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BIOMASS GAIN, FEED EFFICIENCY AND SURVIVAL RATES IN WHITELEG SHRIMP (*Litopenaeus vannamei*) CULTURED IN AQUAMIMICRY CONCEPT AND CONVENTIONAL METHODS WITH WATER EXCHANGE AND SETTLING CHAMBER

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Abstract
In the present study, biomass performance, feed efficiency, and survival rates of shrimp produced in Aquamimicry concept were comparatively evaluated along with conventional water-exchange-systems with -and without the use of settling chamber. Survival rates of shrimps cultured in the Aquamimicry concept were higher (91-92%) than those farmed with water exchange method with (68.6%) or without settling chamber (81%). In the water-exchange method (0.39) and Aquamimicry treated groups (0.32-0.39), apparent FCRs were almost 3-fold lower than the shrimps exposed to water-exchange system equipped with a settling chamber (0.97). Final biomass at harvest were higher in the Aquamimicry groups compared to traditional methods of water exchange with -or without settling chamber. The Aquamimicry group supplied with twice higher pellet-feed, but same amount of rice bran, demonstrated 1.4-fold higher final biomass compared to the less pellet-feed, but same level rice bran supplement group at DOC30. Water temperature (27.28 ± 1.12°C), dissolved oxygen (6.96 ± 0.46 mg/L), and pH (7.65 ± 0.18) were similar in all treatment groups. Minimum total ammonia nitrogen (TAN) of 0.67 and 1.17 mg/L were found in the water-exchange and Aquamimicry treatment with less pellet supply, whereas higher rates of 2.23 and 5.85 mg/L were found for the Aquamimicry group fed twice more pellet-diets and the water-exchange with settling chamber treatment, respectively. The lowest NO_2 level (1.84 mg/L) was obtained in the Aquamimicry group with

less pellet supply, and the highest NO_2 (4.02 mg/L) was found in the Aquamimicry group fed with high pellet supply. Alkalinity were similar in both water-exchange treatment groups either with or without settling chamber. The findings of this study provide useful support for farm managers for improving shrimp production towards more environment-friendly level by less - or even zero water exchange, with cost-effective method supporting population stability and economic improvements for the sustainability of shrimp aquaculture in future.

Keywords: water exchange system, settling tank, shrimp performance, biomass, Aquamimicry, KAMI SYS

Introduction

The world population reached nearly 8 billion people that remarkably increased food demand for the growing human population on earth (Worldometer, 2022). Global aquaculture production increased by around 57,3% in the last decade from 77.789.403,5 tons in 2010 to 122.340.397,4 tons in 2020 (FAO, 2022a). The economic activity increased by 100,49% from 140.408.465,9 USD to 281.499.275,5 USD over the last decade (FAO, 2022b), providing important inputs for food security, livelihood opportunities to many countries in the world. Considering the 8 billion people, world per capita fish supply shows a hit around 65.4 kg by 2020. Therefore, the aquaculture industry seems to be capable in meeting the increasing demand for human nutrition. However, it is highly important to increase food supply from aquaculture production with less usage of natural resources of water and land (Avnimelech, 2012). The increase of intensive aquaculture activities especially in shrimp culture causes significant waste outputs. Higher stocking densities and more intensive applications in shrimp farms, uncontrolled and irresponsible use of therapeutic agents has led to deterioration of water quality that in turns result in serious problem such as disease outbreaks (Deepak et al., 2020). Further, increased feeding rates for high stocking densities contribute to increased levels of total suspended solids (TSS) (Ebeling et al., 2006), that leads to poor water quality and may negatively affect health conditions and growth performance of aquatic animals under farm conditions (Hargreaves 2006; Van Wyk, 2006; Vinatea et al., 2010). For removal and management of TSS, settling tank systems are commonly used practices in shrimp farming (Ogle et al., 2006), which is also costs-effective compared to filtration systems (Timmons & Ebeling 2007). Recently, new technologies are introduced to achieve sustainable goals of aquaculture. The biofloc technology (BFT), and just recently introduced Aquamimicry concept of aquaculture are new methods in developing ecological shrimp production with less or zero waste discharges. The BFT uses recycled waste nutrients as food for fish, and depends on carbon to nitrogen (C: N) balance (Khanjani et al., 2022). The principal approach of BFT is to culture suitable microorganisms along with aquatic species (fish or shellfish) to produce a sustainable system with minimum -or even zero water exchange. The supplement of additionally carbon into the water helps the conversion of potentially harmful organic matter into consumable biomass, which is a process that can lessen the necessity for water exchange, which in turns provides biosecurity with environment-friendly approach (Romano, 2017). Compared to recirculating aquaculture systems (RAS), where only 10% of total water is replaced daily, the BFT is more cost-effective than the RAS method. However, the BFT requires continues aeration to keep the wastes (microbial floc) in constant suspension, which may increase operating costs (Romano, 2017). Further, the most recently introduced concept is called Aquamimicry that attracts more and more attention in sustainable aquaculture as an innovative approach simulating natural estuarine conditions through the development of copepods, which provide high value nutritional supplement for the shrimp in the culture environment. This new concept of Aquamimicry depends on organic carbon without the supply of specific C to N ratio. This method uses the interactive relation between a prebiotic source, that actually consists of an oligosaccharide, generated by fermentation of a carbon source which is usually rice bran, and a probiotic source such as *Bacillus* sp. that provides natural conditions by blooming phytoplankton and zooplankton, especially copepods, which then can be used as live food for shrimp (Khanjani et al., 2022). Also, the propagation of propitious and productive bacteria in the Aquamimicry system may provide consistency of the culture environment supporting better performance and welfare of shrimp in healthy culture conditions.

In the present study, growth performance and survival rates of shrimp produced in Aquamimicry concept were compared with those in conventional water-exchange-systems with -or without settling chambers. Further, the level of feed supply was also evaluated in terms of biomass and total ammonia nitrogen outputs in Aquamimicry culture conditions. The findings of this study are aimed to provide support for farm managers to shift their production towards more environment-friendly level by less -or even zero water exchange, as well as cost-effective method supporting social stability and economic improvement in countries.

