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Filtration rate and remediation effectiveness of blood cockle (*Tegillarca granosa*) as a bioremediator of vannamei shrimp pond effluent

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Abstract. *Ihwan, Syamsuddin R, Yaqin K, Trijuno DD, Niartiningsih A, Haris A, Samawi MF, Rahim SW, Hasni, Sani YA, Ghulam S, Mariam S, Khatima H, Almunawar, Zalsabila M. 2025. Filtration rate and remediation effectiveness of blood cockle* (Tegillarca granosa) *as a bioremediator of vannamei shrimp pond effluent. Biodiversitas 26: 3985-3993.* The intensive culture of whiteleg shrimp (*Litopenaeus vannamei*) generates organic waste that can disrupt the balance of aquatic ecosystems. The blood cockle (*Tegillarca granosa*), a filter-feeding organism or bivalve remediation, has potential as a natural biofilter for remediating such waste. This study aimed to evaluate the filtration and bioremediation effectiveness of *T. granosa* on aquaculture waste from *L. vannamei* ponds, considering variations in size and density. Laboratory-scale experiments were conducted using a two-factor factorial design, with two levels of cockle size (2-3 cm and 4-5 cm) and two levels of density (15 and 30 individuals per 10 L, replicated three times for each level of density. Observed water quality parameters included Total Organic Matter (TOM), nitrite (NO_2), nitrate (NO_3), phosphate (PO_4), and other physicochemical parameters. The results showed that *T. granosa* effectively remediated waste, with the highest TOM remediation rate of 24.49%, nitrate removal of 18.32%, phosphate removal of 21.67%, and COD removal of 26.75%, achieved at a size of 4-5 cm and density of 30 individuals per 10 L. The highest nitrite remediation effectiveness was achieved at a treatment size of 4-5 cm and a density of 15 individuals per 10 L. The filtration rate of *T. granosa* reached 4.71 mL/h in the treatment with a size of 4-5 cm and a density of 30 individuals/10 L. The optimal treatment was Treatment D. Therefore, utilizing *T. granosa* as a natural biofilter can be a sustainable strategy for managing intensive whiteleg shrimp pond waste, contributing to aquaculture sustainability and promoting water improvement, especially when size and density factors are carefully considered in its application. These findings highlight the potential of *T. granosa* as an effective biofilter species for integration into IMTA systems to enhance water quality and sustainability.

Keywords: Aquaculture sustainability, bivalve biofilter, *Litopenaeus vannamei,* nutrient removal, water quality improvement

INTRODUCTION

The cultivation of *Litopenaeus vannamei* (Boone, 1931), also known as whiteleg shrimp, has experienced rapid growth over the past decade, solidifying the position as one of the most prominent aquaculture sectors worldwide, including in Indonesia. This expansion is largely driven by the species' numerous advantages, making it highly favored by shrimp farmers. *L. vannamei* is known for fast growth rate, allowing for shorter production cycles and increased yields (Liang et al. 2025). Additionally, it has strong resilience to diverse environmental conditions, enabling successful cultivation in various water parameters (Ayaz et al. 2015). The high tolerance of stocking densities also supports intensive farming systems (Han et al. 2018; Aparna et al. 2024). The continuously increasing market demand for *L. vannamei* has led to intensive production on a global scale (Naser et al. 2022). This rapid expansion, while economically beneficial, also brings significant environmental challenges. One of the primary challenges is the substantial increase in organic waste generated from intensive aquaculture practices. The accumulation of uneaten feed, fecal matter, and other organic residues can lead to water pollution, eutrophication, and ecosystem degradation when not properly managed and controlled.

Sustainable strategies are crucial for mitigating the environmental impacts and ensuring responsible shrimp farming practices (Ahmed 2015). The organic waste generated from *L. vannamei* shrimp farming primarily comes from uneaten feed, feces, and various chemical inputs commonly used in intensive aquaculture systems (Paena et al. 2023). Uneaten feed accumulates in pond sediments, contributing to nutrient overload, while shrimp feces further increase the levels of organic matter in the water. Chemical inputs such as fertilizers, antibiotics, and disinfectants, commonly applied to maintain water quality and shrimp health, can also worsen environmental issues such as water pollution, antibiotic resistance, and ecosystem degradation if not carefully managed (Bull et al. 2021). These waste materials have the potential to affect water quality and surrounding ecosystems (Martins et al. 2010; Pędziwiatr et al. 2017). When not effectively managed, the accumulation of organic waste from *L. vannamei* shrimp farming can have serious environmental consequences. Excess nutrients from uneaten feed and feces potentially lead to eutrophication, promoting excessive algal growth that depletes oxygen levels in the water. Additionally, increased sedimentation alters the physical and chemical properties of aquatic habitats, negatively impacting biodiversity. The resulting hypoxia, or oxygen depletion, threatens the survival of aquatic organisms and disrupts ecological balance. These factors contribute to long-term environmental degradation, affecting both farmed and wild aquatic species (Krogh et al. 2018). Although the nutrients in shrimp pond waste can support phytoplankton growth, including *Chlorella* sp., excessive accumulation poses serious risks. High nutrient levels can degrade water quality, leading to algal blooms, oxygen depletion, and imbalanced ecosystems. These impacts ultimately threaten the long-term sustainability of aquaculture operations (Tangguda et al. 2015; Tangguda and Suryanti 2017).

