Ability to convert nutrients from the wastewater of autotrophic and mixotrophic shrimp farming into *Artemia* biomass

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Abstract. Cultivating *Artemia* (brine shrimp) using whiteleg shrimp (*Litopenaeus vannamei*) wastewater is highly effective, providing a sustainable feed source that boosts shrimp growth, survival, and feed efficiency. This integrated approach, using nutrient-rich effluent to grow natural food (*Artemia*) that is then fed back to the shrimp, creates a more circular aquaculture model, cutting costs and environmental impact. The results of the study indicated that *Artemia* can be successfully cultured using wastewater from shrimp farming. The dry biomass of *Artemia*, on 14th day, cultured in the autotrophic treatment exhibited significantly greater length, biomass, and nitrogen content ($p < 0.05$) such as 8.1±0.01 mm, 359.0±9.30 mg, and 29.1±0.92 mg container^{-1}, respectively, in comparision with the mixotrophic, including 7.9±0.15 mm, 310.5±5.26 mg, and 25.2±0.77 mg container^{-1}. The nitrogen recovery in wastewater could reach up to 9.3%, using the wastewater from an autotrophic shrimp system supplemented with microalga *Chaetoceros muelleri* during the shrimp culture cycle. Meanwhile the nitrogen could be recovered up to 7.1% with using the waster water from the mixotrophic shrimp culture system. After 14 days, these findings highlighted the potential of this method in effectively recycling nutrients, reducing environmental pollution and enhancing the sustainability of shrimp farming.

Key Words: *Artemia* biomass, effluents, nitrogen recovery, shrimp culture, wastetwater.

Introduction. According to the Global Seafood Alliance, global farmed shrimp production increased from 3.2 million tons in 2010 to 5.6 million tons in 2023 and is projected to continue rising in the coming years (Jory 2023; FAO 2024). Water consumption for producing 1 kg of market-size shrimp varies considerably, reaching 45.5 m^3 in Vietnam, 14 m^3 in Thailand, 55 m^3 in Indonesia, 39.2 m^3 in India, and 76.8 m^3 in Ecuador; meanwhile, feed conversion ratios (FCR) range from 1.2 to 1.6 (Boyd et al 2021). One kilogram of commercial shrimp feed typically contains approximately 35% protein, equivalent to about 56 g of nitrogen; however, shrimp assimilate only 19-25% of the nitrogen intake, while the remainder is released into the culture environment as feces, excretory products, and uneaten feed (Chen et al 2018; Iber & Kasan 2021). The rapid expansion of shrimp aquaculture has consequently imposed substantial pressure on natural ecosystems, primarily due to the accumulation of inorganic nitrogen in effluents, which contributes to eutrophication, disease outbreaks, and biodiversity loss, ultimately threatening the sustainability of the industry (Iber & Kasan 2021; Tom et al 2021).

To mitigate the adverse environmental impacts of shrimp farming effluents, a range of advanced aquaculture systems - such as biofloc technology, recirculating aquaculture systems (RAS), aquaponics, autotrophic systems, mixotrophic systems, and integrated multi-trophic aquaculture (IMTA) - have been widely implemented (Chang et al 2020; de Moraes et al 2020; Lothmann & Sewilam 2023). These systems function based on nutrient transformation along natural food webs, in which inorganic nitrogen is ingested by microorganisms and microalgae and subsequently converted into biomass that can serve as a food source for heterotrophic organisms such as oysters, copepods, and tilapia fish (Poli et al 2019; Chang et al 2020).

Microalgae are considered a highly promising biological agent for wastewater treatment due to their ability to absorb dissolved inorganic nitrogen and phosphorus (Khatoon et al 2016; Magnotti et al 2016). They also serve as a high-quality feed source for *Artemia*, oysters, and copepods (Sorgeloos 1985; Magnotti et al 2016; Chang et al 2020). Furthermore, autotrophic shrimp farming systems supplemented with beneficial microalgae have demonstrated notable improvements in water quality and shrimp productivity (Godoy et al 2012; Ge et al 2016; Meng et al 2024).

