

Innovations

Influence of Different Feeding Regimens on the Survival and Growth Performance of Gladiator Swimming Crab (*Callinectes pallidus*, Rochebrune, 1883) Culture in Three Indoor Systems from Cameroon

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Abstract: *This study evaluated the impact of different feeding regimens, specifically trash fish and commercial feed on the survival and growth performance of Gladiator swimming crab (*Callinectes* sp.) aquaculture. Across three different systems: Recirculating Aquaculture System (RAS) with Ultra Violet filter (System A), RAS without Ultra Violet filter (System B), and a flow-through system (System C). Preliminary growth assessments revealed similar average initial weight of 1.63 g across all systems. After six weeks of feeding, the impact of trash fish and commercial feed was assessed revealing that crabs fed with trash fish demonstrated higher growth performance than those fed with commercial feed. Significant differences in final weight, carapace length, and width were observed among the systems ($p < 0.05$). Crabs in System C exhibited the highest growth performance, achieving a final average weight of 16.45 ± 0.58 g, a Specific Growth Rate (SGR) of $35.50 \pm 1.0\%$, and carapace measurements of 31.45 ± 1.34 mm in length and 52.40 ± 0.93 mm in width. Principal Component Analysis (PCA) indicated that System C, demonstrated superior growth performance metrics, followed by Systems A and then System B. These findings highlight the importance of optimized appropriate feeding strategies in enhancing the growth and survival of Gladiator swimming crabs in aquaculture systems. The study concluded that flow-through systems offer the most favorable environment for *C. pallidus* growth, particularly when combined with trash fish feeding. These results can inform future aquaculture practices and contribute to the sustainable production of Gladiator swimming crab in tropical regions.*

Keywords: *Advanced technology; trash fish; Ultraviolet filter; production systems; crab aquaculture*

1. Introduction

Swimming crabs have been commercialized in the United States for more than 150 years (Hungria et al., 2017) and a little over 100 years in Asia (Yeo et al., 2008). Hungria et al., (2017), reported that the production of soft-shell swimming crabs may have been one of the first forms of culture of aquatic organisms consumed by native American in the United States. Initially, soft-shell swimming crabs were obtained incidentally through fishing and were kept in simple fencing systems until ecdysis. Later on, controlled production of soft-shell swimming crabs has been on the rise due to advances in production technologies and the increased in demand for soft-shell swimming crab farming into an effective component of the seafood industry (Tavares et al., 2018; Lwin, 2018). Currently, catches for swimming crabs are no longer accidental. Catching swimming crabs is the focus of a particular kind of fishing. Although they are still in the pre-moult stage, crabs that exhibit telltale indicators of the approaching ecdysis period are targeted for collection (Cilenti et al., 2024). Crab culture has the potential to be an economically sustainable enterprise and help the much-needed goal of poverty alleviation in developing countries (Apineet et al., 2023)

This research therefore focused on developing a sustainable indoor culture system for the Gladiator swimming crab (*C. pallidus*), utilizing simple design technologies and locally sourced juvenile crabs. The study evaluated the performance of three innovative indoor systems, addressing critical aspects such as growth, survival, and feed efficiency. By doing so, this research will generate practical solutions for crab farming, providing a pathway to diversify aquaculture practices in Cameroon, while aligning with global trends in sustainable aquaculture development.

2. Material and Methods

The study was conducted at the Divisional Delegation of Livestock, Fisheries, and Animal Industries (MINEPIA) in Limbe.

Three aquaculture system designs: Recirculating Aquaculture System (RAS) with UV filter (System A), RAS without UV filter (System B), and flow-through systems (System C). The systems were designed to assess the growth performance of *Callinectes* spp. juveniles across all three systems.

The RAS systems were constructed using locally available materials, including plastic containers and PVC pipes purchased from a nearby pet shop. Four rearing containers were plumbed to a sedimentation unit using normalized PVC pipes. The sedimentation unit contained locally sourced materials known as "kakabans," which trapped solid waste from the water. An electric pump was submerged in the sedimentation unit to lift water into the biofiltration unit (Timmons et al., 2002).

The biofilter was composed of imported filter blocks covered with a tarpaulin batch, which provided a suitable environment for the growth of nitrifying bacteria, including *Nitrosomonas* sp. and *Nitrobactersp.* These bacteria facilitated the nitrification process, breaking down harmful ammonia into nitrites and subsequently into less harmful nitrates, thus maintaining water quality in the system (Chen et al., 2006). In System A, a 13-watt UV sterilizer was connected to the pipe transferring water from the biofilter back to the rearing containers, ensuring that pathogens were controlled before the water returned to the rearing tanks. In contrast, System B followed the same recirculation process but without passing water through a UV sterilizer, relying solely on the biofiltration unit for water treatment (Crab et al., 2007).

2.1. Experiment

Juveniles of *Callinectes* spp. were caught from the wild from target areas of high crab activity using seine net, ensuring minimal environmental disturbance. The crabs were sorted and selected to endure only apparently healthy ones with complete morphological features. They were then transported to the laboratory using aerated plastic aquaria.

Upon arrival, the crabs were quarantined for 24 hours to ensure their safety and acclimatize with aerated seawater before commencing the experiment (Shelley & Lovatelli, 2011).