Materials and methods

Study area and experimental shrimps

This study was carried out in April 2020 at the shrimp production facilities of the private company CTO-D.V.M., AD GOCHANG LTD in Jeollabuk-do, South Korea. A total of 970.000 individuals of PL (post-larvae) of Whiteleg *shrimp* (*Litopenaeus vannamei*) were used in this study. Four tanks with different culture methods were used in this study. The Tank-1 consisted of water exchange system with settling chamber (WE-SET), whereas Tank-2 was also set with water exchange system but without settling chamber (WE). For the other two culture methods, the Aquamimicry concept (AC), following the “Super Intensive Indoor Shrimp Farming System (KAMI SYS)” protocols, developed by the first author of this study (Yongkil Glen Cho) in Korea in early 2015, was applied in the present study in a recirculating aquaculture system (RAS) with two different feeding protocols, namely AC-1 (Tank-3) with low level pellet feeding, and AC-2 (Tank-4) with twice higher pellet feeding, but both AC groups were supplemented with similar amounts of fermented rice bran (FRB).

Surface area of WE-SET and WE tank environments were 154 and 80 m^2, respectively, and for the AC, both tanks were equal-sized with 80m^2 surface area for each of the culture tanks with no settling chambers allocated. Out of the total batch of 970.000 PLs, 350.000 and 240.000 PLs were randomly distributed to WE and WE-SET groups at stocking densities of 2.272 PLs/m^2, and 3.000 PLs/m^2, respectively. The culture tanks of the AC group were stocked with 180.000 and 200.000 PLs at densities of 2.250 and 2.500 PLs per square meter, respectively. The PLs were cultured in the intensive nursery tanks for 30 days.

Feed and feeding program

In the WE-SET (Tank-1) and WE (Tank-2) shrimps were fed with feed pellets over a period of 30 days. In AC-1 (Tank-3) and AC-2 (Tank-4), which followed the Aquamimicry concept, two different feeding protocols were applied. Shrimps in the present study received feed pellets starting with initial pellet size of 0.5 mm Ø and gradually increase to 0.5-1.0 mm Ø size throughout the study period of 30 days. Diets were purchased from shrimp feed manufacturing company of “Sajo Dong-A-won, Korea”, containing 50% crude protein and 7% crude fat. Nutritional composition and specifications of the commercial shrimp diets used in this study have been presented in Table 1.

Table 1. Nutritional composition and specifications of the commercial shrimp diets used for 30-days study period

Shape / form	Product Name*	Size	Crude protein (%) min	Crude fat (%) min	Crude fiber (%) max	Ash (%) max	Ca (%) min	P (%) max
Powder	Gold one	> 500um	50	7	4	17	1.2	2.7
Crumble	Gold 1-C	0.5~1.0mm	50	7	4	17	1.2	2.7

* Manufacturing company: Sajo Dong-A-won, Korea

Feeding in Tank-1 treated with WE-SET culture system was initiated with 0.42 kg/day at DOC-1 and continued in gradually increasing manner until DOC30 (days of period 30), that indicates a study period of 30 days in total. The WE group (Tank-2) also received feed pellets of 0.30 kg/day at DOC-2, again in increasing levels until DOC30. Shrimps exposed to Aquamimicry culture method (AC-1, Tank-3; AC-2, Tank-4) received pellets + fermented rice bran (FRB). Both AC groups were supplied with same amount of fermented rice bran (FRB). In the AC-2 group however, pellet-diet was supplied at twice higher concentrations compared to the AC-1 treatment group. AC-1 received fermented rice bran (FRB) only for the initial 5 days (DOC1-5), thereafter feed pellets were accompanied with FRB (DOC 5-30), whereas shrimps in AC-2 were given FRB from DOC-1 and accompanied with feed pellets at day-2 throughout the feeding trial (DOC2-30). The 30-days feeding protocol of shrimps cultured in the WE-SET and WE systems and those exposed to Aquamimicry concept with two different feeding protocols have been illustrated in Table 2, and 3, respectively.

Table 2. Daily increase of diet supply based on DOC for 30 days from 01.04.2020 to 30.04.2020 for shrimp cultured in water exchange systems with and without settling chamber.

DOC	**WE-SET Tank-1**		**WE Tank-2**	
	Feed (kg/day)	Cumulative feed (kg)	Feed (kg/day)	Cumulative feed (kg)
1	0.42	0.42	NFS	NFS
2	0.42	0.84	0.30	0.30
3	0.35	1.19	0.60	0.90
4	0.35	1.54	0.60	1.50
5	0.50	2.04	0.40	1.90
6	0.60	2.64	0.50	2.40
7	0.70	3.34	0.50	2.90
8	0.90	4.24	0.50	3.40
9	2.00	6.24	0.50	3.90
10	2.10	8.34	0.50	4.40
11	2.20	10.54	0.60	5.00
12	2.40	12.94	0.70	5.70
13	2.60	15.54	0.70	6.40
14	2.80	18.34	0.80	7.20
15	6.00	24.34	0.80	8.00
16	7.00	31.34	0.90	8.90
17	8.00	39.34	0.90	9.80
18	9.00	48.34	0.90	10.70
19	10.00	58.34	0.90	11.60
20	10.00	68.34	1.10	12.70
21	7.00	75.34	0.70	13.40
22	10.00	85.34	0.70	14.10
23	14.00	99.34	1.20	15.30
24	6.00	105.34	1.30	16.60
25	4.00	109.34	1.30	17.90

26	7.00	116.34	1.40	19.30
27	3.00	119.34	1.40	20.70
28	7.00	126.34	1.40	22.10
29	7.00	133.34	0.80	22.90
30	8.00	141.34	0.80	23.70
Total	**141.34**	**141.34**	**23.70**	**23.70**
Mean ± SD	**4.71 ± 3.79[b]**		**0.82 ± 0.32[a]**	

Feed supply indicated with different superscript letters in last are significantly different at 0.05 level.
WE-SET: water exchange system with settling chamber
WE: water exchange system without settling chamber
DOC: days of culture
CF: cumulative feed
NFS: no feed supply

Table 3. Daily increase of diet supply based on DOC for 30 days from 01.04.2020 to 30.04.2020 for shrimp cultured in Aquamimicry concept with two different feeding protocols