An ecosystem-based approach that utilizes natural organisms as biofilters has been proposed as an innovative solution to mitigate the environmental impact of shrimp pond waste. One of the organisms is cockles or bivalves that play an important role in water remediation through biofiltration, as they can naturally remove suspend solids, nutrients, and various pollutants from aquatic environments. Their ability to reduce contaminant levels makes them valuable for improving water quality, particularly in areas affected by industrial waste (Deepthi et al. 2020). Blood cockle (*Tegillarca granosa* (Linnaeus, 1758)), as a filter-feeding organism, has the ability to filter organic particles and plankton from the water, thereby naturally improving pond water quality (Syahrir et al. 2021; Renitasari et al. 2023). This biological filtration process not only reduces water turbidity but also decreases the accumulation of organic matter that may trigger eutrophication (bin Ramli et al. 2014; Wulandari et al. 2019). The filtration efficiency of blood cockle is influenced by various factors, including individual size, population density, and environmental parameters such as temperature, pH, and salinity (Riisgård 2001; Kusumawati et al. 2015).

Therefore, this study aimed to evaluate the effectiveness of blood cockle (*T. granosa*) in filtering organic waste from intensive vannamei shrimp ponds, considering variations in size and density. This study was conducted to assess the bioremediation performance of *T. granosa* on key water quality parameters such as TOM, nitrite, nitrate, phosphate, and COD; determine the filtration rate of *T. granosa* under different size and density treatments; and identify the optimal size-density combination for maximizing waste removal efficiency. The results are expected to provide a scientific basis for developing more sustainable pollution mitigation strategies in shrimp aquaculture.

MATERIALS AND METHODS

Sampling and physiochemical characterization

This study was conducted on a laboratory scale at the Politeknik Kelautan dan Perikanan Bone, Bone District, South Sulawesi, Indonesia. In situ observations were carried out over seven days to evaluate water quality parameters (Nicholaus et al. 2019; Hossain et al. 2024; Meitei et al. 2025), including temperature, salinity, pH, Dissolved Oxygen (DO), and Total Dissolved Solids (TDS) which were measured in situ in the media using a multiparameter measuring instrument. Meanwhile, ex situ analyses of nitrite (NO_2), nitrate (NO_3), phosphate (PO_4) were measured ex situ in the laboratory using the spectrophotometric method (APHA 2012). The Total Organic Matter (TOM) and Total Suspended Solids (TSS) were measured ex situ using the gravimetric method in accordance to SNI 06-6989.3-2004 and the condition of the cockle was performed at the Water Quality Laboratory of the Brackish Water Aquaculture Research and Fisheries Extension Center (BRPBAP3) in Maros District, South Sulawesi, Indonesia.

Container and test organism

A tarpaulin-lined tank measuring 50 cm × 50 cm × 30 cm was used as the experimental container. A pump was installed at the bottom of each container to maintain water circulation and prevent sedimentation from occurring. Each container was filled with 50 L of wastewater collected from an intensive *L. vannamei* shrimp farm at Politeknik Kelautan dan Perikanan Bone. The wastewater was pumped, stored, and subsequently distributed to the experimental containers. Blood cockle, serving as the test organisms, were obtained from fishermen in Patte'ne Village, Maros District, and transported to the research site using the wet transport method. Before being placed into the experimental containers, the cockle was subjected to a 24 h acclimatization period in sterile seawater without feeding. Following the study objectives, the test specimens were classified based on shell length, which was measured using a caliper. Two size categories were tested: small (2-3 cm) and large (4-5 cm). Each size category was further tested at two stocking densities: namely 15 and 30 individuals per 10 L of water. The cockle was then distributed into the experimental containers according to the designated size and density without aeration.

Experimental design

The experimental factorial design was used with two factors and three replications. The treatments applied were based on shell size and stocking density (Table 1). Treatment A consisted of small-sized cockle (2-3 cm) with a density of 15 individuals per 10 L, while B included small-sized cockle with a density of 30 individuals per 10 L. Treatment C had large-sized cockle (4-5 cm) with a density of 15 individuals per 10 L, and D comprised large-sized cockle with a density of 30 individuals per 10 L.