Artemia, a genus comprising filter-feeding zooplankton species, exhibits high filtration capacity - up to 64 mL individual^{-1} per day - and can consume approximately 6.4×10^6 algal cells per day. It is particularly efficient at removing suspended organic particles smaller than 50 μm (Ogburn et al 2023; Truong & Nguyen 2024). *Artemia* is also a widely used live feed for various aquaculture species at the larval stage, including shrimp, fish, and crabs (Sorgeloos et al 1998; Nguyen 2011). Thus, *Artemia* represents a promising candidate for nutrient recovery and wastewater reuse in shrimp aquaculture.

This study aims to evaluate the potential use of nutrient-rich effluents - containing microalgae and organic matter - from autotrophic shrimp farming systems, compared with mixotrophic systems lacking microalgal supplementation, for *Artemia* biomass production. Additionally, organic nitrogen levels in both shrimp-culture effluents and *Artemia* biomass were quantified to assess nitrogen recovery efficiency. The findings are expected to contribute to environmentally friendly solutions for reducing effluent pollution, improving the sustainability and productivity of shrimp farming systems, and providing an economically valuable *Artemia* biomass source for other aquaculture species.

Material and Method

Description of the study sites. The experiment was conducted from July to October 2025 at the Cam Ranh Centre for Tropical Marine Research and Aquaculture, Aquaculture Institute, Nha Trang University, Vietnam.

Microalgae culture. The microalga *Chaetoceros muelleri* was sourced from the laboratory of the Aquaculture Institute and cultured in 5-L glass flasks, following Doan et al (2018). Sterilized seawater (by using chlorine 20 ppm) with a salinity of 25 ppt was enriched with f/2 medium and maintained under controlled conditions such as the temperature of 26°C, an initial inoculation density of 50,000 cells mL^{-1}, illumination of 4600 lux provided by Phillips 60-W bulbs, and a 24:0 h light:dark cycle. Those cultures reaching densities above 3×10^6 cells mL^{-1} were used for the autotrophic shrimp system and as feed for *Artemia* prior to experimentation.

Artemia culture. *Artemia franciscana* (Vinh Chau strain, Soc Trang, Vietnam) were hatched and reared in 200L tanks containing filtered seawater at a density of 1500 individuals L^{-1}. They were fed *C. muelleri* according to daily feeding rates described by Naegel (1999). *Artemia* aged 7 days were used for the experiment.

Shrimp culture. Shrimp were reared for 60 days in twelve 1 m^3 circular composite tanks under two systems (six replicates each): 1) autotrophic system: adding *C. muelleri* + silicate: 2) mixotrophic system (as the control): adding silicate only. Each treatment consisted of six replicates. Tanks were sheltered from direct sunlight and aerated continuously. Shrimp were stocked at 200 individuals per tank with an initial mean weight of 1.22±0.08 g, and fed a commercial diet (40% protein) at 4-8% body weight/day in four feedings (07:00, 11:00, 16:00, 21:00). Uneaten feed and waste were siphoned twice daily (09:00, 18:00), and 10-20% water was exchanged daily. To maintain autotrophic conditions, *C. muelleri* was supplemented twice weekly to sustain algal densities above 30,000 cells mL^{-1} (Meng et al 2024). Silicate (Na_2SiO_3) was added to both systems at 5 ppm twice weekly (Emerenciano et al 2022). Alkalinity was stabilized by adding $NaHCO_3$ at 10 ppm every three days; CaO at 20 ppm every 3-5 days was used for pH regulation and algal biomass control. When total ammonia nitrogen (TAN) exceeded 2 ppm, carbon from refined sugar (50% carbon content) was added at a C:N ratio of 6:1 following Mohammadi et al (2023).

Water quality was maintained within the following ranges: $NH_4^+ < 2$ mg L^{-1}, $NO_2^- < 5$ mg L^{-1}, alkalinity 120-160 mg L^{-1}, pH 7.8-8.5, temperature 27-31°C, DO > 5 mg L^{-1}, salinity 25-34 ppt.

Shrimp effluent used for Artemia culture. Effluent was collected on day 32 of shrimp culture, when shrimp reached 7.7±0.46 g and were fed 76 g feed/tank/day. Effluents from the two systems were filtered through < 50 μm mesh bags and stored separately in 2000 L aerated composite tanks. Water quality parameters (salinity, alkalinity, pH, temperature, DO, NH_4^+, NO_2^-, total Kjeldahl nitrogen (TKN), algal composition, algal density, and total suspended solids (TSS)) were monitored every seven days throughout the 21-day *Artemia* culture.