DOC	**AC-1** Tank-3 (low amount pellet + FRB)				**AC-2** Tank-4 (twice higher pellet + FRB)			
	Feed kg/day	CF kg	FRB kg/day	C-FRB kg/day	Feed kg/day	CF Kg	FRB kg/day	C-FRB kg/day
1	NFS		2.00	40.0	NFS		2.00	40.0
2	NFS		2.00	42.0	NFS		2.00	42.0
3	NFS		2.00	44.0	0.30	0.30	2.00	44.0
4	NFS		2.00	46.0	1.50	1.80	2.00	46.0
5	NFS		2.00	48.0	1.68	3.48	2.00	48.0
6	0.90	0.90	2.00	50.0	2.00	5.48	2.00	50.0
7	0.66	1.56	2.00	52.0	1.00	6.48	2.00	52.0
8	1.05	2.61	2.00	54.0	0.45	6.93	2.00	54.0
9	1.20	3.81	2.00	56.0	1.00	7.93	2.00	56.0
10	1.23	5.04	1.00	57.0	1.80	9.73	1.00	57.0
11	1.41	6.45	1.00	58.0	2.00	11.73	1.00	58.0
12	1.50	7.95	0.00	58.0	3.20	14.93	0.00	58.0
13	1.59	9.54	2.00	60.0	3.60	18.53	2.00	60.0
14	1.80	11.34	0.00	60.0	4.00	22.53	0.00	60.0
15	1.95	13.29	2.00	62.0	3.00	25.53	2.00	62.0
16	2.10	15.39	0.00	62.0	3.00	28.53	0.00	62.0
17	1.50	16.89	2.00	64.0	4.00	32.53	2.00	64.0
18	1.60	18.49	0.00	64.0	4.00	36.53	0.00	64.0
19	2.55	21.04	1.00	65.0	3.00	39.53	1.00	65.0
20	1.80	22.84	0.00	65.0	3.00	42.53	0.00	65.0
21	1.90	24.74	1.00	66.0	4.60	47.13	1.00	66.0
22	2.00	26.74	0.00	66.0	3.60	50.73	0.00	66.0
23	2.10	28.84	1.00	67.0	3.60	54.33	1.00	67.0
24	2.20	31.04	0.00	67.0	4.80	59.13	0.00	67.0
25	2.20	33.24	0.00	67.0	4.80	63.93	0.00	67.0
26	2.30	35.54	0.00	67.0	5.20	69.13	0.00	67.0
27	2.40	37.94	1.00	68.0	5.20	74.33	1.00	68.0
28	2.40	40.34	0.00	68.0	5.60	79.93	0.00	68.0
29	2.60	42.94	1.00	69.0	4.20	84.13	1.00	69.0
30	1.30	44.24	2.00	71.0	3.90	88.03	0.00	69.0
Total	**44.24**	**44.24**	**33.0**	**71.0**	**88.03**	**88.03**	**31.0**	**69.0**
Mean ± SD*	**1.77 ± 0.53[a]**		**1.1 ± 0.88[1]**		**3.14 ± 1.5[b]**		**1.03 ± 0.89[1]**	

Pellet feeds highlighted in dark grey, and FRB supply given in light grey color.
*Feed supply indicated with different superscript letters among dark grey-color columns are significantly different at 0.05 level.

*FRB supply indicated with same superscript numbers among light grey-color columns are not significantly different at 0.05 level.
AC: Aquamimicry concept
DOC: days of culture
CF: cumulative feed
FRB: fermented rice bran
C-FRB: cumulative fermented rice bran
NFS: no feed supply

Water quality parameters
Dissolved oxygen and temperature were measured using an automatic multiparameter probe device. A pH meter and refractometer were used in measuring pH and salinity values, respectively. The variables of alkalinity (Alk) and suspended solids (SS) were analyzed following the methods of APHA (2005) 2320B and 2540D, respectively. The TSS was measured using fiberglass microfilters of 0,6 micrometer (GF-6, Macherey-Nagel, Germany). The rates for nitrite (NO_2), nitrate (NO_3), and total ammonia nitrogen (TAN) were analyzed spectrophotometrically as described by Bendschneider & Robinson (1952), and Koroleff (1969), respectively.

Statistical analysis
Data for feeding levels were exposed to one-way analysis of variance (package super-ANOVA, Abacus Concepts, Berkeley, California, USA). Duncan's multiple range test was applied for the mean separation procedure in case of significance was noted in the ANOVA at 0.005 level ($P<0.05$).

Results
Shrimp production
Parameters for all shrimp production treatment groups differed considerably (Table 4), except for survival in the AC treatment groups (AC-1: 91%, AC-2: 92%), which were higher than the WE-SET (68.6%) and WE (81%) treatments. Also, similar apparent FCRs were found for the WE (0.39) and AC treatment groups (AC-1: 0.32, AC-2: 0.39), which were far lower compared to the WE-SET treatment, that presented twice higher FCR of 0.97 than the other treatment groups.

The final biomass of shrimps at harvest was highest in the AC method, 1.6-fold and 2.7-fold higher than that of the WE-SET and WE treatment groups, respectively. Among the AC groups, the AC-2 that received twice more pellet-diets, but same amount of FRB, presented 1.4-fold higher biomass by the end of the study at DOC30, compared to the AC-1 group fed with less pellet-diet. The stocking densities, average feed supply, average weight at final, feed conversion rate, survival, and average nitrogen input rates are given in Table 4.

Table 4. Stocking densities, feed supply, growth performance of shrimps produced in different culture systems for a period of 30 days (DOC30) from 01.04.2020 to 30.04.2020.

	WE-SET Tank-1	**WE Tank-2**	**AC-1 less pellet-diet Tank-3**	**AC-2 twice higher pellet-diet Tank-4**
Number of PLs, initial	350.000	240.000	180.000	200.000
Surface area (m^2)	154	80	80	80
Stocking density (PLs/m^2)	2.272	3.000	2.250	2.500
Survival rate (%)	68.6	81.0	91.0	92.0

Number of PLs, final	240.100	194.400	144.000	160.000
Feed (kg)	141.34	23.70	44.24	88.03
Average weight (g) DOC30, final	0.56	0.25	0.99	1.22
Biomass final (kg)	134.5	48.6	142.6	195.2
Biomass final (kg/m^3)	0.87	0.61	1.78	2.44
Apparent FCR	0.97	0.39	0.32	0.39
Fermented Rice Bran	-	-	71.0	69.0
Total Nitrogen Input (mg/L)	70.0	30.0	70.2	106.0
Water exchange conditions	Settling chamber	No settling chamber	RAS	RAS

WE-SET: water exchange system with settling chamber
WE: water exchange system without settling chamber
AC: Aquamimicry concept
PL: post larvae
RAS: recirculating aquaculture system
DOC: days of culture
Apparent FCR: feed conversion rate = feed supply (g) / wet weight gain (g)

Water Use and Quality

The amount of water consumed for each culture method was not measured during the production phase at the commercial facility. However, the AC methods were conducted in a RAS system, indicating the lowest water consumption among the culture treatments, whereas the WE treatment consumed higher amount of water during culture than that observed in the WE-SET treatment. It is worth noting that less water was replaced with new inflow to replace the loss during sludge removal in the WE-SET system, compared to the water removal by tank draining in the WE treatment.