Table 1. Treatments

Treatments	Replication		
	1	2	3
A (2-3 cm, 15 individuas/10 L)	A_1	A_2	A_3
B (2-3 cm, 30 individuals/10 L)	B_1	B_2	B_3
C (4-5 cm, 15 individuals/10 L)	C_1	C_2	C_3
D (4-5 cm, 30 individuals/10 L)	D_1	D_3	D_3

Water quality analysis

The remediation effectiveness of cockle was assessed based on the extent of water quality improvement facilitated. Hence, water quality measurements were conducted. Water quality was monitored periodically over seven consecutive days, both in situ and ex situ. In situ observations included temperature, salinity, pH, DO, and TSD, which were measured every three hours (01:00, 04:00, 07:00, 10:00, 13:00, 16:00, 19:00, 22:00) using a multiparameter water quality tester. Other water quality parameters, including nitrite (NO_2), nitrate (NO_3), phosphate (PO_4), TOM, and TSS, were analyzed once daily at 10:00. Water samples were collected and subsequently analyzed using spectrophotometry at the Water Quality Laboratory of the Brackishwater Aquaculture Research and Fisheries Extension Center (BRPBAP3) in Maros District, South Sulawesi, Indonesia.

Remediation effectiveness

The remediation effectiveness was expressed as the percentage change in water quality parameters related to the filtration capacity of cockle. This was calculated by comparing the initial and final concentrations of the water quality parameters using the following formula (McLeod et al. 2017):

$$P\ (\%) = \frac{Ko - Kt}{KO}\ x\ 100$$

Where :

P : Percentage of the change in water quality parameters
Ko : Initial concentration
Kt : Final concentration

Filtration rate

The filtration rate is defined as the ability of blood cockle to filter dissolved organic matter within a given time unit. The calculation of the filtration rate follows the equation proposed by Riisgård (2001):

$$FR = \left(\frac{V}{nt}\right) \ln \left(\frac{Co}{Ct}\right)$$

Where :

FR : Filtration rate (mL/h)
V : Media volume (mL)
n : Number of test animals (ind)
t : Duration (h)
Co : Initial concentration (mg/L)
Ct : Final concentration (mg/L)

Statistical analysis

The remediation effectiveness and filtration rate were statistically analyzed using Analysis of Variance (ANOVA) at a significance level of $p<0.05$ to test for differences between treatments. This was followed by a Least Significant Difference (LSD) test to determine significant differences among the data. A linear regression analysis was performed to investigate the daily variation in the filtration rate of blood cockle in relation to TOM and nitrite concentrations.

RESULTS AND DISCUSSION

Remediation effectiveness

A significant decrease in dissolved oxygen concentration, an increase in ammonia and nitrate concentrations, a rise in phosphate levels, and a significant increase in TDS and TSS were observed (Table 2). The result presents the effectiveness of four different treatments (A, B, C, and D) in improving water quality over a 7-day remediation period. Key water quality indicators were measured at the beginning (Day 0) and at the end (Day 7), and the percentage of Reduction or increase in each parameter was calculated to assess treatment efficacy.

Table 2. Water quality parameters and remediation effectiveness

Treatments	Observation time	Water quality parameters								
		pH	DO (mg/L)	TDS (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	NH_3 (mg/L)	PO_4 (mg/L)	TOM (mg/L)	TSS (mg/L)
A	Initial (D0)	7.75	8.80	19.90	7.23	0.34	1.16	0.02	70.40	18.00
	Final (D7)	7.04	1.43	20.29	6.33	24.89	1.04	0.05	57.03	55.33
	Reduction (%)	9.16^{a}	83.79^{c}	(1.95)^{a}	12.48^{c}	(7.263.20)^{a}	10.08^{a}	(123.62)^{b}	18.99^{a}	(207.41)^{a}
B	Initial (D0)	7.75	8.80	19.90	7.23	0.34	1.16	0.02	70.40	18.00
	Final (D7)	7.34	1.23	20.22	2.98	16.17	3.45	0.06	54.82	67.83
	Reduction (%)	5.33^{b}	86.06^{bc}	(1.62)^{a}	58.82^{b}	(4.685.22)^{a}	(197.52)^{b}	(213.37)^{a}	22.14^{a}	(276.85)^{a}
C	Initial (D0)	7.75	8.80	19.90	7.23	0.34	1.16	0.02	70.40	18.00
	Final (D7)	7.19	0.83	20.26	1.52	21.20	3.29	0.05	55.00	39.34
	Reduction (%)	7.18^{ab}	90.53^{b}	(1.79)^{a}	78.93^{a}	(6.172.12)^{a}	(184.13)^{b}	(150.49)^{b}	21.87^{a}	(118.56)^{a}
D	Initial (D0)	7.75	8.80	19.90	7.23	0.34	1.16	0.02	70.40	18.00
	Final (D7)	7.16	0.13	20.46	1.94	22.69	2.93	0.05	53.16	61.67
	Reduction (%)	7.66^{a}	98.56^{a}	(2.79)^{b}	73.12^{ab}	(6.612.11)^{a}	(153.13)^{b}	(153.40)^{b}	24.49^{a}	(242.59)^{a}

