrimp (*Litopenaeus vannamei*) in biofloc technology system using artificially salinized freshwater: zootechnical performance, economics and nutritional quality. Aquaculture 520:734960.

Pizarro F., 1978 [Agricultural drainage and recovery of saline soils]. Editora Agrícola Española, Madrid, 521 pp. [in Spanish]

Rahi M. L., Azad K. N., Tabassum M., Irin H. H., Hossain K. S., Aziz D., Moshtaghi A., Hurwood D. A., 2021 Effects of salinity on physiological, biochemical and gene expression parameters of black tiger shrimp (*Penaeus monodon*): potential for farming in low-salinity environments. Biology 10(12):1220.

Ray A. J., Lotz J. M., 2017 Comparing salinities of 10, 20, and 30‰ in intensive, commercial-scale biofloc shrimp (*Litopenaeus vannamei*) production systems. Aquaculture 476:29-36.

Roy L. A., Davis D. A., Saoud I. P., Henry R. P., 2007 Effects of varying levels of aqueous potassium and magnesium on survival, growth, and respiration of the Pacific white shrimp, *Litopenaeus vannamei*, reared in low salinity waters. Aquaculture 262(2-4): 461-469.

Roy L. A., Davis D. A., Saoud I. P., Boyd C. A., Pine H. J., Boyd C. E., 2010 Shrimp culture in inland low salinity waters. Reviews in Aquaculture 2(4):191-208.

Samocha T. M., Hamper L., Emberson C. R., Davis A. D., McIntosh D., Lawrence A. L., Van Wyk P. M., 2002 Review of some recent developments in sustainable shrimp farming practices in Texas, Arizona, and Florida. Journal of Applied Aquaculture 12(1):1-42.

Saoud I. P., Roy L. A., Davis D. A., 2007 Chelated potassium and arginine supplementation in diets of Pacific white shrimp reared in low-salinity waters of West Alabama. North American Journal of Aquaculture 69(3):265-270.

Suantika G, Situmorang M. L., Kurniawan J. B., Pratiwi S., et al, 2018 Development of a zero water discharge (ZWD) – recirculating aquaculture system (RAS) hybrid system for super intensive white shrimp (*Litopenaeus vannamei*) culture under low salinity conditions and its industrial trial in commercial shrimp urban farming in Gresik, East Java, Indonesia. Aquacultural Engineering 82:12-24.

Szuster B. W., Flaherty M., 2002 Cumulative environmental effects of low salinity shrimp farming in Thailand. Impact Assessment and Project Appraisal 20(3):189-200.

Uawisetwathana U., Situmorang M. L., Arayamethakorn S., Haniswita, Suantika G., et al, 2021 Supplementation of ex-situ biofloc to improve growth performance and enhance nutritional values of the Pacific white shrimp rearing at low salinity conditions. Applied Sciences 11(10):4598.

Valencia-Casteneda G., Frías-Espericueta M. G., Vanegas-Perez R. C., Chávez-Sanchez M. C., Páez-Osuna F., 2019 Toxicity of ammonia, nitrite and nitrate to *Litopenaeus vannamei* juveniles in low-salinity water in single and ternary exposure experiments and their environmental implications. Environmental Toxicology and Pharmacology 70:103193.

Wafi A., Ariadi H., Fadjar M., Mahmudi M., Supriatna, 2020 [Partial harvest simulation model on intensive shrimp culture management of vannamei shrimp (*Litopenaeus vannamei*)]. Samakia: Jurnal Ilmu Perikanan 11(2):118-126. [in Indonesian]

Wurmann C. G., Madrid R. M., Brugger A. M., 2004 Shrimp farming in Latin America: current status, opportunities, challenges and strategies for sustainable development. Aquaculture Economics and Management 8(3-4):117-141.

Yunarty, Kurniaji A., Budiyati, Renitasari D. P., Resa M., 2022 [Water quality characteristics and growth performance of vaname shrimp cultivation (*Litopenaeus vannamei*) intensive pattern]. PENA Akuatika: Jurnal Ilmiah Perikanan Dan Kelautan 21(1):75-88. [in Indonesian]

Zebua V. F., Ayuningrum D., Jati O. E., 2023 [Laboratory scale test effect of *Alcaligenes* sp. bacteria on water quality (DO, pH, temperature) in vannamei shrimp (*Litopenaeus vannamei*)]. Jurnal Pasir Laut 7(1):55-59. [in Indonesian]

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