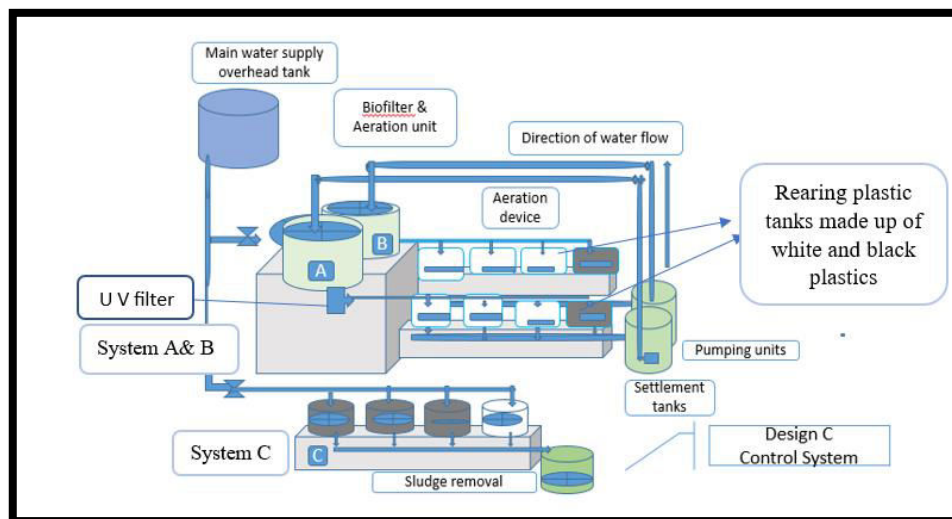


Figure 1: Design view of System A, System B and System C

The three aquaculture system designs: Recirculating Aquaculture System (RAS) with UV filter (System A), RAS without UV filter (System B), and flow-through systems (System C) were constructed using similar materials, and housed in an indoor environment to minimize environmental variability. Each system contained four

plastic containers with a uniform volume of 24 liters of water per container and a total 120l per system. A total of 24 juvenile crabs with same average initial weight of 1.63g were randomly distributed across the three systems. Stocked at a rate of 2 crablets per 24-liter container. The crablets were maintained for 42 days, and all systems were monitored daily for water quality and crab growth parameters.

Detailed measurements of critical morphological parameters, including carapace width, length, and the distances between spines were recorded using digital calipers. Observed features were systematically documented in a standardized data sheet, which included measurements, coloration patterns, and spine arrangements. To confirm species-level identification, a dichotomous key was applied systematically (Saxena, 2005).

Crablets were fed a diet of trash fish of the species (*Sardinellamaderensis*) and commercial catfish feed (Gouessant) crush into paste at a rate of 3 mg/L, constituting 5% of their body weight. Feeding occurred twice daily, at 08:00 AM and 05:00 PM. This feeding regime was followed for the entire 6-week duration of the experiment to assess how different system designs influenced growth and survival rates of Crablets (Parker et al., 2014). Trash fish was selected as a feed source due to its local availability and nutritional suitability for promoting growth in crabs (Lutz, 2003).

2.3 Growth performance measurement

Growth was measured once a week by weighing a sample of crablets from each system. To ensure accuracy, the crablets per treatment container were selected for weekly weighing. Each crablet was weighed using an analytical balance with a precision of 0.01 g, as outlined by Boyd & Tucker (1998). The mean wet body weight (BW) of the sampled crablet in each treatment was calculated and recorded due to cannibalism only one survived per rearing container. These mean BW values were used to track growth over time.

The Specific Growth Rate (SGR) was calculated at the end of the experiment using the following formula:

$$\text{SGR (\%)} = \frac{(W_t - W_0)}{t} \times 100$$

Where:

W_0 = Initial body weight of the crablets (g)

W_t = Final body weight of the crablets (g)

t = Culture period (days)

The SGR was calculated for each system having four containers (System A, System B, and System C) to compare the growth performance across the different treatments. The initial body weight (W_0) was measured at the start of the experiment, while the final body weight (W_t) was measured at the end of the 42-day culture period.

2.4. Survival rate measurement

Survival rates were monitored daily to assess the effect of trash fish feeding on crab health and viability. Any mortalities were immediately recorded, and the cause of death (if identifiable) was noted (Lutz, 2003). The total number of live crabs in each replicate was counted at the end of each week. The survival rate (%) for each system was calculated weekly using the following formula:

$$\text{Survival rate (\%)} = \frac{\text{Number of live crabs}}{\text{initial number of crabs}} \times 100$$

Survival rates were compared between the systems to determine the impact of trash fish on crab survival under different rearing conditions.

2.5. Statistical analysis

The data collected from the experiment were analysed using SPSS for Windows version 16.0. To assess whether there were statistically significant differences between treatments, ANOVA test was employed. This test was chosen to compare the means of different treatments and determine the impact of system design and trash fish feeding on the growth and survival of Atlantic blue swimming crabs (*Callinectes* sp.). Results were presented as means \pm standard deviation (SD) to provide a clear understanding of the variability within each treatment group. Differences between treatments were considered statistically significant if the p-value was less than 0.05 ($p < 0.05$), following standard statistical conventions. This significance threshold allowed for the identification of meaningful differences between the growth performance and survival rates of crabs in the three culture systems. In addition, Principal Component Analysis and Canonical Correspondence analysis were also carried out using Origin Pro 2022.

3. Results

Crab growth performance across the different systems

The growth performance of Gladiator swimming crabs (*Callinectes* spp.) was assessed across three aquaculture systems: RAS with UV filter (System A), RAS without UV filter (System B), and flow-through system (System C).

The crabs had a uniform initial average weight of 1.63 g across all systems. After the 6-week experimental period, significant differences ($p < 0.05$) in final average weight were observed among the systems. Crabs in System C (flow-through system) exhibited the highest final average weight of 16.45 ± 0.58 g, followed by System A (RAS with UV filter) at 14.00 ± 0.63 g, and System B (RAS without UV filter) at 8.45 ± 0.46 g. The Specific Growth Rate (SGR) followed a similar trend, with System C demonstrating the highest SGR of $35.50 \pm 1.0\%$, significantly surpassing System A at $29.67 \pm 0.9\%$ and System B at $16.24 \pm 0.7\%$ ($p < 0.05$). These results indicated that

the flow-through system provided optimal conditions for weight gain and growth rate compared to the other systems.