Table 3. Change in nitrite concentration

Treatments	TOM concentration (mg/L)							
	D0	D1	D2	D3	D4	D5	D6	D7
A	70.40	55.54	56.10	54.20	52.12	54.18	56.47	57.03
	Reduction	14.86	14.30	16.20	18.28	16.22	13.93	13.37
B	70.40	66.75	58.18	54.51	57.10	54.70	54.82	54.76
	Reduction	3.65	12.22	15.89	13.30	15.70	15.58	15.64
C	70.40	60.76	52.85	57.37	56.82	54.87	54.82	55.00
	Reduction	9.64	17.55	13.03	13.58	15.53	15.58	15.58
D	70.40	61.03	57.82	60.49	56.17	56.32	54.39	53.16
	Reduction	9.37	12.58	9.91	14.23	14.08	16.01	17.24

Table 4. Filtration rate of blood cockle on TOM

Treatments	Filtration rate (mL/h)						
	D1	D2	D3	D4	D5	D6	D7
A	4.43^{a}	3.17^{b}	2.97^{b}	3.33^{a}	2.62^{a}	2.13^{a}	1.88^{a}
B	1.51^{a}	1.35^{a}	1.56^{a}	3.69^{b}	4.50^{b}	4.78^{b}	4.19^{b}
C	2.08^{a}	4.02^{b}	2.09^{ab}	1.82^{c}	1.82^{c}	1.76^{c}	1.54^{c}
D	2.02^{a}	1.37^{a}	0.92^{a}	1.60^{d}	1.62^{d}	2.44^{d}	4.71^{d}

The result of the study shows that blood cockle was able to remediate water quality parameters, specifically nitrite and TOM. Statistical analysis showed that shell size as an independent factor ($p<0.05$) and its interaction with stocking density ($p<0.05$) had a significant effect on the remediation effectiveness of shrimp pond wastewater, as indicated by the reduction in nitrite and TOM concentrations. However, stocking density alone did not have a significant effect ($p>0.05$) on the reduction of these compounds, indicating no significant contribution to water quality improvement.

Based on the LSD test results, the highest nitrite remediation effectiveness was observed in treatment C (cockle size 4-5 cm with a density of 15 individuals per 10 L of wastewater) and treatment D (cockle size 4-5 cm with a density of 30 individuals per 10 L of wastewater). The highest nitrite remediation efficiency was recorded in treatment C at 78.93%, which was not significantly different from treatment D (73.12%) but was significantly higher than treatment A (12.48%) and treatment B (58.82%) ($p>0.05$). Although the difference was not statistically significant compared to the other treatments, TOM remediation effectiveness was relatively higher in treatment D, reaching 24.49%

Filtration rate

The filtration rate was calculated based on the change in waste concentration from the initial to the end of the study, taking into account the exposure time. Daily concentration data and the reduction in TOM concentration were analyzed (Table 3).

There were no statistically significant differences among all treatments in the TOM filtration rate from Day 1 to Day 3, while minor differences began to emerge from Day 1 onward (Table 4).

Single factors of density and blood cockle size significantly affected the filtration rate of TOM concentration ($p<0.05$). However, no significant interaction effect was observed between the two factors on TOM filtration rate ($p>0.05$). On days 4, 5, and 6, treatment B exhibited the highest filtration rate, with values of 3.69 mL/h, 4.50 mL/h, and 4.78 mL/h, respectively, which were significantly different from those of the other treatments ($p<0.05$). Smaller cockle sizes (2-3 cm) showed higher filtration rates compared to larger cockle sizes (4-5 cm). Treatment A (2-3 cm, 15 individuals/10 L) showed filtration rates of 2.13 mL/h and 1.88 mL/h on days 6 and 7, respectively, while treatment C (4-5 cm, 15 individuals/10 L) had filtration rates of 1.76 mL/h and 1.54 mL/h on days 6 and 7, respectively. Cockle density had a greater impact on filtration rate compared to cockle size. A higher cockle density (30 individuals/10 L) resulted in higher filtration rates compared to a lower density (15 individuals/10 L). Furthermore, higher filtration rates were observed at the end of the study, on days 6 and 7. Treatment B (2-3 cm size with 30 individuals/10 L density) showed filtration rates of 4.78 mL/h and 4.19 mL/h, while treatment D (4-5 cm size with 30 individuals/10 L density) had filtration rates of 2.44 mL/h and 4.71 mL/h on days 6 and 7, respectively.