Water temperature (27.28 ± 1.12°C), dissolved oxygen (6.96 ± 0.46 mg/L), and pH (7.65 ± 0.18) were similar in all treatment groups. Minimum total ammonia nitrogen (TAN) of 0.67 and 1.17 mg/L were found for WE and AC-1, respectively, and higher rates of 2.23 and 5.85 mg/L were found for treatments AC-2 and WE-SET, respectively. The NO_2 concentration was the lowest (1.84 mg/L) in the AC-1 treatment and the highest (4.02 mg/L) in the AC-2 treatment group. Alkalinity was similar in both WE-SET and WE groups with slightly higher value of 154.75 in the WE treatment group (Table 5).

Table 5. Overall water quality parameters in the commercial shrimp farm measured from 01.04.2020 to 30.04.2020.

Parameter	Temp. °C	Salinity g/L	DO mg/L	pH	TAN mg/L	NO_2 mg/L	NO_3 mg/L	SS ml/L	Alkalinity
WE-SET	26.29	28.18	N/A	7.63	5,85	2.89	N/A	N/A	145.75
WE	28.84	N/A	6.64	7.46	0.67	3.61	22.54	N/A	154.75
AC-1	26.71	N/A	7.29	7.90	1.17	1.84	5.35	1.38	N/A
AC-2	27.28	N/A	N/A	7.61	2.23	4.02	N/A	N/A	N/A
Mean ±SD	27.28 ±1.12	28.18	6.96 ±0.46	7.65 ±0.18	2.48 ±2.34	3.09 ±0.95	13.95 ±12.15	1.38	150.25 ±6.36

DO: dissolved oxygen
TAN: total ammonia nitrogen
NO_2: nitrite
NO_3: nitrate
SS: suspended solid

Considering the entire growth period of 30 days, the TAN concentration in WE-SET remained low for the first 3 weeks (0.8-6.0 mg/L), but increased to higher levels in the fourth week (8.0-

16.0 mg/L), then lowered in the following week (1.0-8.0 mg/L). The NO_2 levels showed an increase to 6.0 mg/L in week 4 from 0.6-2.4 mg/L of the previous week, but then declined back to the 1.5-4.5 mg/L by the end of the study at DOC30 (Fig. 1). Alkalinity was almost constant during the first weeks (124.0-145.0), with variations at week 2 (145.0-158.0), peaked at week 3 (171.0), and lowered thereafter to 146.0-147.0 by week-4.

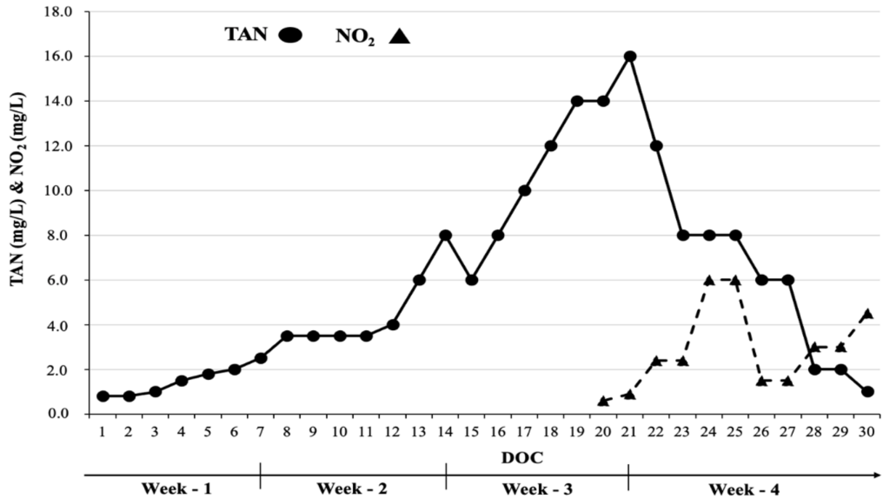

Figure 1. TAN and NO_2 concentrations versus DOC in the water-exchange with settling chamber (WE-SET) culture method

In the WE treatment, the concentrations of TAN were almost constant (0.2-0.8 mg/L) during the first 2 weeks, but variations initiated at week 3 (1.0-4.0 mg/L) and declined to 0.2-0.8 mg/L by the end of the study. Low levels of NO_2 were also recorded for the first 2 weeks (0.1-0.3 mg/L), with variations in week 3 (0.6-5.4 mg/L), and peaked to 9.0 mg/L in week 4. Variations in NO_3 concentrations initiated in week 3 (2.3-22.5 mg/L), and increased at week 4 (22.5-36.0 mg/L), with a peak of 45.0 mg/L by the end of the study at DOC30 (Fig. 2). Alkalinity in WE treatment group peaked to 173.0 in week 3, and declined to 120.0 at week 4.

In the AC-1 treatment group, NO_2 levels were low in week 2 (0.10-0.9 mg/L), peaked to 7.2 mg/L at week 3, and declined to 1.0-2.0 mg/L at week 4. Variations in NO_3 were recorded at week 3 (2.0-7.0 mg/L), and remained at high levels (7.0 mg/L) until the end of the study at DOC30 (Fig. 3). Suspended solids remained low the first week (0.5-0.8 ml/L), and variations were recorded thereafter until DOC30 (1.0-2.0 ml/L).

The TAN and NO_2 concentrations in AC-2 group were high at week 1 (3.0-8.0 mg/L and 3.0-8.3 mg/L), with peak levels of 8.0 and 8.3 mg/L, respectively. TAN levels showed a decline thereafter and remained at 1.0 mg/L level until the end of DOC30, whereas variations in NO_2 were found at week 2 (3.6-5.9 mg/L), with a second peak of 6.4 mg/L at week 3, which declined to 0.3 mg/L by the end of the study (Fig. 4).