Experimental design of Artemia culture. Artemia were reared in 24 plastic containers containing 8 L of water, assigned to 2 treatments (12 containers each) as described following: treatment A - effluent from the autotrophic shrimp system; treatment B: effluent from the mixotrophic system (without microalgal supplementation). Initial stocking density of *Artemia sp.* was 100 individuals L^{-1} with a uniform body length of 3.1±0.04 mm. Total experimental duration was 21 days. Concerning the sampling schedule, at the day 7th, 14th and 21st, four containers of each treatment were randomly collected to determine *Artemia* length, survival, dry biomass, nitrogen content, total effluent volume supplied, and nitrogen concentration in effluent.

Experimental management. Containers were kept under shelter and aerated continuously. Effluent was supplied 2-6 times/day depending on biomass increase. The daily effluent volume was calculated using *Artemia* filtration rate based on Li et al (2024):

$$FFR = 0.487 \cdot BL + 0.067 \cdot T - 0.01 \cdot D - 0.064 \cdot PS - 1.508$$

where: FFR = filter-feeding rate, BL = body length (mm), T = temperature (°C), D = density (ind L^{-1}), PS = particle size (μm).

Adjustments were made based on water clarity and gut fullness (Thong et al 2024; Nguyen et al 2024). Before each effluent addition, an equivalent volume was removed to maintain a constant 8 L per container. Discharged water from each treatment was collected separately in 2000L tanks, and water quality was analyzed on the day 1st, 7th, 14th, and 21st.

Data collection and evaluation

Water quality parameters. Dissolved oxygen content, temperature, salinity and pH were measured using HI 9147 and ENZO 7011 handheld meters. Chemical oxygen demand (COD) was determined by the Closed Reflux, Titrimetric Method according to SMEWW 5220C:2023; (NH_3-N) was detected using the Phenate method (SMEWW 4500- NH_3-F), NO_2^--N using the colorimetric method (SMEWW 4500-NO_2-B) and Total Kjeldahl Nitrogen (TKN) via the Kjeldahl method (SMEWW 4500-Norg C); total suspended solids (TSS) was figured out by gravimetric method (SMEWW 2540D) and chlorophyll-*a* was found out via fluorometry (APHA 2017).

Algal density. Algal density was quantified using an improved Neubauer hemocytometer under a compound microscope (Olympus BX41TF, Japan, 400×). Density was classified following Thong et al (2024), such as +++ = > 60% (high), ++ = 30-60% (medium), + = < 30% (low).

Artemia growth and biomass. Growth was measured as body length from the anterior tip to the base of the furca using a digital caliper (0.1 mm resolution). Dry biomass was determined by drying samples at 105-130°C (TCVN 3700-90) and weighing with a Sartorius CP224S analytical balance (accuracy 0.1 mg). Nitrogen content in *Artemia* was quantified by the Kjeldahl method.

Nitrogen recovery. Nitrogen supplied from effluent was calculated as below:

$$\text{Recovery efficiency (\%)} = (\text{N taken up} / \text{Total N applied}) \times 100$$
$$\text{N taken up} = (Bt \times \%Nt) - (Bo \times \%No)$$

where: Bo, Bt: *Artemia* biomass (g or mg) at the initial and biomass at time T; %No, %Nt: nitrogen taken up at the initial and biomass at time T.

$$\text{Day } 7^{th}\text{: } N = (TKN_1 + TKN_7)/2 \times V_{1-7}$$
$$\text{Day } 14^{th}\text{: } N = (TKN_1 + TKN_7 + TKN_{14})/3 \times V_{1-14}$$
$$\text{Day } 21^{st}\text{: } N = (TKN_1 + TKN_7 + TKN_{14} + TKN_{21})/4 \times V_{1-21}$$

where: TKN_1, TKN_7, TKN_{14}, and TKN_{21} represent total nitrogen concentrations (mg L^{-1}), and V_{1-7}, V_{1-14}, V_{1-21} are cumulative effluent volumes supplied during the respective intervals.

***Statistical analysis*.** Data were analyzed using IBM SPSS Statistics 26.0. Normality and homogeneity of variance were confirmed prior to one-way ANOVA. When significant differences were detected, Duncan's multiple range test was applied for post-hoc comparisons at a significance level of $p < 0.05$. All values are expressed as mean± standard deviation (SD).