Treatments B and D, both with higher densities, exhibited increased filtration rates over time as the blood cockle remained in the wastewater, effectively reducing TOM concentrations from the first day to the end of the study (Figure 1). The strength of the relationship between the TOM filtration rate and the duration of the cockle' presence in the wastewater is indicated by the correlation coefficients, $R^2 = 0.7961$ and $R^2 = 0.4552$, respectively. Treatments with low density (A and C) showed a negative correlation, where filtration rates decreased over time as the cockle remained in the wastewater.

Based on the daily concentration data and the observed decrease in nitrite levels (Table 5), the effectiveness of the treatment in reducing nitrogen compounds can be evaluated. The filtration rate was calculated daily during the experiment using standard methods, and comparative data were recorded for all treatments. The results presented that on Days 3, 4, 5, and 6, the treatment B demonstrated the highest filtration rate among all treatments (Table 6).

Cockle density had a significant single effect ($p<0.05$) on nitrite filtration rate, regardless of cockle size, whether small (2-3 cm) (treatment B) or large (4-5 cm) (treatment D). Similarly, cockle size had no significant effect, either singly ($p>0.05$) or in interaction with density ($p>0.05$), was observed on nitrite filtration rate. The significant effect of cockle density on nitrite filtration rate was apparent from 3-7 day. Based on the LSD, the filtration rates in treatment B (density of 30 individuals/10 L wastewater with small size) were significantly higher on days 3, 4, 6, and 7 with values of 4.74 mL/h, 12.35 mL/h, 17.48 mL/h, and 17.32 mL/h, respectively, compared to treatment A (density of 15 individuals/10 L wastewater with small size), which were 1.72 mL/h, 1.11 mL/h, 0.85 mL/h, and 1.19 mL/h, respectively. Similarly, treatment D (density of 30 individuals/10 L with large cockle size) showed significantly higher filtration rates on the same days, at 11.67 mL/h, 11.19 mL/h, 15.72 mL/h, and 21.48 mL/h, respectively, compared to treatment C (density of 15 individuals/10 L wastewater with large size), which had values of 2.96 mL/h, 1.80 mL/h, 12.09 mL/h, and 9.71 mL/h, respectively.

Treatments B, C, and D showed an increasing filtration rate over time as the blood cockle remained in the wastewater and were able to reduce TOM concentration from the first day until the end of the study (Figure 2). The strength of the relationship between nitrite filtration rate and the duration of mussel presence in the wastewater was indicated by positive correlation coefficients of $R^2 = 0.6829$, $R^2 = 0.7448$, and $R^2 = 0.6941$ for Treatments B, C, and D, respectively. Treatments with high density (B and D) consistently demonstrated a positive correlation between filtration rate and exposure time. In contrast, the low-density treatment with small-sized muscles (Treatment A) exhibited a negative correlation, indicating a decline in the filtration rate as the mussels remained in the wastewater for a longer duration.