By the harvest time, TAN concentrations decreased significantly ($p<0.05$) despite the peaks at different weeks in all four treatment groups. The NO_2 concentrations, however, lowered significantly by the end of harvest in both Aquamimicry concept groups of AC-1 and AC-2, compared to the water exchange groups with (WE-SET) -or without settling chamber (WE). A number of water quality variables measured in four different culture systems have been given in Tables 6-9.

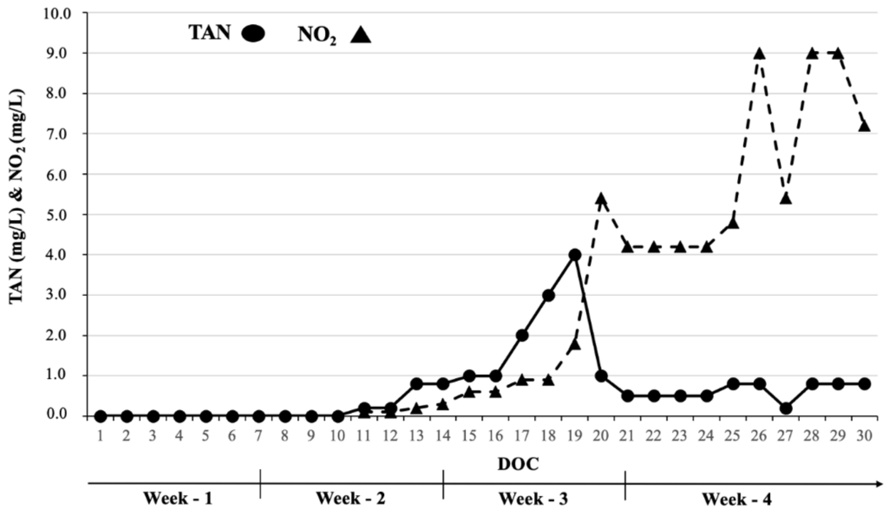

Figure 2. TAN and NO_2 concentrations versus DOC in the water-exchange without settling chamber (WE) culture method

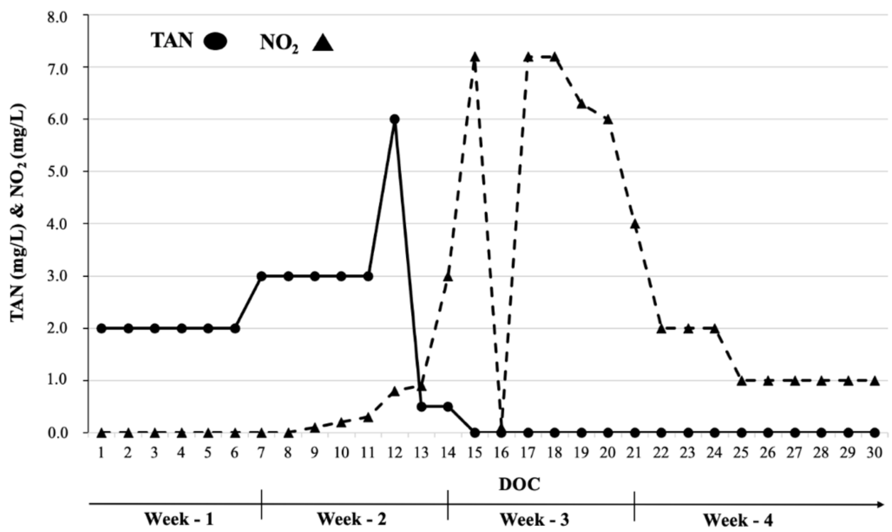

Figure 3. TAN and NO_2 concentrations versus DOC in the Aquamimicry concept (AC) culture method (AC-1, less pellet-diet + FRB)

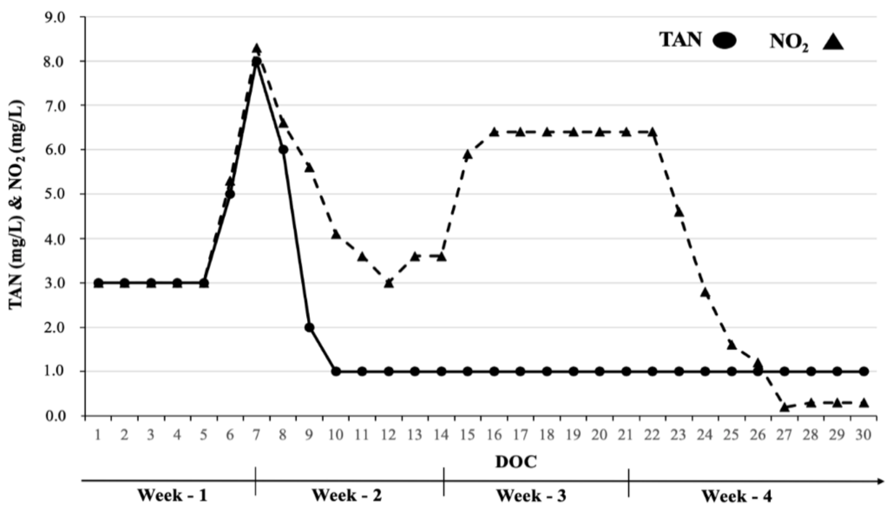

Figure 4. TAN and NO_2 concentrations versus DOC in the Aquamimicry concept (AC) culture method (AC-2, twice higher pellet-diet + FRB)

Table 6. Water quality variables for 30-days growth trial in the WE-SET (Water exchange system with settling tank, Tank-1).