Carapace length and width were also significantly influenced by the culture system ($p < 0.05$). The initial carapace length was uniform at 15.00 mm across all systems. After the experimental period, the final carapace lengths were recorded as 31.45 ± 1.34 mm in System C, 29.45 ± 1.16 mm in System A, and 26.88 ± 0.97 mm in System B. Similarly, the initial carapace width was uniform at 31.00 mm across all systems, while the final carapace widths were 52.40 ± 0.93 mm in System C, 51.70 ± 0.95 mm in System A, and 47.50 ± 1.10 mm in System B. These findings highlight that System C consistently outperformed the other systems in facilitating carapace growth.

Overall, the flow-through system (System C) demonstrated superior growth performance in terms of weight gain, SGR, and carapace measurements, followed by the RAS with UV filter (System A), while the RAS without UV filter (System B) exhibited the least favorable results.

Table 1: Overall crab growth performance in the different systems

Parameter	System A (Mean \pm SD)	System B (Mean \pm SD)	System C (Mean \pm SD)
Initial Weight (g)	1.63 \pm 0.0 ^a	1.63 \pm 0.0 ^a	1.63 \pm 0.0 ^a
Final Weight (g)	14.00 \pm 0.63 ^b	8.45 \pm 0.46 ^c	16.45 \pm 0.58 ^a
Specific Growth Rate (SGR, %)	29.67 \pm 0.9 ^b	16.24 \pm 0.7 ^c	35.50 \pm 1.0 ^a
Initial Carapace Length (mm)	15.00 \pm 0.0 ^a	15.00 \pm 0.0 ^a	15.00 \pm 0.0 ^a
Final Carapace Length (mm)	29.45 \pm 1.16 ^b	26.88 \pm 0.97 ^c	31.45 \pm 1.34 ^a
Initial Carapace Width (mm)	31.00 \pm 0.0 ^a	31.00 \pm 0.0 ^a	31.00 \pm 0.0 ^a
Final Carapace Width (mm)	51.70 \pm 0.95 ^b	47.50 \pm 1.10 ^c	52.40 \pm 0.93 ^a

3.1. Survival rate of crabs in each system

Table 2 presents the Feed Conversion Ratio (FCR) and Survival Rate of blue crabs across the three experimental systems. The FCR values indicated that System A had a significantly better feed conversion efficiency (1.45) compared to System B (3.10), while System C (1.40) demonstrated comparable efficiency to System A. The survival rate (%) showed notable differences, with System C achieving the highest survival rate at 50%, followed by System A at 37.5%, and System B with the lowest survival rate at 12.5%.

Table 2: Feed Conversion Ratio (FCR) and Survival Rate of blue crabs across the three experimental systems

Parameter	System A	System B	System C
Feed Conversion Ratio (FCR)	1.45	3.1	1.4
Survival Rate (%)	37.5	12.5	50

3.2. Effect of trash fish and commercial feed on the survival and growth performance of Blue crabs

The results comparing the final weight gain of Gladiator swimming crabs across different feeding regimens and systems highlight the significant impact of trash fish on growth performance. In System A, which utilized commercial feed, the average final weight gain was 13.38 g, whereas crabs fed with trash fish achieved a higher average weight gain of 15.53 g, demonstrating the effectiveness of trash fish in enhancing growth. This pattern was even more pronounced in System C, where the average weight gain for crabs fed commercial feed was 14.76 g, while those receiving trash fish reached an average of 18.14 g. In stark contrast, System B showed the lowest overall performance; crabs fed commercial feed gained an average of only 7.61 g, while those on trash fish fared better, gaining 9.30 g, but still significantly less than their counterparts in Systems A and C (Table 3).

Table 3: Survival and growth performance of Blue crabs from Cameroon

Final Weight Gain of all System								
		Plastic 1	plastic 2	Plastic 3	Plastic 4	Average wgt.	Av. Com. Feed wgt	Av. Trash Feed wgt.
System A	com Feed	13.28	13.48			14.45	13.38	15.525
	Trash feed			15.58	15.47			
System B	com Feed	7.54	7.67			8.45	7.605	9.3
	Trash feed			9.23	9.37			
System C	com Feed	14.77	14.74			16.45	14.755	18.135
	Trash feed			18.36	17.91			

The results of this study highlight the significant impact of dietary regimens, particularly the use of trash fish, on the growth performance and survival of Gladiator swimming crabs reared in different aquaculture systems. Across the three systems examined (A, B, and C), crabs fed with trash fish consistently outperformed those fed with commercial feed, demonstrating that trash fish is a superior dietary option for optimizing crab growth.

In System A, which employed a recirculating aquaculture system (RAS) with a UV filter, crabs fed with commercial feed had an average final weight gain of 13.38 g. However, those provided with trash fish exhibited a significantly higher average final weight gain of 15.53 g. The superior performance of trash fish in this system can be attributed to its higher nutritional value and natural suitability to the feeding habits of blue crabs, which are opportunistic scavengers that benefit from the consumption of whole fish tissue (Bautista-Teruel et al., 2011).

In System B (RAS without UV filter), the overall growth performance was notably lower compared to Systems A and C, with crabs fed commercial feed gaining an average of only 7.61 g. Those fed trash fish did slightly better, with an average weight gain of 9.30 g. The reduced performance in System B may be due to the absence of UV filtration, which could have led to poorer water quality, negatively affecting the crabs' metabolic rates and overall growth (Cowan et al., 1995). The superior performance of trash fish over commercial feed in this system, despite the suboptimal conditions, underscores the importance of nutrient-rich diets in compensating for less ideal rearing environments.

In System C, which was a flow-through system, the difference in growth between commercial feed and trash fish was the most pronounced. Crabs fed with commercial feed gained an average of 14.76 g, while those fed with trash fish achieved an impressive 18.14 g. The high performance of trash fish in this system suggests that the flow-through system, with its frequent water exchanges, provided an environment that allowed for optimal digestion and nutrient absorption, thereby maximizing the growth-promoting effects of the trash fish diet (Le Vay et al., 2001).

