Freshwater Pacific white shrimp (*Penaeus vannamei*) culture integrated with agriculture in Lampung Province, Indonesia

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Abstract. Pacific white shrimp (*Penaeus vannamei*) cultivation using freshwater has been carried out by farmers in Indonesia, especially in Lampung Province. The cultivation areas using freshwater can be conducted by farmer with agricultural activities where shrimp farming waste can be used as fertilizer for rice plants. However, information regarding the performance of Pacific white shrimp cultivation in freshwater in Indonesia and its problems is still very limited. This research aimed to study the cultivation of freshwater Pacific white shrimp integrated with agriculture in Lampung Province, its performance, economic analysis, and future development prospects. This research method used observation and literature study, and the data collected were the pond area, groundwater quality, stocking density, treatment during the cultivation process, problems, and the performance of Pacific white shrimp. Four freshwater shrimp ponds located in Palas District, South Lampung Regency (40 km from the nearest coastline) were observed. The results showed that Pacific white shrimp can be cultivated using freshwater with good performance. The average growth, survival rate, productivity, and B/C (benefit/cost) ratio is 0.22 g day^{-1}, 82%, 1.5 kg m^{-2}, and 0.7, respectively. The problem that often occurs is the death of shrimp caused by failure to molt due to a lack of macrominerals mainly calcium and potassium. Calcium concentration can be increased by application of $CaCO_3$ while potassium concentration can be increased by application of KCl. Meanwile, Pacific white shrimp cultivation using freshwater has good prospects for development and integration with agriculture due to good performance, economically profitable, and the waste can be used as fertilizer for plants.
Key Words: B/C ratio, growth, macromineral, molt, productivity.

Introduction. Shrimp farming in Indonesia has developed rapidly since the early 2000s (Kopot & Taw 2004). Before 2000, farmers cultivated *Penaeus monodon* shrimp but later changed to Pacific white species (*Penaeus vannamei*) due to several considerations (Supono 2006). Pacific white shrimp has a high survival rate (Duraiappah et al 2000), fast growth, tolerance to high stocking densities (Briggs et al 2004), high productivity (Boyd & Clay 2002), and high feed efficiency (Briggs et al 2004; Supono 2021). Furthermore, it can live in a wide range of salinity between 0.5 and 40 ppt (Wyban & Sweeney 1991), allowing it to be cultivated far from the coastline to be more environmentally friendly. According to Boyd (1989), the optimal salinity for the growth of Pacific white shrimp is 15-25 ppt. One of the provinces with the most innovations in shrimp farming is Lampung, located on the island of Sumatra, Indonesia. The province has a shrimp farming area of 38,505 ha, which is 1,050 km along the coast. Furthermore, farmers in these areas have also developed the cultivation of low-salinity Pacific white shrimp with a production of more than 10 tons per hectare (Supono 2021).

The rapid development of shrimp farming in Lampung Province has increased production. However, it raises several problems, such as limited land and the emergence of diseases due to environmental quality degradation. Diseases due to viruses such as white spots (Koesharyani et al 2019) and infectious myonecrosis (Taukhid & Nur'aini 2008), as well as white feces (Supono et al 2019) have caused failures in Pacific white shrimp culture. Therefore, a strategy is needed to overcome these problems to increase shrimp production in Indonesia.

One effort to overcome this problem is using freshwater as a medium of cultivation because this shrimp has a high salinity tolerance (Chong-Robles et al 2014). The growth of *Vibrio parahaemoliticus* as a cause of white feces disease is inhibited in freshwater (Bintari et al 2016), while the ferocity of the virus will be reduced. Pacific white shrimp cultivation in freshwater has been successfully carried out by Araneda et al (2008) and Scabra et al (2021). The main problem in brackishwater shrimp farming is the high amount of waste produced which causes environmental quality degradation and disease outbreaks (Millard et al 2021). Wastewater from ponds contains a lot of inorganic nitrogen and phosphorus due to the high protein content in the feed (Lee & Lee 2018). The advantage is the waste produced that can be used as fertilizer for plants and integrated with the agricultural industry. This research aimed to study the application of freshwater shrimp culture technology integrated with agriculture in Lampung Province and the prospects for its development in the future.

Material and Method

Period of study. This study was carried out from June 2022 to March 2023.