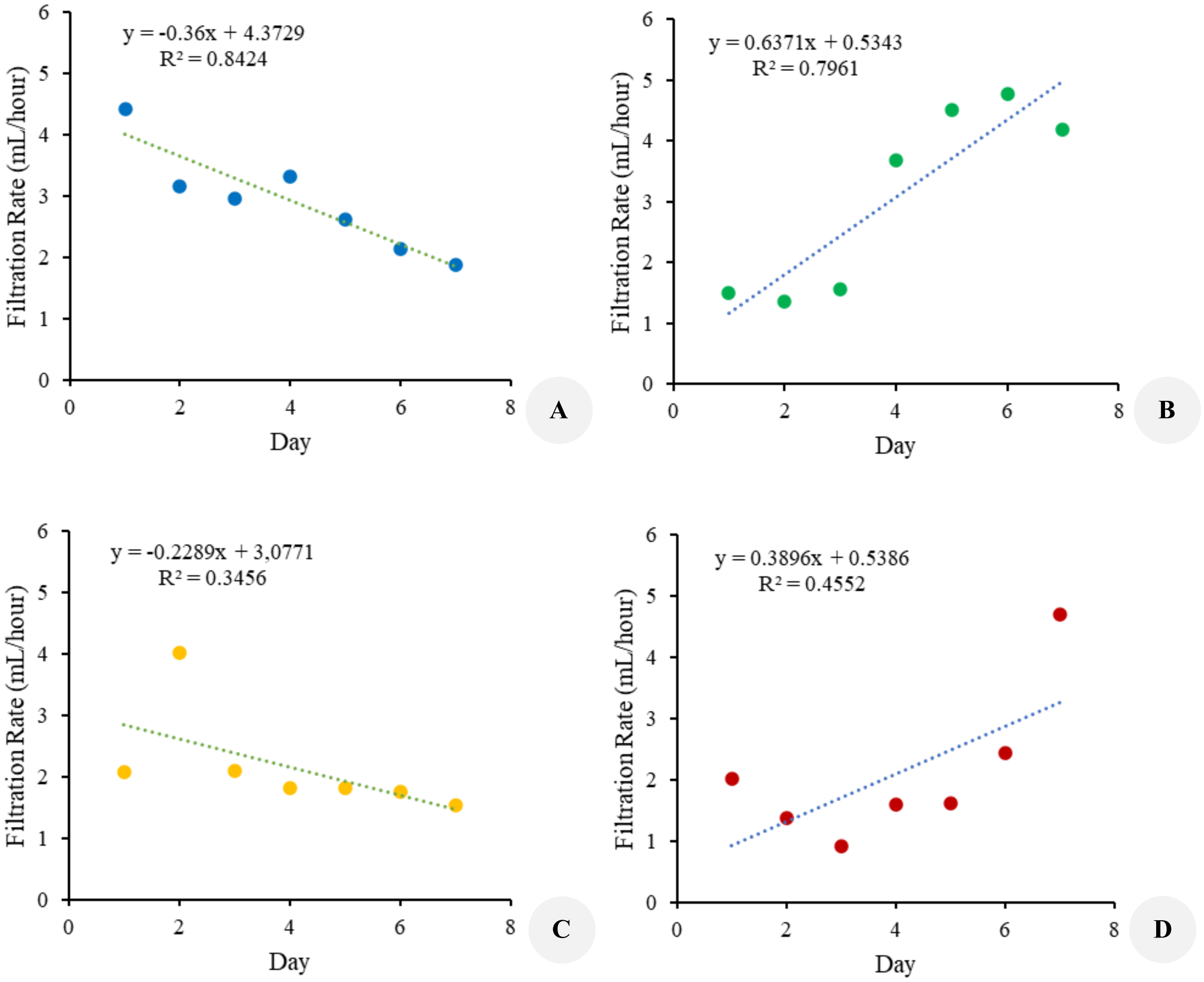

Figure 1. Effects of blood cockle exposure duration on TOM filtration rate in all treatments