The impact of trash fish on survival rates was less dramatic than on growth performance, but the results still favoured trash fish over commercial feed. Although detailed survival data are not provided in the table, the higher weight gains in crabs fed with trash fish suggest improved overall health and resilience, which are often associated with better survival outcomes (Guillaume et al., 2001).

The superior growth performance observed in crabs fed trash fish across all systems can be attributed to several key factors. Trash fish is rich in essential nutrients, including protein, lipids, and minerals, which are crucial for the growth and development of blue crabs (New et al., 2010). Moreover, trash fish closely resembles the natural diet of blue crabs in the wild, providing a more palatable and digestible food source compared to commercial feed, which may contain artificial ingredients and lower-quality proteins (Bautista-Teruel et al., 2011). Additionally, the lipid composition of trash fish, particularly in terms of omega-3 fatty acids, likely contributed to better growth performance by enhancing metabolic efficiency and supporting the energy-intensive molting process (D'Abramo et al., 1997).

The findings of this study are consistent with previous research on the benefits of natural diets in crab aquaculture. Le Vay et al., (2001) reported that crabs fed natural prey or whole fish exhibited significantly better growth rates compared to those fed artificial diets. Similarly, Bautista-Teruel et al., (2011) found that feeding juvenile crabs with diets containing fishmeal or fish by-products improved their growth and survival compared to commercial feeds. The results from the current study add to

this body of evidence, confirming the efficacy of trash fish as a dietary option for enhancing growth performance in blue crabs.

3.3. Linear regression analysis of the relationship between feed type and weight gain in Gladiator swimming crabs

The regression analysis showed that the relationship between weight gain (dependent variable) and the feed type and system (independent variables) had limited predictive power. The intercept was 5.44 ± 2.38 g and statistically significant ($p = 0.028$), indicating a significant baseline weight gain. The slope was 1.48 ± 1.50 g, with a p-value of 0.33, indicating no significant influence of feed type and system on weight gain. The model accounted for only 2.77% of the variation in weight gain, with an R-squared value of 0.0277 and an adjusted R-squared value of -0.0009, showing no improvement in explanatory power with the predictors. Pearson’s correlation coefficient was 0.166, indicating a weak positive linear relationship. ANOVA results supported these findings, with an F-value of 0.97 and a p-value of 0.33, indicating no statistically significant relationship. The residual sum of squares was 691.25, reflecting substantial unexplained variation.

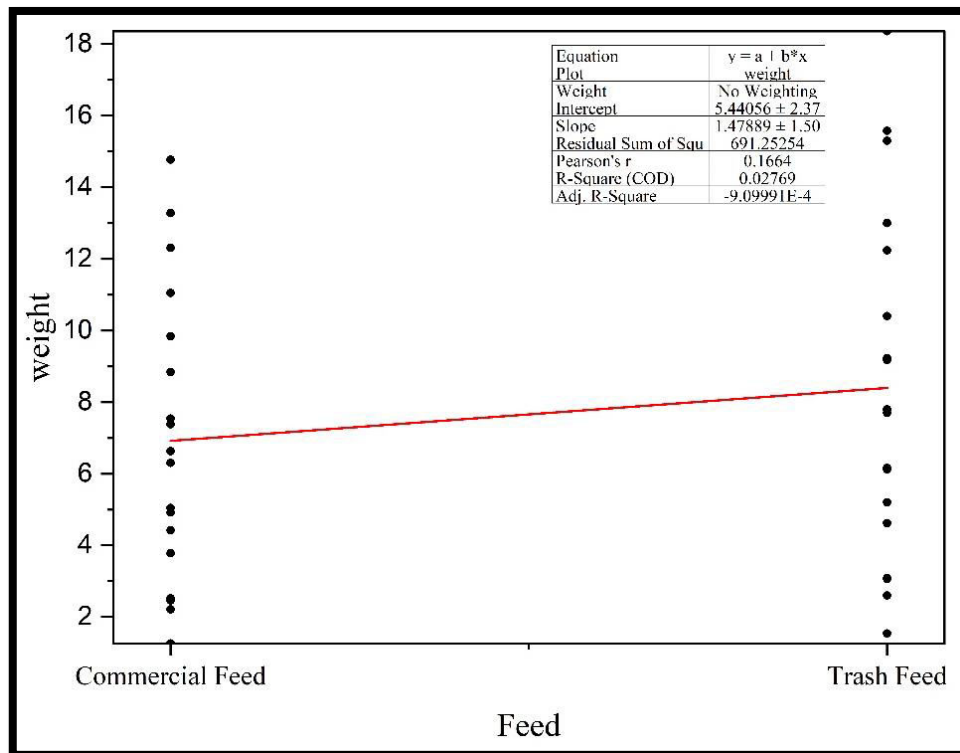


Figure 2: Fitted curve plot of regression analysis showing the relationship between weight gain (dependent variable) and the feed type (independent variables)

As revealed in **Figure 2**, the residuals versus independent variable plot indicates that the residuals are dispersed randomly around zero for both feed types, suggesting that there is no evident pattern or systematic bias in the residuals associated with either type of feed. However, the variability in residuals indicates that the model does not fully capture all the factors affecting weight gain. The residuals versus fitted values plot similarly reveals a random distribution of residuals around zero, which suggests that the model does not violate the assumption of linearity. The histogram of residuals demonstrates a distribution that is approximately symmetric but slightly skewed to the right. While the residuals roughly follow a normal distribution. The Q-Q plot supports this observation, showing that while most residuals align with the theoretical normal distribution, deviations are present at the tails, indicating minor departures from normality.