Date	DOC	Temperature °C	Salinity g/L	pH	TAN mg/L*	NO_2 mg/L*	Alkalinity
01.04.2020	1	25.0	30.8	7.92	0.8	N/A	124
02.04.2020	2	26.5	28.0	7.90	0.8	N/A	130
03.04.2020	3	27.5	28.0	7.95	1.0	N/A	131
04.04.2020	4	27.5	28.0	7.90	1.5	N/A	132
05.04.2020	5	26.5	28.0	8.0	1.8	N/A	140
06.04.2020	6	27.5	28.0	8.0	2.0	N/A	143
07.04.2020	7	27.5	28.0	8.0	2.5	N/A	145
08.04.2020	8	27.8	28.0	8.0	3.5	N/A	145
09.04.2020	9	26.9	28.0	8.0	3.5	N/A	150
10.04.2020	10	26.8	28.0	7.92	3.5	N/A	155
11.04.2020	11	27.5	28.0	7.80	3.5	N/A	154
12.04.2020	12	27.5	28.0	7.90	4.0	N/A	149
13.04.2020	13	27.5	28.0	7.80	6.0	N/A	145
14.04.2020	14	26.5	28.0	7.80	**8.0**	N/A	158
15.04.2020	15	26.5	28.0	7.80	**6.0**	N/A	N/A
16.04.2020	16	26.5	28.0	7.70	**8.0**	N/A	N/A
17.04.2020	17	26.0	N/A	7.60	**10.0**	N/A	135
18.04.2020	18	26.5	N/A	7.50	**12.0**	N/A	160
19.04.2020	19	26.0	N/A	7.50	**14.0**	N/A	N/A
20.04.2020	20	26.5	N/A	7.50	**14.0**	0.6	171
21.04.2020	21	26.0	N/A	7.40	**16.0**	0.9	N/A
22.04.2020	22	25.0	N/A	7.40	**12.0**	2.4	156
23.04.2020	23	24.7	N/A	7.40	**8.0**	2.4	147
24.04.2020	24	25.5	N/A	7.30	**8.0**	**6.0**	145
25.04.2020	25	25.0	N/A	7.40	**8.0**	**6.0**	N/A
26.04.2020	26	25.5	N/A	7.50	6.0	1.5	N/A
27.04.2020	27	24.2	N/A	7.50	6.0	1.5	N/A
28.04.2020	28	24.5	N/A	7.50	2.0	3.0	N/A
29.04.2020	29	26.0	N/A	7.48	2.0	3.0	N/A
30.04.2020	30	26.0	N/A	7.50	1.0	4.5	N/A
Mean ± SD		**26.29 ± 1.04**	**28.18 ± 0.70**	**7.63 ± 0.21**	**5.85 ± 4.42**	**2.89 ± 1.88**	**145.75 ± 11.62**

* High concentrations and peak levels indicated in bold and grey color
DOC: days of culture
TAN: total ammonia nitrogen
NO_2: nitrite

Table 7. Water quality variables for 30-days growth trial in the WE (Water exchange system with no settling tank, Tank-2).

Date	DOC	Temp. °C	DO mg/L	pH	TAN mg/L*	NO_2 mg/L*	NO_3 mg/L	Alkalinity
01.04.2020	1	22.6	6.04	N/A	0.0	N/A	N/A	N/A
02.04.2020	2	22.8	6.22	N/A	0.0	N/A	N/A	N/A
03.04.2020	3	25.0	5.76	N/A	0.0	N/A	N/A	N/A
04.04.2020	4	26.2	5.86	N/A	0.0	N/A	N/A	N/A
05.04.2020	5	27.3	5.19	7.52	0.0	N/A	N/A	155
06.04.2020	6	29.1	4.85	7.44	0.0	N/A	N/A	N/A

07.04.2020	7	28.9	6.22	N/A	0.0	N/A	N/A	N/A
08.04.2020	8	29.3	N/A	N/A	0.0	N/A	N/A	171
09.04.2020	9	29.4	N/A	N/A	0.0	N/A	N/A	N/A
10.04.2020	10	30.0	N/A	7.75	0.0	N/A	N/A	N/A
11.04.2020	11	29.7	N/A	N/A	0.2	0.1	N/A	N/A
12.04.2020	12	29.7	N/A	N/A	0.2	0.1	N/A	N/A
13.04.2020	13	29.8	N/A	N/A	0.8	0.2	N/A	N/A
14.04.2020	14	30.9	N/A	N/A	0.8	0.3	N/A	N/A
15.04.2020	15	30.7	N/A	N/A	1.0	0.6	N/A	N/A
16.04.2020	16	30.9	N/A	N/A	1.0	0.6	2.3	N/A
17.04.2020	17	31.2	N/A	N/A	2.0	0.9	2.3	N/A
18.04.2020	18	31.3	6.10	7.40	3.0	0.9	2.3	N/A
19.04.2020	19	31.5	N/A	N/A	**4.0**	1.8	5.6	173
20.04.2020	20	31.5	N/A	7.60	1.0	5.4	16.9	N/A
21.04.2020	21	31.1	N/A	N/A	0.5	4.2	22.5	N/A
22.04.2020	22	30.8	N/A	N/A	0.5	4.2	22.5	N/A
23.04.2020	23	30.5	7.50	7.40	0.5	4.2	24.8	N/A
24.04.2020	24	31.0	7.50	N/A	0.5	4.2	28.1	N/A
25.04.2020	25	31.5	7.70	7.36	0.8	4.8	30.4	N/A
26.04.2020	26	31.0	7.70	7.32	0.8	**9.0**	33.8	N/A
27.04.2020	27	31.33	7.68	7.33	0.8	5.4	33.8	N/A
28.04.2020	28	31.1	7.73	7.33	0.2	**9.0**	33.8	120
29.04.2020	29	31.51	7.61	7.3	0.8	**9.0**	36.0	N/A
30.04.2020	30	30.9	6.22	7.57	0.8	**7.2**	45.0	N/A
Mean ± SD		**28.84 ± 3.0**	**6.64 ± 0.98**	**7.46 ±0.13**	**0.67 ± 0.91**	**3.61 ±3.18**	**22.54 ±13.8**	**154.75 ±24.5**

* High concentrations and peak levels indicated in bold and grey color
DOC: days of culture
DO: dissolved oxygen
TAN: total ammonia nitrogen
NO_2: nitrite
NO_3: nitrate

Table 8. Water quality variables for 30-days growth trial in the AC-1 (Aquamimicry concept, less pellet-diet + FRB: Tank-3).