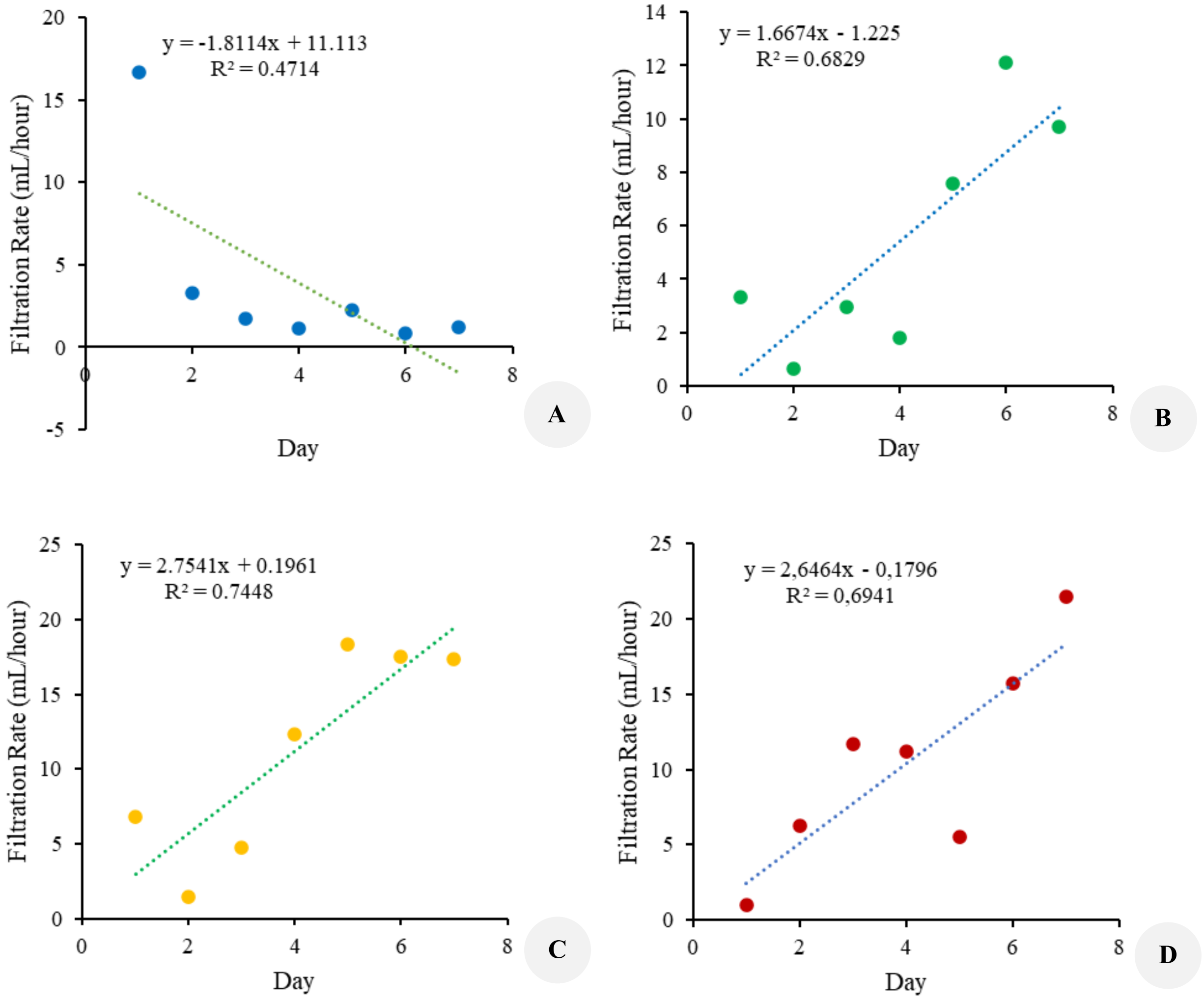

Figure 2. Effects of blood cockle exposure duration on nitrite filtration rate in treatments A, B, C, and D

Table 5. Change in nitrite concentration

Treatments	Nitrite concentration (mg/L)							
	D0	D1	D2	D3	D4	D5	D6	D7
A	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23
	Reduction	3.26	1.50	1.01	0.69	1.49	0.61	0.90
B	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23
	Reduction	1.58	1.31	3.91	3.71	4.65	3.79	4.25
C	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23
	Reduction	1.53	0.33	1.83	1.38	4.66	5.93	5.71
D	7.23	7.23	7.23	7.23	7.23	7.23	7.23	7.23
	Reduction	0.50	3.54	6.18	5.65	3.28	5.88	5.29

Table 6. Filtration rate of blood cockle on nitrite

Treatments	Filtration rate of blood cockle (mL/hour)						
	D1	D2	D3	D4	D5	D6	D7
A	16.65^{a}	3.29^{a}	1.72^{a}	1.11^{b}	2.27^{b}	0.85^{b}	1.19^{b}
B	6.85^{b}	1.43^{a}	4.74^{b}	12.35^{a}	18.32^{a}	17.48^{a}	17.32^{ab}
C	3.32^{c}	0.65^{a}	2.96^{c}	1.80^{bc}	7.58^{ab}	12.09^{ab}	9.71^{ab}
D	1.01^{d}	6.28^{a}	11.67^{d}	11.19^{ac}	5.49^{ab}	15.72^{ab}	21.48^{a}

Discussion

Changes in the concentration of inorganic and organic compounds in water indicate the occurrence of decomposition processes associated with dissolved organic matter in wastewater, including uneaten feed, feces, and other metabolic waste generated during shrimp culture. The accumulation of organic matter leads to oxygen depletion and increased concentrations of ammonia and nitrate, which not only negatively affect shrimp health and growth but also pose environmental risks, such as eutrophication of surrounding waters (Singh et al. 2021; Akinnawo 2023). Ammonia is a byproduct of protein decomposition derived from uneaten or undigested feed that is released into the water during shrimp cultivation. The increase in nitrate concentration occurs due to the partial oxidation of ammonia by bacteria through the nitrification process, which consists of two phases: namely the initial oxidation of ammonia to nitrite by *Nitrosomonas* bacteria, followed by the oxidation of nitrite to nitrate by *Nitrobacter* (Lu et al. 2021).

As the blood cockle continues their feeding process through filtration, these organisms absorb TOM and nitrite into their tissues, leading to a decrease in the concentration of these compounds in the water. The ability of blood cockle to remediate wastewater is attributed to both filtration (Riisgård 2001; Fitriani et al. 2022) and bioturbation processes (Nicholaus et al. 2019). Blood cockle obtains food by filtering suspended particles from the water (Koo and Seo 2020). This mechanism occurs by drawing in water and trapping dissolved particles on the gills and labial palps, which play a crucial role in sorting large amounts of particulate matter (Rosa et al. 2018). The highest remediation effectiveness, indicated by the greatest reduction in TOM concentration, was observed in the treatment with larger-sized cockle (Treatment D). Meanwhile, the highest nitrite remediation effectiveness was recorded in Treatment C. Both treatments had large-sized cockle, despite differences in shrimp density.

The decrease in nitrite concentration can be attributed to two possible mechanisms i.e., the oxidation of nitrite to nitrate during the nitrification process, specifically in the nitration phase mediated by *Nitrobacter,* and the utilization of nitrite for the formation of biomass proteins in the blood cockle. The highest nitrite remediation effectiveness observed in treatments with larger shrimp suggests that remediation capacity improves with increasing size, as more TOM and nitrite are filtered and incorporated into the biomass. The size of key organs, particularly the gills, is positively correlated with cockle size, indicating that larger cockle has a greater capacity for organic matter absorption (Gonzalez et al. 2021). In addition to the gills, other organs, such as the muscles, foot, and mantle, contribute to the filtration process by working together to generate strong water currents (Meseck et al. 2020). The effectiveness of remediation is closely linked to the bioturbation activity of blood cockle, as larger mussels exhibit higher bioturbation levels than smaller ones (Lukwambe et al. 2018, 2020; Gonzalez et al. 2019). Bioturbation results from cockle activity that stirs both water and sediments (Rosa et al. 2018). This process includes repetitive shell opening and closing movements, which facilitate water mixing and enhance filtration efficiency (Nicholaus et al. 2019).