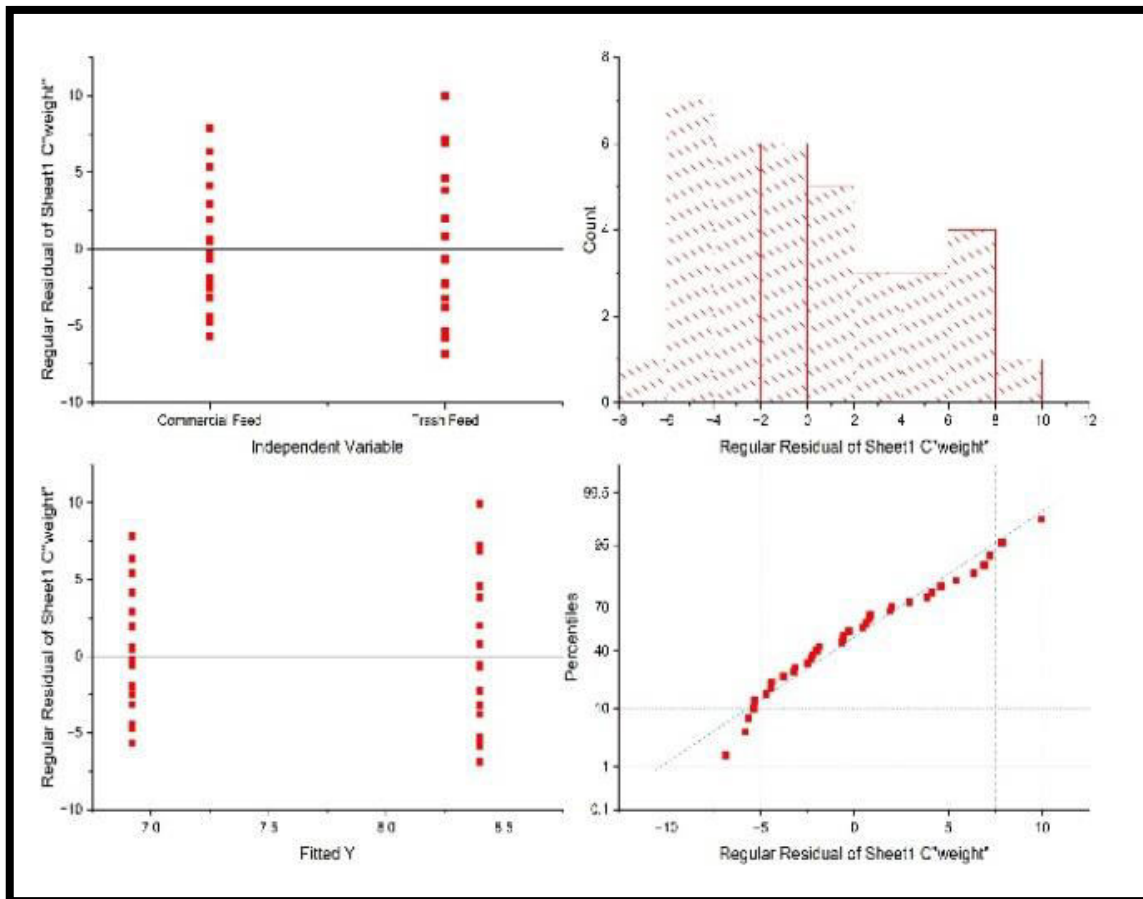


Figure 3: Residual plot similarly reveals a random distribution of residuals around zero

These findings align with studies highlighting the multifactorial nature of weight gain in crustaceans, where feed quality, environmental conditions and system management interact to influence growth. For example, studies on mud crabs (*Scylla*

serrata) have demonstrated that feed type alone is not always a strong predictor of growth; instead, nutrient balance and environmental factors such as temperature and dissolved oxygen play critical roles (Farr et al., 2020; Kumar et al., 2019). Similarly, for Gladiator swimming crabs (*Callinectes sapidus*), weight gain has been shown to depend heavily on protein content and digestibility of feed, but environmental parameters often modulate these effects (Davis et al., 2005). The weak correlation observed in this study may reflect suboptimal feed formulations or variability in other growth-determining factors, consistent with findings from these earlier studies. The limited explanatory power of the model suggests why the research investigated a broader range of variables to improve the understanding of weight gain in blue crabs. For instance, incorporating factors such as water temperature, salinity, and others provided a more comprehensive understanding of the determinants of crab growth. These findings also underscore the importance of designing holistic aquaculture systems that account for both feed efficiency and environmental parameters to optimize production.

3.4. Crab growth performance across the different systems

The growth performance of Gladiator swimming crabs across different aquaculture systems highlights the critical role of system design. System C, the flow-through system, showed superior growth compared to both Recirculating Aquaculture Systems (RAS) with and without UV filtration. The higher final average weight in System C (16.45 ± 0.58 g) versus System A (14.00 ± 0.63 g) and System B (8.45 ± 0.46 g) can be attributed to continuous water exchange, which likely maintained optimal environmental conditions such as higher dissolved oxygen and lower ammonia levels, both critical for better growth (Keene et al., 2017; Sallenave, 2019). Continuous water replacement in flow-through systems reduces waste buildup, as supported by Boyd (2017), who emphasized the importance of high-water quality in mitigating the negative effects of nitrogenous waste on crustaceans. In contrast, System B, the RAS without UV filtration, resulted in significantly lower final weights (8.45 ± 0.46 g) and specific growth rate (SGR) ($16.24 \pm 0.7\%$). The absence of UV filtration likely led to poorer water quality due to increased microbial activity and organic waste buildup, raising ammonia and nitrate levels, which negatively impact growth (Aich et al., 2020). Previous studies (Ding et al., 2017) indicate that elevated ammonia causes stress and reduces feeding efficiency, as seen in the significantly lower final weight in System B.