Date	DOC	Temperature °C	DO mg/L	pH	TAN mg/L*	NO_2 mg/L*	NO_3 mg/L	SS ml/L
01.04.2020	1	23.0	6.70	7.89	2.0	0.0	N/A	0.5
02.04.2020	2	25.5	7.10	7.91	2.0	0.0	N/A	0.5
03.04.2020	3	28.0	6.90	7.93	2.0	0.0	N/A	0.5
04.04.2020	4	28.3	6.70	7.99	2.0	0.0	N/A	0.5
05.04.2020	5	28.4	6.40	8.0	2.0	0.0	N/A	0.5
06.04.2020	6	27.1	7.60	7.99	2.0	0.0	N/A	0.8
07.04.2020	7	27.2	7.20	8.03	3.0	0.0	N/A	0.8
08.04.2020	8	26.3	7.30	8.07	3.0	0.0	N/A	1.0
09.04.2020	9	26.7	7.30	8.04	3.0	0.1	N/A	1.2
10.04.2020	10	26.1	7.40	8.03	3.0	0.2	N/A	0.8
11.04.2020	11	26.2	7.30	8.03	3.0	0.3	N/A	1.0
12.04.2020	12	26.5	7.40	7.58	3.0	0.8	N/A	1.5
13.04.2020	13	26.1	7.40	7.83	**6.0**	0.9	N/A	1.5
14.04.2020	14	25.7	7.40	7.66	0.50	3.0	2	2.0

15.04.2020	15	26.1	7.30	7.61	0.0	**7.2**	2	3.0
16.04.2020	16	26.0	7.20	7.74	0.0	**7.2**	2	2.0
17.04.2020	17	27.1	7.20	7.67	0.0	**7.2**	2	2.0
18.04.2020	18	26.2	7.40	7.77	0.0	**7.2**	2	2.0
19.04.2020	19	25.9	7.40	7.78	0.0	6.3	4	0.8
20.04.2020	20	26.2	7.40	7.66	0.0	6.0	7	2.0
21.04.2020	21	26.8	7.50	7.65	0.0	4.0	7	2.0
22.04.2020	22	27.2	7.70	7.62	0.0	2.0	7	0.5
23.04.2020	23	26.8	7.60	7.74	0.0	2.0	7	1.0
24.04.2020	24	27.0	7.50	7.69	0.0	2.0	7	2.0
25.04.2020	25	27.2	7.30	7.72	0.0	1.0	7	2.0
26.04.2020	26	27.1	7.30	7.66	0.0	1.0	7	2.0
27.04.2020	27	27.3	7.60	7.75	0.0	1.0	7	2.0
28.04.2020	28	28.1	7.60	7.66	0.0	1.0	7	2.0
29.04.2020	29	28.5	7.60	7.68	0.0	1.0	7	2.0
30.04.2020	30	N/A	N/A	N/A	N/A	1.0	7	1.0
Mean ± SD		**26.71 ± 1.09**	**7.29 ±0.29**	**7.90 ±0.31**	**1.17 ± 1.53**	**1.84 ±2.45**	**5.35 ± 2.34**	**1.38 ± 0.69**

* High concentrations and peak levels indicated in bold and grey color
DOC: days of culture
DO: dissolved oxygen
TAN: total ammonia nitrogen
NO_2: nitrite
NO_3: nitrate
SS: suspended solids

Table 9. Water quality variables for 30-days growth trial in the AC-2 (Aquamimicry concept, twice higher pellet-diet + FRB: Tank-4).

Date	**DOC**	**Temperature °C**	**pH**	**TAN mg/L***	**NO_2 mg/L***
01.04.2020	1	27.4	7.8	3	3.0
02.04.2020	2	27.8	7.8	3	3.0
03.04.2020	3	28.1	7.8	3	3.0
04.04.2020	4	28.8	7.7	3	3.0
05.04.2020	5	29.0	7.7	3	3.0
06.04.2020	6	28.8	7.7	**5**	5.3
07.04.2020	7	27.9	7.7	**8**	**8.3**
08.04.2020	8	27.9	7.6	**6**	**6.6**
09.04.2020	9	26.8	7.6	2	**5.6**
10.04.2020	10	27.6	7.6	1	4.1
11.04.2020	11	27.8	7.6	N/A	3.6
12.04.2020	12	28.1	7.3	N/A	3.0
13.04.2020	13	27.9	7.5	N/A	3.6
14.04.2020	14	27.2	7.4	N/A	3.6
15.04.2020	15	26.0	7.6	1	5.9
16.04.2020	16	26.2	7.6	1	**6.4**
17.04.2020	17	26.6	7.7	1	**6.4**
18.04.2020	18	26.0	7.6	1	**6.4**
19.04.2020	19	25.9	7.6	1	**6.4**
20.04.2020	20	26.3	7.5	1	**6.4**

21.04.2020	21	26.7	7.6	1	**6.4**
22.04.2020	22	27.0	7.6	1	**6.4**
23.04.2020	23	26.2	7.6	1	**4.6**
24.04.2020	24	26.1	7.7	1	2.8
25.04.2020	25	26.5	7.5	1	1.6
26.04.2020	26	26.5	7.5	1	1.2
27.04.2020	27	27.1	7.6	N/A	0.2
28.04.2020	28	27.5	7.6	N/A	0.3
29.04.2020	29	27.8	7.6	N/A	0.3
30.04.2020	30	28.3	7.5	N/A	0.3
Mean ± SD		**27.28 ± 0.90**	**7.61 ± 0.11**	**2.23 ± 1.93**	**4.02 ± 2.28**

* High concentrations and peak levels indicated in bold and grey color
DOC: days of culture
TAN: total ammonia nitrogen
NO_2: nitrite

Discussion

Findings from the present study show that different culture methods applied affected the performance and survival of shrimps and the water quality of the culture environment. Growth performance, apparent FCRs, and survival rates found for all four culture methods tested in this study were comparable with earlier reports of Ray et al. (2010, 2011), Schveitzer et al. (2013), and Arantes et al. (2017). Biomass per cubic meter for biofloc shrimp culture were reported between 2.2 and 2.8 kg/m^3 (Ray et al., 2011), which was in line with the findings in this study for the Aquamimicry concept group fed with twice more pellet-diet, but same amount of FRB supplement (AC-2, 2.44 kg/m^3). Schveitzer et al. (2013) found lower final biomass of 1.0 kg/m^3 in shrimp cultured without the addition of artificial substrates, which was in agreement with our findings in the water exchange system with settling chamber (0.87 kg/m^3), but higher than the results obtained for the water exchange system without settling chamber. However, Schveitzer et al. (2013) reported higher biomass of 2.1 kg/m^3 in their study when artificial substrates were added. This was in agreement with the results in this study for the Aquamimicry concept treatment groups. Further, similar findings to our results were also reported by Ray et al. (2010), who found biomass between 2.2-3.23 kg/m^3, and 2.1-2.8 kg/m^3 in their study with fishmeal-based -and plant-based diets, respectively. In a comparative investigation on water exchange and settling tank systems for the management of suspended solids removal in intensive biofloc system, Arantes et al. (2017) reported 1.0 and 1.6 kg/m^3 biomass for the water exchange and settling tank methods, respectively, which were almost twice higher than our findings obtained for the same treatment systems (water exchange: 0.61 kg/m^3; settling tank: 0.87 kg/m^3). However, biomass per cubic meter reported by Arantes et al. (2017) were far lower than our findings obtained for the Aquamimicry concept method (1.78-2.44 kg/m^3) applied in this study.