The bioturbation activity of *T. granosa* also enhances oxygen distribution, promoting the formation of redox zones around the mixing points. These zones support bacterial growth and increase the activity of nitrifying bacteria involved in the oxidation of ammonia to nitrite (Nicholaus et al. 2019). Consequently, bioturbation enhances mussel metabolism by stimulating aerobic bacteria, which play a crucial role in the degradation of organic matter (Ma et al. 2015). The reduction in nitrite concentration due to bioturbation further stimulates nitrification by *Nitrobacter*, which biologically oxidizes nitrite to nitrate. This process becomes more intensive as the cockle size increases. Thus, bioturbation activity in mussel populations significantly contributes to reducing aquaculture waste (Muangkeow et al. 2007; Lukwambe et al. 2018).

The single factors of cockle density and size had a significant effect ($p<0.05$) on the filtration rate of TOM concentration. Larger blood cockle (4-5 cm) filtered wastewater and absorbed dissolved organic matter at a higher volume per unit time. Although blood cockle can reduce organic matter content through digestion, assimilation, and decomposition (Lukwambe et al. 2018; Nicholaus et al. 2019), larger cockle has a greater filtration capacity for TOM-rich water through the inhalant and exhalant mechanisms during each shell opening and closing cycle (Rosa et al. 2018) compared to smaller cockle. This enhanced filtration ability is likely due to the larger gills and greater surface area, which enable more efficient capture of food particles and organic matter suspended in the water (Pouil et al. 2021). Additionally, higher cockle density facilitates greater TOM absorption into the biomass, as the larger volume of water filtered collectively by all individuals results in increased TOM removal.

Several studies have reported the filtration performance of other bivalves under different environmental condition. *Perna viridis* (Linnaeus, 1758) can absorb carbon, nitrogen, and phosphorus with filtration rates found to be 2128.72, 265.41, and 66.67 mg/year/indv, respectively (Tantanasarit et al. 2013). Adsorption using *P. viridis* (green mussel) media was able to remove up to 65% of Chemical Oxygen Demand (COD) and 45% of ammoniacal nitrogen (NH_3-N), indicating a relatively effective filtration performance (Detho et al. 2022). In comparison, *T. granosa* in the present study exhibited considerable filtration capacity, making it a viable candidate for wastewater treatment in aquaculture systems. The application of *T. granosa* at larger scales holds promise, particularly due to its wide availability and adaptability in coastal environments. However, potential limitations include its sensitivity to elevated ammonia levels, which may affect survival and filtration efficiency under highly polluted conditions. Further studies are needed to evaluate the species long term tolerance thresholds. Moreover, integrating *T. granosa* into Integrated Multi Trophic Aquaculture (IMTA) systems could enhance sustainability by simultaneously improving water quality and diversifying production (Azhar and Memiş 2023). As a natural biofilter, blood cockles could complement shrimp or finfish culture by removing excess nutrients and organic matter, reducing environmental impacts and contributing to circular nutrient management in aquaculture.

Based on the result, only cockle density, as a single factor, had a significant effect on the filtration rate of nitrite in the water. This is a logical outcome, as higher cockle density results in a larger total volume of water being filtered by the entire population. Smaller cockle had a lower TOM filtration rate compared to larger ones but showed a higher filtration rate for nitrite. This may be due to their lower ability to absorb TOM as a food source, leading to a higher proportion of nitrite being absorbed instead. Consequently, smaller cockle demonstrated a higher nitrite filtration rate than their larger counterparts.

In conclusion, this study demonstrates the potential of *T. granosa* as an effective natural biofilter in intensive *L. vannamei* culture. The optimal configuration cockle size of 4-5 cm at a density of 30 individuals per 10 L achieved the highest Total Organic Matter (TOM) reduction (24.29%) and filtration rate (4.71 mL/h) over the 7-day trial. These results highlight the importance of selecting appropriate size and density to maximize nutrient removal efficiency and maintain water quality. From a practical standpoint, integrating *T. granosa* into shrimp pond systems could reduce organic loading, improve culture conditions, and support the design of more sustainable aquaculture operations. The use of bivalve biofilters aligns with circular nutrient management principles and can complement existing waste treatment strategies. Future work should focus on scaling this approach to commercial pond systems, assessing long-term performance, and evaluating ecological impacts to ensure its viability as a sustainable solution for shrimp farming.

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