System A, the RAS with UV filtration, performed better than System B with a final weight of 14.00 ± 0.63 g and an SGR of $29.67 \pm 0.9\%$, but still lagged behind System C. UV filtration likely improved water quality by reducing microbial contamination and ammonia, leading to better growth outcomes compared to System B (Timmons

et al., 2018). However, the recirculating nature of RAS introduces challenges in water quality management, particularly regarding dissolved oxygen and waste accumulation, which may explain why System A did not match the performance of System C. Crabs in System C had the largest final carapace length (31.45 ± 1.34 mm) and width (52.40 ± 0.93 mm), followed by those in System A (29.45 ± 1.16 mm and 51.70 ± 0.95 mm). System B produced the smallest crabs (26.88 ± 0.97 mm and 47.50 ± 1.10 mm), reflecting the negative impact of suboptimal water quality (Boyd et al., 2020). Larger carapace dimensions in System C suggest that stable and optimal water conditions in the flow-through system promote better growth.

3.5. Survival rate of crabs in each system

The survival rate and feed conversion ratio (FCR) are critical indicators of the efficiency and sustainability of aquaculture systems, providing insight into both the health and well-being of the cultured species and the economic viability of the production system. In this study, the survival rate of blue crabs varied significantly across the three experimental systems, as did the feed conversion efficiency.

The survival rate was highest in System C, the flow-through system, with 50% survival, followed by System A, the RAS with UV filtration, at 37.5%, and System B, the RAS without UV filtration, at 12.5%. The marked difference in survival rates across these systems can be explained by the different water management practices and their impact on water quality. In flow-through systems, like System C, the continuous exchange of water helps maintain optimal environmental conditions by reducing the accumulation of toxic waste products such as ammonia and nitrite. Several studies have demonstrated that poor water quality, particularly elevated ammonia levels, can lead to high mortality rates in crustaceans due to the toxic effects on gill function and metabolic processes (Aich et al., 2020; Ding et al., 2017). The superior survival rate in System C, therefore, reflects the positive impact of stable water quality on crab health and longevity. System A, the RAS with UV filtration, had a lower survival rate than System C but still performed significantly better than System B. The use of UV filtration likely contributed to improved water quality by reducing microbial load and controlling the spread of pathogens, which is a common challenge in recirculating systems. Studies by Li et al., (2023) have shown that UV filtration can significantly reduce mortality rates in aquaculture by limiting disease outbreaks. However, the recirculating nature of RAS systems still presents challenges in maintaining consistently high-water quality, particularly with respect to waste accumulation and oxygen levels. Despite these challenges, the UV filtration in System A helped mitigate some of the negative effects, resulting in a higher survival rate compared to System B, which lacked UV filtration. System B, the RAS without UV filtration, had the lowest survival rate at 12.5%, highlighting the

detrimental effects of poor water quality management. Without UV filtration, System B likely experienced higher microbial activity and increased accumulation of organic waste, leading to more stressful and potentially harmful conditions for the crabs. The elevated mortality in System B aligns with findings from previous studies that have reported higher mortality rates in RAS systems without adequate water treatment mechanisms (Boyd, 2020). The buildup of ammonia, nitrite, and other waste products in recirculating systems can lead to toxic conditions that impair the crabs' ability to respire and maintain metabolic function, ultimately resulting in higher mortality rates (Romano & Zeng, 2013; Ong et al., 2019).

In terms of feed conversion efficiency, System C (FCR of 1.4) and System A (FCR of 1.45) showed comparable performance, both achieving significantly better feed conversion than System B (FCR of 3.1). The FCR values reflect the amount of feed required to produce a unit of crab biomass, with lower values indicating more efficient feed utilization. The superior feed conversion in Systems A and System C can be attributed to better overall water quality, which likely allowed the crabs to feed more effectively and convert the nutrients in their feed into biomass. Optimal environmental conditions are known to enhance feeding efficiency in aquatic organisms, as they experience less stress and can allocate more energy to growth (Heugens et al., 2001; Goodrich & Clark, 2023). The high FCR in System B indicates poor feed utilization, likely due to the stressful conditions caused by suboptimal water quality, which would have reduced the crabs' appetite and ability to convert feed into biomass.

3.6. Efficiency of water quality maintenance in each system

The pH maintenance across the three systems demonstrated variability, with System A (RAS with UV filter) showing the most stable pH levels (mean 7.48 ± 0.22). This stability is likely attributed to the UV filter, which aids in controlling microbial populations and organic matter, ultimately reducing the biochemical activities that cause pH fluctuations. The use of UV filtration has been shown to effectively reduce organic load and microbial activity, which may otherwise alter water chemistry, leading to pH changes (Li et al., 2023). In comparison, System B (RAS without UV filter) had a slightly lower mean pH of 7.44 ± 0.27 but showed higher variability. The absence of UV filtration in System B likely contributed to the accumulation of organic waste and a subsequent increase in microbial activity, which can lead to periodic shifts in pH due to microbial respiration and ammonia production. Meanwhile, System C (flow-through system) maintained the lowest pH (7.24 ± 0.11) with minimal variability. The lower pH in System C could be due to the frequent water exchanges typical of flow-through systems, which may dilute buffering agents and lead to lower but more consistent pH values. The findings from this study align with those reported

by Badiola et al. (2012), where recirculating systems with filtration tend to exhibit more stable pH levels compared to flow-through systems.