Results

***Water quality parameters*.** The water quality parameters of the influent and effluent from the autotrophic and mixotrophic treatments during the 21-day *Artemia* culture period were presented in Table 1.

Table 1
Water quality parameters of influent and effluent from shrimp-culture wastewater used for artemia culture in the two treatments

Parameters	*Autotrophic*		*Mixotrophic*	
	Input	*Output*	*Input*	*Output*
Temperature (°C)	28.3 ± 0.63^a	28.4 ± 0.65^a	28.5 ± 0.53^a	28.4 ± 0.36^a
Salinity (ppt)	32.7 ± 0.21^a	33.9 ± 0.31^a	33.2 ± 0.19^a	34.1 ± 0.35^a
DO (mg L^{-1})	6.2 ± 0.47^a	6.0 ± 0.56^a	5.95 ± 0.66^a	5.78 ± 0.62^a
pH	7.9 ± 0.18^a	7.8 ± 0.21^a	8.1 ± 0.18^a	7.9 ± 0.22^a
Alkalinity (mg L^{-1})	112.0 ± 8.4^a	105.5 ± 12.6^a	121.3 ± 9.5^a	107.0 ± 12.8^a
NH_4^+ (mg L^{-1})	0.47 ± 0.16^a	0.73 ± 0.17^{bc}	0.68 ± 0.09^b	0.85 ± 0.13^c
NO_2^- (mg L^{-1})	0.83 ± 0.25^a	0.90 ± 0.21^a	0.73 ± 0.34^a	0.93 ± 0.42^a
TKN (mg L^{-1})	2.45 ± 0.26^b	1.95 ± 0.24^a	2.75 ± 0.38^b	2.12 ± 0.36^a
Chlorophyll-a (µg L^{-1})	138.3 ± 8.96^c	39.6 ± 14.43^a	117.8 ± 12.04^b	36.3 ± 10.31^a
COD (mg L^{-1})	27.5 ± 4.66^b	18.8 ± 3.30^a	29.0 ± 3.92^b	19.2 ± 4.08^a
TSS (mg L^{-1})	54.8 ± 7.14^b	28.5 ± 4.51^a	50.5 ± 8.51^b	27.8 ± 9.22^a

Data are expressed as mean±SD. Different superscript letters in the same row indicate statistically significant differences ($p < 0.05$).

No significant differences ($p > 0.05$) were observed between the two wastewater sources in temperature, salinity, DO, pH, alkalinity, NO_2^-, TKN, COD, and TSS. However, significant differences ($p < 0.05$) were detected in NH_4^+, and chlorophyll-*a* between the two treatments.

The effluent from artemia culture, in both treatments, exhibited significantly lower concentrations of TKN, TSS, COD, and chlorophyll-*a* compared with influent water ($p < 0.05$). Other parameters - including temperature, salinity, DO, pH, and alkalinity - did not differ significantly between influent and effluent ($p > 0.05$). These results indicate that *Artemia* effectively reduced COD, TSS, TKN, and chlorophyll-*a* concentrations in shrimp-farm wastewater during the 21-day culture period. However, the results showed that NH_4^+ concentrations in the effluent were not reduced in both treatments.

Phytoplankton composition in wastewater. Phytoplankton taxa identified in the wastewater of both systems are presented in Table 2.

Table 2

Phytoplankton composition in wastewater from the two systems used for *Artemia* culture

Species	*Mixotrophic*	*Autotrophic*
Bacillariophyta		
Chaetoceros muelleri	+	++
Nitzschia sp.	+	+
Navicula sp.	+	+
Thallassiosira sp.	+	+
Skeletonema sp.	+	-
Chlorophyta	+	
Nannochloropsis sp.	+	+
Chlorella sp.	+	+
Other species	+	+

Density: ++ = > 30-60% (medium), + ≈ < 30% (low).

Analysis revealed seven genera, of which five were diatoms: *Chaetoceros muelleri, Nitzschia* sp., *Navicula* sp., *Thalassiosira* sp., *Skeletonema* sp., *Nannochloropsis* sp., *Chlorella* sp., along with several unidentified low-density species. In the autotrophic system, *C. muelleri* dominated (++) to other taxa, while *Skeletonema* sp. was absent.

Growth performance, biomass, and nitrogen accumulation in Artemia. *Artemia* growth, survival, dry biomass, and nitrogen content across treatments and sampling times are shown in Table 3.