The feed conversion rates in the present study with water-exchange culture system coupled with settling chamber methods (WE-SET, 0.97), and without settling chamber (WE, 0.39) were far lower than the findings of Arantes et al. (2017), who reported FCRs of 1.6 and 1.0 for the settling chamber and water exchange only treatments, respectively. Considering the culture methods applied in this study, especially the Aquamimicry concept, the apparent FCRs in this study were very remarkably lower (AC: 0.32-0.39; WE: 0.39; WE-SET: 0.97) than those reported by Ray et al. (2010) (1.95-2.89), Ray et al. (2011) (2.5-3.3), and Schveizer et al. (2013) (1.6-4.1).

The survival rates for shrimps found for all treatment groups (68.6-92%) were higher than those reported by Ray et al (2011) (71%). Arantes et al. (2017) provided similar survival rates for shrimps produced in water exchange (57.8%) and settling tanks (73.8) compared to the results obtained in this study with same treatments of water exchange only (81%) and settling tank method (68.6%). Results of Schveizer et al. (2013) in terms of survival rate (70.6-95.2%) were also in close agreement with our study.

The water quality parameters of temperature, pH, dissolved oxygen, salinity, and alkalinity measured over the 30-days study were within acceptable limits for intensive shrimp culture according to Van Wyk & Scarpa (1999) and Roy et al. (2010). The variations in ammonia levels between week-3 along with the increasing concentrates of nitrite over the following week might be attributed to the initiation of nitrifying bacterial activity as also reported earlier (Cohen et al., 2005; Mishra et al. 2008; Arantes et al., 2017). The ammonia concentrations peaked with 16.0 and 4.0 mg/L by the end of week-3 in both water exchange system equipped with settling chamber (WE-SET) and water exchange only system (WE), and declined to minimum levels by week-4, which can be linked to the availability of nitrifying bacteria enough to take control on ammonia production in the culture environment. In the WE-SET group, the alkalinity ranged between 124-171 (mean±SD, 145.75±11.62), reaching a peak level of 171 along with the peak of 16.0 mg TAN per L by the end of week-3. In the WE treatment group, alkalinity showed a variation between 120-173 (mean±SD, 154.75±24.53), showing a peak of 173 again along with the peak of 4.0 mg TAN per L at week-3. Alkalinity in both treatment groups of WE-SET and WE were in within the values reported by Schveizer et al. (2013).

In the Aquamimicry concept of culture methods with both low and high pellet feeding levels applied in this study however, the peaks of ammonia concentrations were observed earlier than those recorded in the WE-SET and WE culture systems. Namely, ammonia level reached highest rate of 6.0 mg/L at week-2 in AC-1 with less pellet-diet, but same amount of FRB supplement, and thereafter decreased to minimum levels by the end of week-2, an indication that enough nitrifying bacteria were available to control ammonia production. In both Aquamimicry treatment groups of AC-1 and AC-2, the peaks of ammonia concentrations were seen by week-2 and even by the end of week-1 for AC-2, possibly due to the sufficiently enough nitrifying bacteria in the culture environment. The fermented rice bran (FRB) used as a carbon source in the Aquamimicry culture environments, possibly generated phytoplankton and zooplankton abundance, hence simulating the natural conditions. Eventually, these plankton groups possibly provided additional nutrition for the shrimps and also improved water quality in the tank, as reported earlier by Vijayan (2019). This might explain the early peak in ammonia and increase NO_2 thereafter in the Aquamimicry treatment groups with FRB supplement compared to the traditional WE-SET and WE culture methods.

Conclusion

The findings of this study underline that higher survival of shrimps was obtained in the Aquamimicry concept compared to the other culture methods with water exchange coupled with -or without settling chamber. The apparent FCRs, final biomass at harvest were best for the Aquamimicry treated groups. It is worse noting that the lower TAN levels were recorded in both water-exchange and Aquamimicry treatments when lower amounts of pellets were supplied, which was also the case for the NO_2 levels. In brief, the results indicate that the Aquamimicry concept demonstrated a more sustainable and environment-friendly production method for the shrimp aquaculture compared to the traditional culture methods. The RAS system used for each module in this study, supported by the biological filtration with bottom feeder fish, filter feeder bivalve, inorganic feeder seaweed, co-culture in the same water body was an implemented IMTA production system in land-based farm. Many living organisms can cooperate to each other by releasing and producing some bio-stimulating materials like substitutions of antioxidants, antibiotics, antiviral, and immune enhancers. Among the agri-byproducts, rice bran with high contents of fat was successfully applied in this study, and suggested for future shrimp farm operations for the sustainability of shrimp farm activities in the future. Fermented rice bran has multi-functional works in aquaculture. Future investigations are encouraged to use lower fat contents bran like wheat, barley, oat bran incorporated by some high bioavailable oils like olive or corn oil. In overall, based on the findings of the present study, opting the Aquamimicry concept for shrimp production is more efficient in terms of biomass gain, feed conversion and survival rate in shrimp farming, which also supports the sustainability of shrimp aquaculture in terms of eco-friendly production compared to conventional farm systems.

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Conflict of Interests
The authors declare that they have no conflict of interest.

Ethical Approval
The study is based data collected from a commercial shrimp farm, and all shrimps measured in weigh at final were randomly collected from the harvest-batch of the commercial farm after an operational period of 30 days. Hence the present study did not involve any legal or ethical issues for welfare of animals prior to and during death, live transport or storage.

Informed Consent
Informed consent was obtained from all individual participants included in the study.

Data availability statement
The authors declare that data are available from authors upon reasonable request.

Funding organizations
This study was conducted at the shrimp farm of the private company CTO-D.V.M., AD GOCHANG LTD in Jeollabuk-do, South Korea. All data for this study were collected from the harvest batch of the shrimp farm. Feed and shrimp individuals were part of the commercial activities of the company. No other funding organizations available for this study.

Contribution of authors
All authors in this study have equally contributed in terms of conceptualization, data curation and evaluation, writing original draft, investigation, methodology, resources, validation, and visualization, and finalizing paper.

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