Study site*.* The location was in South Lampung, Lampung Province, Indonesia, about 40 km from the nearest coastline in the middle of an agricultural area (Figure 1).

Figure 1. a. Located in the middle of rice fields; b. Lampung Province; c. Freshwater shrimp pond.

Method*.* This research method used observation and literature study, and the data collected concerned the pond area, stocking density, treatment during the cultivation process, and the performance of Pacific white shrimp cultivated in freshwater media. Four freshwater shrimp ponds located in Palas District, South Lampung Regency (40 km from the nearest coastline) were observed. Pacific white shrimp performance data comprised growth, survival rate, feed conversion ratio, and economic analysis. Meanwhile, the water quality data measured included mineral content, alkalinity, hardness, total ammonia nitrogen, salinity, and total organic matter (TOM). The microbiological parameters observed were total *Vibrio* count (TVC) and total bacteria count (TBC). Mineral content (magnesium, calcium, potassium) was measured using the U.S. EPA 200.7 method (U.S. EPA 1994), alkalinity, hardness, total ammonia nitrogen, and TOM were measured using the APHA (2017) method, while the TVC and TBC were analyzed using the method performed by Chau et al (2011). Water quality measurements were carried out on groundwater as a source of water for ponds.

Data analysis. Data on the water quality and performance of freshwater Pacific white shrimp were analyzed descriptively and compared with brackishwater ones. Analysis of the economic feasibility of cultivation was conducted by calculating the revenue/cost (R/C) ratio and benefit/cost (B/C) ratio (Bosman et al 2021).

Results and Discussion

Groundwater quality overview. Water quality is important in supporting farming success because shrimp are very sensitive to the environment. The quality of the water in the pond is inseparable from the condition of the quality of the source water used. The quality of the groundwater locations is presented in Table 1.

Table 1

Quality of groundwater

No	*Parameters*	*Concentration*	*Brackishwater*
1	Salinity (g L^{-1})	< 1	12-25*
2	Alkalinity (mg L^{-1})	80	> 120*
3	Hardness (mg L^{-1} $CaCO_3$)	200	> 1000*
4	Mg (mg L^{-1})	29.8	> 109*
5	Ca (mg L^{-1})	0	> 60*
6	K (mg L^{-1})	20.9	> 55*
7	TOM (mg L^{-1})	114	< 100 mg L^{-1}**
8	TVC (CFU mL^{-1})	0	< 10^3***
9	TBC (CFU mL^{-1})	1,200	-
01	TAN (mg L^{-1})	0.2	< 1*

*Venkateswarlu et al (2019); **Lien & Giao (2020); ***Adam et al (2022).

Compared to brackishwaters, most values for water quality variables are smaller, such as salinity, alkalinity, hardness, magnesium, calcium, and potassium. According to Boyd (2018), a decrease in salinity results in a decrease in alkalinity and macrominerals Na, Ca, Mg, and K. Meanwhile, the concentration of hardness is directly related to magnesium and calcium (Boyd 2015). Groundwater tends to have a low hardness value and high alkalinity (Raju et al 2014), and *Vibrio* is not detected in the water source.

Water preparation. The water source used to cultivate freshwater Pacific white shrimp comes from groundwater. Groundwater is one of the most important sources of water for Pacific white shrimp farming (Priyono et al 2019). The use of river water is limited because of the possibility of contamination from pesticide waste from agricultural activities. Furthermore, using groundwater, freshwater is more sterile from pathogens that infect shrimp such as white spot syndrome virus (WSSV) and infectious myonecrosis virus (IMNV) than seawater, so there is no need to sterilize it with chemicals. The disadvantage as a shrimp culture in freshwater is the low content of macrominerals such as sodium, magnesium, calcium, and potassium. Shrimp need these minerals for osmoregulation and biomass formation (Davis & Gatlin 1996; Davis et al 2005). Low values of magnesium and calcium have implications for reduced hardness values (Boyd 2015). Furthermore, treatment during water preparation focused on increasing macromineral content and plankton culture, both phytoplankton and zooplankton. The magnesium content is increased by applying $MgCl_2$, while calcium and potassium use $CaCO_3$ and KCl fertilizer, respectively. KCl fertilizer is very effective for increasing the potassium content in pond water at a low price (Boyd 2018). Phytoplankton culture is carried out by applying urea ($CO(NH_2)_2$) as a nitrogen source and triple super phosphate (TSP) as a phosphorus source. Zooplankton, especially copepods, are grown by applying fermented rice bran, and the sequence of water preparation for freshwater Pacific white shrimp cultivation is as follows:

- filling water (groundwater) into the pond (depth of 1.0-1.2 m);
- application of macro minerals ($CaCO_3$, $MgCl_2$, KCl) (50-100 mg L^{-1});

- applications of $CO(NH_2)_2$ (10 mg L^{-1});
- application of TSP (1 mg L^{-1});
- application of fermented rice bran (10 mg L^{-1}).

Culture process. Shrimp post-larvae (PL) comes from a hatchery in Kalianda City, South Lampung, about 40 km from the cultivation site. Salinity reduction is carried out from the post-larvae stage. The water salinity in the hatchery is around 29-30 g L^{-1} at PL 1 and then lowered slowly, 2-4 points per day, until it reaches 0-1 g L^{-1} at PL 8-10. Furthermore, shrimp seed stocking density is 70-100 PL m^{-2}, and feeding in the first month uses the blind feeding program method. In the second month, the demand-feeding program method is adopted. The feed used contains min. 30% protein, min. 5% fat, max. 4% fiber, and max. 11% moisture. The frequency of feeding was done 4 times a day. Macromineral applications are carried out routinely every month. Dolomite ($CaMg(CO_3)_2$) was applied as much as 10-50 mg L^{-1} to increase the content of calcium (Ca) and magnesium (Mg) in pond water.

Disease. The disease is the main cause of failure in shrimp farming, caused by viruses and bacteria. In brackishwater and low salinity, attacks of white feces disease caused by *Vibrio parahaemolyticus* are common (Limsuwan 2010; Supono et al 2019). Diseases caused by viruses and bacteria have not been found, and the TVC test results show a very low value (not detected.). Apart from white feces disease (WFD), *V. parahaemolyticus* is a cause of acute hepatopancreatic necrosis disease (AHPND) (Kumar et al 2021). During the observation, no Pacific white shrimp were infected with WFD or AHPND in freshwater ponds.

Problems. Farmers have successfully cultivated Pacific white shrimp, but many obstacles remain. Meanwhile, several cases of death in the 2nd month, especially when molting occurred, are suspected of mineral deficiency causing low survival rate (SR) (SR pond No. 1: 70%, SR pond No. 2: 76%, SR pond No. 3: 88%, SR pond No. 4:94%). This is the possibility that the addition of macrominerals is still not sufficient for shrimp needs. According to Davis et al (2005) and Boyd (2018), potassium deficiency is one of the causes of mortality in Pacific white shrimp cultivation. The case in Ecuador showed that shrimp died in ponds with a potassium concentration of 1 mg L^{-1}. After the potassium concentration was increased to 8 mg L^{-1}, death did not occur (Boyd 2018). Meanwhile, the limited freshwater shrimp seeds became a very serious problem. Only one hatchery produces freshwater Pacific white shrimp seeds, namely PT. OPYE located in Kalianda, South Lampung.

Pond productivities. The observed performance of freshwater Pacific white shrimp ponds is presented in Table 2. Generally, the culture using Pacific white shrimp in the Province of Lampung can develop with high productivity.

Table 2

Performance of observed freshwater shrimp ponds

No	*Pond size (m^2)*	*Stocking density*	*Densities (PL m^{-2})*	*DOC Harvest (day)*	*ABW (g)*	*ADG (g day^{-1})*	*Harvest result (kg)*	*FCR*	*SR (%)*	*Yield (kg m^{-2})*
1	375	30,000	80	92	25	0.27	525	1.48	70	1.4
2	1400	50,000	35	100	25	0.25	950	1.47	76	0.7
3	1400	80,000	57	105	21.7	0.21	1527	1.96	88	1.1
4	900	150,000	166	75	11.7	0.16	1635	1.16	94	1.8
	Average	77,500	84		20.9	0.22		1.52	82	1.5

Notes: DOC = day of culture; ABW = average body weight; ADG = average daily growth; FCR = feed conversion ratio; SR = survival rate.