Table 3

Length, survival, dry biomass, and nitrogen content of *Artemia* cultured in wastewater from the two systems

Parameters	*Treatment*	*Day 1st*	*Day 7th*	*Day 14th*	*Day 21st*
Length (mm)	Autotrophic	3.1±0.04	6.6±0.18^{a}	8.1±0.01^{a}	9.2±0.09^{a}
	Mixotrophic	3.1±0.04	6.4±0.17^{a}	7.9±0.15^{b}	9.1±0.15^{a}
Survival rate (%)	Autotrophic	100	82.3±3.86^{a}	68.7±4.03^{a}	32.5±4.65^{a}
	Mixotrophic	100	79.8±2.98^{a}	60.2±5.37^{a}	25.5±2.64^{b}
Dry biomass (mg container^{-1})	Autotrophic	71.1±0.03	280.8±3.59^{a}	359.0±9.30^{a}	230.0±23.94^{a}
	Mixotrophic	71.1±0.03	276.0±5.44^{a}	310.5±5.26^{b}	191.8±4.27^{b}
Nitrogen content in *Artemia* (mg container^{-1})	Autotrophic	5.46±0.01	22.3±0.42^{a}	29.1±0.92^{a}	22.8±2.43^{a}
	Mixotrophic	5.46±0.01	20.5±0.41^{b}	25.2±0.77^{b}	18.3±1.25^{b}
Cumulative nitrogen content in *Artemia* (mg container^{-1})	Autotrophic	-	16.8±0.42^{a}	23.6±0.93^{a}	17.4±2.44^{a}
	Mixotrophic	-	15.1±0.41^{b}	19.7±0.77^{b}	13.5±1.25^{b}

Data are expressed as mean±SD. Different superscript letters in the same column indicate statistically significant differences ($p < 0.05$).

Initial *Artemia* size was 3.1±0.04 mm (71.1±0.03 mg container^{-1} ≈ 800 individuals container^{-1}). After 7 days, no significant differences ($p > 0.05$) were observed between treatments in length, survival, or biomass. *Artemia* in the autotrophic treatment reached 6.6±0.18 mm length, 82.3±3.86% survival, and 280.8±3.59 mg biomass, similar to the mixotrophic values of 6.4±0.17 mm length, 79.8±2.98%, and 276.0±5.44 mg. However, nitrogen content in *Artemia* was significantly higher ($p < 0.05$) in the autotrophic treatment (22.3±0.42 mg container^{-1}) than in the mixotrophic (20.5±0.41 mg container^{-1}). On day 14, *Artemia* in the autotrophic treatment exhibited significantly greater length, biomass, and nitrogen content ($p < 0.05$) compared with the mixotrophic such as 8.1±0.01 mm, 359.0±9.30 mg, and 29.1±0.92 mg container^{-1}, respectively, versus 7.9±0.15 mm, 310.5±5.26 mg, and 25.2±0.77 mg container^{-1} in the mixotrophic. No significantly difference was observed in survival rates. By day 21, survival, biomass, and nitrogen accumulation decreased markedly in both treatments, although *Artemia* continued to grow in length. The autotrophic treatment maintained higher values (32.5±4.65%, 230.0±23.94 mg container^{-1} and 22.8±2.43 mg container^{-1}) compared with the mixotrophic system (25.5±2.64%, 191.8±4.27 mg container^{-1}, 18.3±1.25 mg container^{-1}). Overall, *Artemia* cultured in autotrophic effluent consistently showed superior growth and nitrogen accumulation compared with those cultured in the mixotrophic effluent.

Nitrogen recovery efficiency. Nitrogen recovery performance in the experiment was summarized in Table 4.

Table 4

Nitrogen recovery efficiency of rtemia in the two wastewater sources

Parameters	*Treatment*	*Day 7th*	*Day 14th*	*Day 21st*
Total volume of wastewater used for 1 mg of *Artemia* biomass (L mg^{-1})	Autotrophic	4.7±0.12^{a}	9.8±0.39^{a}	20.3±2.76^{a}
	Mixotrophic	5.3±0.14^{b}	11.8±0.47^{b}	26.0±2.56^{b}
Total nitrogen input (mg) per 1 mg of *Artemia* biomass	Autotrophic	10.7±0.27^{a}	23.3±0.93^{a}	49.8±6.76^{a}
	Mixotrophic	14.1±0.08^{b}	32.2±1.29^{b}	71.6±7.08^{b}
Nitrogen uptake efficiency of *Artemia* (%)	Autotrophic	9.3±0.23^{a}	4.3±0.17^{a}	2.0±0.28^{a}
	Mixotrophic	7.1±0.20^{b}	3.1±0.12^{b}	1.4±0.13^{b}

Data are expressed as mean±SD. Different superscript letters in the same column indicate statistically significant differences ($p < 0.05$).