Temperature stability is a critical factor for optimal crab growth, and the results indicate that System A (RAS with UV filter) provided the most consistent temperature (mean $25.66 \pm 0.48^{\circ}\text{C}$). This stability is likely due to the enhanced control over water recirculation and filtration provided by the UV system, which helps maintain equilibrium in water conditions. Previous studies suggest that recirculating systems equipped with UV filtration have better control over water temperature due to the enhanced recirculation of water (Xiao et al., 2019). System B (RAS without UV filter) showed the highest average temperature ($26.16 \pm 1.60^{\circ}\text{C}$) with considerable variability. This higher variability could be due to the absence of additional temperature regulation mechanisms, leading to occasional thermal spikes, which could potentially stress the crabs. Such fluctuations are known to affect metabolic rates and growth in aquatic species. System C (flow-through system) maintained the lowest average temperature ($25.29 \pm 0.28^{\circ}\text{C}$), and its stability was likely due to the regular inflow of fresh water, which minimizes temperature fluctuations. However, the cooler conditions might have slightly reduced crab metabolism and growth compared to the warmer, more stable conditions in System A.

Concerning alkalinity, which reflects the buffering capacity of water, showed significant variability among the systems. System A (RAS with UV filter) had a mean alkalinity of 79.86 ± 12.54 mg/L, indicating a relatively stable environment with moderate fluctuations. The UV filter in System A likely contributed to this stability by reducing the organic load and improving water quality through enhanced nitrification processes (Timmons & Ebeling, 2010). System B (RAS without UV filter) recorded a slightly higher alkalinity (85.05 ± 13.18 mg/L), which might be due to the accumulation of organic matter, as the absence of UV filtration can lead to an increase in microbial activity that influences alkalinity (Sarker et al., 2019). However, the difference between Systems A and System B was not drastic, suggesting that the recirculating design itself aids in maintaining alkalinity within a manageable range. In contrast, System C (flow-through system) exhibited the highest alkalinity (90.14 ± 18.37 mg/L) with greater variability. This can be attributed to the frequent water exchanges, which may have introduced variability in the water's buffering capacity. These results are consistent with previous research, which indicates that flow-through systems often experience greater fluctuations in water chemistry, including alkalinity, due to the continuous addition of new water (Hammer, 2020).

Salinity maintenance is critical for aquatic organisms like crabs, which rely on consistent salinity for osmoregulation (Romano & Zeng, 2021). System A (RAS with UV filter) and System B (RAS without UV filter) both exhibited very similar salinity

levels, with means of 32.52 ± 0.19 ppt and 32.53 ± 0.39 ppt, respectively. This suggests that both recirculating systems were effective in maintaining a stable salinity, likely due to their closed-loop design, which minimizes salinity fluctuations. System C (flow-through system), which relies on regular water exchanges, maintained a slightly lower salinity (32.50 ± 0.08 ppt) but displayed the least variability among the systems. This consistency may be attributed to the frequent water replacement, which dilutes any salt accumulation, ensuring a stable salinity.

As for dissolved oxygen (DO), a crucial factor for aquatic life and its maintenance is essential for the health of cultured species like blue crabs. System A (RAS with UV filter) and System B (RAS without UV filter) both maintained similar DO levels, with means of 6.69 ± 0.44 mg/L and 6.68 ± 0.58 mg/L, respectively. These results suggest that the recirculating nature of both systems was effective in maintaining oxygen levels that are favourable for crab culture. However, System B exhibited greater variability, possibly due to the lack of UV filtration, which may have contributed to increased microbial oxygen consumption. System C (flow-through system) displayed a slightly lower mean DO concentration (6.64 ± 0.34 mg/L), which could be a result of lower water flow rates or reduced aeration efficiency compared to the recirculating systems. The importance of maintaining high DO levels is supported by previous research, which shows that inadequate oxygen levels can lead to reduced growth and increased stress in aquatic species (Hammer, 2020).

Ammonia nitrogen is a key indicator of water quality, as elevated levels can be toxic to aquatic organisms. In this study, System A (RAS with UV filter) exhibited a mean ammonia concentration of 0.0461 ± 0.0225 mg/L, while System B (RAS without UV filter) recorded a slightly lower mean of 0.0447 ± 0.0216 mg/L. Despite the absence of UV filtration, System B managed to maintain ammonia levels comparable to System A, possibly due to effective bio filtration in both systems. System C (flow-through system) had the highest mean ammonia concentration (0.0512 ± 0.0209 mg/L), which could be due to the less efficient removal of ammonia through water exchange compared to the biological processes in recirculating systems.

3.7. Correlation between water quality and growth performance

The correlation analysis reveals key insights into how various water quality parameters influence the growth performance of Gladiator swimming crabs, as measured by weight (W), carapace length (CL), and carapace width (CW). The strong positive correlations observed between growth metrics (W, CL, CW) suggested that these dimensions are interrelated and increase simultaneously, consistent with the natural allometric growth patterns in crustaceans, where weight gain is usually proportional to increases in body size (Chang et al., 2012). Ammonia ($\text{NH}_3\text{-N}$) demonstrated a strong positive correlation with crab weight (0.88),

carapace length (0.96), and carapace width (0.96). While elevated ammonia concentrations are generally detrimental to aquatic life due to toxicity (Colt, 2006), this positive correlation could indicate that the ammonia levels in this study were within tolerable limits, potentially reflecting the efficiency of nitrogen removal processes such as nitrification. Nitrifying bacteria convert harmful ammonia into less toxic nitrate, which could explain why crabs in these systems were able to grow efficiently without experiencing ammonia toxicity (Kuhn et al., 2010). The strong correlations with growth parameters highlight the need for controlled levels of ammonia, which, when managed appropriately, may actually reflect favourable conditions for microbial activity and nutrient cycling that support growth.

Conversely, dissolved oxygen (DO) showed a strong negative correlation with crab growth, ranging from -0.7 to -0.81 across weight, carapace length, and width. This suggests that low levels of oxygen hindered the development of blue crabs. Oxygen deficiency in water is known to cause stress, reduce metabolic efficiency, and negatively impact growth (Ciji & Akhtar, 2021; Boyd, 2017). Low DO can impair aerobic respiration, which is essential for energy production in crabs, thus stunting their growth. These findings align with studies that report negative effects of low DO on the growth and survival of crustaceans and other aquatic species (Boyd, 2017).