The daily growth of Pacific white shrimp cultivated in the freshwater reaches 0.22 g day^{-1} with an 82% survival rate and a productivity of 1.5 kg m^{-2} or the equivalent of 15 tons ha^{-1}. The survival rate of Pacific white shrimp ponds no 1 and 2 is low when compared to those reared in brackish water. Compared to the cultivation of Pacific white shrimp at low salinity (10-15 g L^{-1}), the survival rate in freshwater is relatively low at 85-93%, with a productivity of 10-13 tons ha^{-1} (stocking density of 70 PL m^{-2}) (Supono 2021).

Based on economic analysis, the cultivation with a pond area of 900 m^2 can produce 1,635 kg (Table 2) at a selling price of IDR 94,267,000 to earn a profit of IDR 38,767,000, as shown in Table 3.

Table 3

Economic analysis of shrimp culture

No	*Remark*	*Number*	*Price (IDR)*	*Total value (IDR)*
	Production cost			
1	Seed	150,000 PL's	50	7,500,000
2	Feed	1,900 kg	13,000	24,700,000
3	Chemical			3,800,000
4	Electricity			7,500,000
5	Worker	4	1,500,000	6,000,000
6	Others			1,000,000
	Depreciation			5,000,000
				55,500,000
	Harvest value			
1	Partial harvest I	295 kg (size 86)	57,000	16,815,000
2	Final harvest	1,340 kg (size 85)	57,800	77,452,000
	Total harvest value			94,267,000
	Benefit (2-1)			38,767,000
	B/C ratio			0.70
	R/C ratio			1.70

The weight of the shrimp in the partial harvest is almost the same as the final harvest (size 86 and 85) due to the final harvest was done the day after the partial harvest which was caused by mass mortality.

The economic analysis shows that Pacific white shrimp farming is profitable and has good prospects to be developed as an alternative for fish farmers. Freshwater Pacific white shrimp have the same selling price as those cultivated in brackishwater. According to Bosman et al (2021), the shrimp farming business is indeed profitable because it has a revenue/cost (R/C) ratio of more than 1.

Shrimp farming integrated with agriculture. Shrimp farming waste contains several nutrients, such as nitrogen (N), carbon (C), and phosphorus (P). About 80% nitrogen and 75% phosphorus in the feed will be wasted and dissolved in water or settled at the bottom of the pond. The average carbon and nitrogen wasted in the pond environment is around 80% and 75% respectively (Piedrahita 2003). According to Sahu et al (2013), 30% and 18% of nitrogen and carbon respectively are retained in shrimp meat. In aquaculture ponds, organic carbon and inorganic nitrogen are the main feed sources. Ammonia comes from leftover feed, feces, and metabolic waste excreted through the gills (Crab et al 2007).

In freshwater shrimp farming, the waste can be directly used as fertilizer for plants, especially rice. The nutrients of nitrogen (as ammonium) and phosphorus are needed by plants to grow. Many of these nutrients are contained in shrimp cultivation waste. Unlike brackish water, freshwater shrimp cultivation waste can be directly utilized by rice plants. Freshwater shrimp aquaculture ponds in Lampung are in the middle of rice fields. Shrimp cultivation waste from ponds is channeled into agricultural land (rice fields) to provide nutrients, especially nitrogen and phosphorus for rice growth. Preliminary information obtained from farmers indicated that rice fields irrigated with shrimp farming waste produced better productivity. Utilization of shrimp farming waste as agricultural fertilizer realizes the concept of green economy which aims to improve people's welfare, while significantly reducing the risk of environmental damage. This fact indicates that the cultivation of Pacific white shrimp in freshwater which is integrated with agriculture has good prospects for development.

Conclusions. It is known that farmers have successfully conducted Pacific white shrimp cultivation in freshwater in Indonesia with good performance. The survival rate, daily growth, and productivity are 82%, 0.24 g day^{-1}, and 1.5 kg m^{-2} (equivalent to 15 tons ha^{-1}), respectively. The problem is the lack of macrominerals which causes death during molting. Concerning the advantage of freshwater shrimp farming, it can be integrated with agricultural activities. Pacific white shrimp cultivation has bright prospects for future development.

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Conflict of interest. The authors declare that there is no conflict of interest.

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