These results confirm that the autotrophic system - with additional microalgal biomass and higher-quality particulate nutrition - enhanced *Artemia's* ability to assimilate nitrogen from shrimp-farm wastewater, consistent with the nutrient assimilation mechanisms associated with microalgal-microbial pathways.

Discussion. *Artemia* is considered as an essential food in the rearing of aquatic animals. Nguyen et al (2024) used *Artemia* biomass as a supplementary feed for shrimp at the age of about 20-60 days. At that stage, the shrimp reach a size (6.41±0.31 cm length, 1.42±0.13 g shrimp^{-1}) large enough to effectively utilize the *Artemia* biomass (6.72±0.84 mm length). The supplementation of *Artemia* resulted in a substantial increase in shrimp biomass, 8.16 to 14.89%, compared to the control. Specifically, the shrimp biomass in the *Artemia* supplementation groups (10-40% supplemented *Artemia*: 3.05-3.24 g L^{-1}) was significantly higher than that in the control (2.82 g L^{-1}) ($p < 0.05$). Those research results have shown the potential and initial effectiveness of using *Artemia* biomass as supplementary feed for shrimp in intensive shrimp farming models.

The present study aimed to use of waster water from 2 common systems in aquaculture: autotrophic and mixotrophic system to produce *Artemia* biomass. Environmental parameters in shrimp-farm effluents - particularly salinity, temperature, microalgal composition, microalgal density, and suspended organic particles < 50 μm - are primary determinants of *Artemia* growth and survival (Ogburn et al 2023; Thong et al 2024; Nguyen et al 2024). Other variables such as pH, alkalinity, TAN, and TSS also affect *Artemia*, but their influence is limited because the species tolerates broad environmental ranges compared with the variability typically observed in shrimp-farm wastewater (Kumar & Babu 2015; Nguyen et al 2020; Thong et al 2024). *Artemia* can grow satisfactorily at salinities > 15 ppt (Nguyen & Huynh 2017). However, lifespan decreases notably at lower salinity ranges (15-30 ppt), resulting in reduced reproductive output. Previous studies indicate that salinities > 25 ppt are optimal for biomass production (Thong et al 2024). Temperature exerts similarly strong control: growth slows or mortality occurs at < 20°C, whereas temperatures > 36°C cause stress, reduced reproduction, and slow population recovery. The optimal thermal window for the Vinh Chau *A. franciscana* strain is 25-32°C (Tran et al 2018; Thong et al 2024).

Nutritional quality of wastewater - reflected through microalgal assemblages, algal biomass, TSS, and TKN - is a key driver of *Artemia* performance, as these components constitute the primary food available in the aquacultural system (Ogburn et al 2023; Shyne Anand et al 2024). Numerous reports (Nguyen 2014; Pacheco-Vega et al 2015; Mohebbi et al 2016) confirmed that diatoms represent the preferred food group for *Artemia* and support superior growth to other microalgal taxa. Moreover, a mixture of microalgae and fine organic particulates enhanced *Artemia* growth more effectively than microalgae alone (Tran et al 2018; Shyne Anand et al 2024). In this study, both wastewater sources displayed a high proportion of diatoms and a diverse microalgal community, indicating suitable nutritional conditions (Tran et al 2018; Thong et al 2024). Organic particulates (TSS = 50.5-54.7 mg L^{-1}) likely provided an additional nutritional supplement (Yao et al 2018; Nguyen et al 2020).

Early survival and growth of *Artemia* were strongly linked to food availability, especially microalgae. Tran et al (2018) reported survival rates > 91% and > 81% on days 7th and 14th respectively, when microalgae were incorporated into the diet. Magnotti et al (2016) also demonstrated survival up to 85% with microalgae constituting 25% of feed. Conversely, *Artemia* fed only bioflocs exhibited very low survival (16-22%) (Yao et al 2018). Survival, in the present study, exceeded that of *Artemia* cultured using shrimp-hatchery wastewater (Nguyen et al 2020) or grow-out effluent (Nguyen et al 2024; Thong et al 2024), but remained below that of pond-cultured *Artemia* (Nguyen 2014) or systems supplemented with 25% microalgal feed (Magnotti et al 2016). Variations among studies largely reflected the differences in food quality and composition across wastewater sources. The marked decline in survival after day 14th likely corresponds to the onset of reproduction, when energy demands exceeded the nutritional supply available in untreated wastewater - an interpretation consistent with Hoa et al (2011), who observed reduced survival when *Artemia* were fed microalgae alone.

Body growth is influenced by food quality, ration, stocking density, and initial *Artemia* condition. Growth in this study was lower than previously reported (Magnotti et al 2016; Nguyen et al 2020; Thong et al 2024), likely due to differences in stocking density and daily nutrient input. Although both treatments received equal wastewater volumes, differences in microalgal composition - especially high *C. muelleri* abundance and elevated chlorophyll-*a* - and differences in fine organic matter (TSS) accounted for variation in size and survival observed from day 7 onward.

Higher performance in the autotrophic effluent treatment reflects the dominance of *C. muelleri*. Prior work showed that *Chaetoceros* sp. diets produce higher survival, growth, and biochemical quality of *Artemia* than *Nannochloropsis* sp. or *Chlorella* sp. (Hoa et al 2011; Nguyen 2014). Consequently, *Artemia* cultured in autotrophic effluent achieved greater biomass due to higher survival and larger body size.

Nitrogen recovery was consistently higher in the autotrophic treatment across all sampling times, despite similar wastewater N concentrations and water replacement rates. This effect was driven primarily by greater *C. muelleri* biomass in the autotrophic effluent. Very few studies quantify nitrogen recovery by *Artemia* from shrimp-farm wastewater, although nitrogen removal processes are well documented (Ogburn et al 2023; Truong & Nguyen 2024). Comparatively, the nitrogen recovery efficiency achieved here (7.1-9.3%) exceeds that reported for bivalves (5.3-7.51%) (Chang et al 2020; Bayer et al 2024) over one-year periods. Sorgeloos (1985) similarly observed that *Artemia* converted microalgal protein (*Chaetoceros* sp.) into biomass more efficiently (41.1%) than bivalves such as *Tapes japonica* (11.7%) over 14 days in flow-through systems.

A key finding of this study is that nitrogen recovery by *Artemia* occurs rapidly, within 7-14 days. Furthermore, *Artemia* biomass can be produced at high density in compact systems (Thong et al 2024), making it suitable for industrial-scale waste-to-biomass conversion. The resulting biomass can be reused as feed for high-value aquaculture species (larval shrimp, marine ornamentals, juvenile fish, and mollusks). Nevertheless, *Artemia* population biomass remained dependent on initial stocking density. Lifespan in wastewater-only systems was shorter than in systems supplemented with formulated diets or combined food sources. Although reproduction occurred during the 21-day trial, recruitment was insufficient to offset mortality.

This study demonstrates that *A. franciscana* can effectively recover nitrogen from shrimp-farm effluents within a short culture period of 7-14 days. Nitrogen recovery efficiency was strongly influenced by the microalgal composition, microalgal biomass, and suspended organic matter present in the wastewater, with effluents enriched in *C. muelleri* supporting superior *Artemia* growth, biomass production, and N assimilation.

Conclusions. This study has successfully documented the use of wastewater from shrimp culture systems for production of *Artermia* biomass. The findings highlight the potential of integrating microalgae–*Artemia* modules into intensive shrimp-farming systems as a practical strategy to convert nitrogenous wastes into high-value live biomass, while simultaneously improving effluent quality. Such integration offers dual benefits: (1) reducing environmental nitrogen loads, and (2) enhancing nutrient circularity by producing reusable *Artemia* biomass for larval and juvenile aquaculture species.

Overall, the results provide a scientific basis for developing circular, resource-efficient shrimp aquaculture models, where wastewater is not merely treated but biologically upgraded into a valuable product. Further research is recommended to optimize stocking density, nutrient supplementation, and system design to maximize biomass yield and nitrogen recovery under commercial-scale conditions.

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

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