Alkalinity also exhibited strong positive correlations with growth performance (0.87 to 0.92), underscoring its importance in maintaining optimal water chemistry for crab development. Alkalinity acts as a buffer against pH fluctuations, which is crucial for the physiological processes of blue crabs, including osmoregulation and shell formation (Boyd et al., 2016). The positive relationship between alkalinity and growth is consistent with prior research that highlights the role of stable alkalinity in promoting better health and growth outcomes in aquatic species (Boyd, 2017; Li et al., 2023).

The weaker correlations observed between temperature, pH, salinity, and growth performance suggest that these factors, while important, may not have had as direct an impact on crab growth as ammonia, DO, and alkalinity. Temperature, for instance, is a well-documented factor in regulating metabolic rates, but within the range observed in this study, its influence on growth may have been overshadowed by other more dominant water quality parameters. Similarly, pH and salinity, which remained within acceptable ranges, may not have exhibited strong correlations due to their relative stability across the different systems (Timmons & Ebeling, 2010).

3.8. Component Analysis of water quality and growth performance

The Principal Component Analysis (PCA) revealed key relationships between water quality parameters and growth performance metrics across the three systems. PC1

and PC2 explained a combined variance of 10.8%, with PC1 driven primarily by pH, while PC2 was dominated by temperature and dissolved oxygen (DO). Ammonia nitrogen (NH_3^-) played a significant role in PC2, showing a positive relationship with growth performance indicators such as weight gain (WG) and specific growth rate (SGR), while feed conversion ratio (FCR) exhibited an inverse relationship. System clustering revealed distinct performance patterns, with System C showing superior growth metrics linked to higher ammonia nitrogen levels, while System A was influenced by favourable pH and DO levels.

The findings highlight the critical interplay between water quality and growth performance in aquaculture systems. The strong negative loading of pH in PC1 indicates its influence on overall system variance, suggesting that deviations in pH may significantly impact system stability and biological processes. The prominence of temperature and DO in PC2 underscores their importance in influencing metabolic and physiological functions, aligning with their established roles in regulating growth and survival in crustaceans (Zhang et al., 2020). The positive loading of ammonia nitrogen (NH_3^-) in PC2, correlated with growth metrics such as WG and SGR, may initially seem counterintuitive given the potential toxicity of ammonia in aquaculture systems. However, its association with enhanced growth performance in System C suggests that the system may have had a well-adapted microbial community or optimized bio filter design capable of managing ammonia levels without reaching toxic thresholds (Boyd & Tucker, 2012). This finding aligns with studies indicating that low to moderate levels of ammonia can stimulate growth by promoting nitrogen assimilation in aquatic organisms (Bossier & Ekasari, 2017).

These findings are consistent with existing studies emphasizing the importance of water quality parameters in crustacean aquaculture. For instance, Boyd and Tucker (2012) highlighted the critical role of pH in enzymatic activity and shell formation, which may explain its central role in PC1. Additionally, the negative relationship between DO and PC2 aligns with findings by Chen et al. (2015), which demonstrated that low DO levels can inhibit metabolic processes, leading to reduced growth performance. The positive correlation between ammonia nitrogen and growth metrics, as observed in System C, is supported by studies on biofloc technology (BFT), where controlled ammonia levels promote microbial protein production and enhance feed utilization efficiency (Ekasari et al., 2015). However, excessive ammonia levels remain detrimental, emphasizing the need for precise management. This study underscores the importance of understanding system-specific interactions between water quality and growth performance in aquaculture. The clustering of systems based on PCA indicates that tailored water quality management strategies can optimize growth and survival rates, particularly in systems like System C, which demonstrated superior performance metrics. The

findings also highlight the potential of incorporating advanced water treatment techniques, such as bio filters or microbial management systems, to mitigate ammonia toxicity and enhance production efficiency. These insights are valuable for informing sustainable aquaculture practices, particularly for species like blue crabs, which have high commercial value in domestic and international markets.

3.9. Influence of environmental conditions on growth performance

The canonical correlation analysis revealed a strong association between environmental conditions and growth performance in the cultured species. The first canonical variate accounted for 64.43% of the total variation and demonstrated a very strong correlation (0.96619, $p = 0.09197$), indicating that parameters such as ammonia nitrogen, dissolved oxygen, temperature, and pH significantly influenced growth metrics like specific growth rate (SGR), feed conversion ratio (FCR), and weight gain (WG). Ammonia nitrogen and dissolved oxygen were the most significant contributors to the first variate. The second canonical variate, though moderately correlated (0.90181, $p = 0.43561$), explained 35.69% of the variation and highlighted the continued importance of ammonia nitrogen and temperature, though its contribution was less pronounced.

The strong association between ammonia nitrogen (NH_3^-) and SGR underscores the importance of maintaining low ammonia levels in aquaculture systems. High ammonia concentrations can impair metabolic processes, reduce feed intake, and ultimately stunt growth (Zhang et al., 2021). Similarly, dissolved oxygen (DO) showed a strong positive relationship with growth performance, aligning with its role in supporting aerobic respiration, efficient feed conversion, and overall fish vitality (Boyd et al., 2020). Temperature and pH, while contributing less significantly, are known to influence metabolic rates and enzyme activity (Hossain et al., 2019). The negative loading of FCR on the second canonical variate may reflect inefficiencies in feed utilization under suboptimal environmental conditions. The varied contributions of temperature, pH, and ammonia nitrogen on growth metrics suggest that a combination of stressors could differentially impact growth performance, depending on their intensity and interaction.

The findings are consistent with existing studies that highlight the critical role of water quality parameters in aquaculture. For instance, Li et al. (2020) demonstrated that ammonia nitrogen levels above 0.5 mg/L negatively affect growth rates and feed conversion efficiency in crustaceans. Similarly, Boyd and Tucker (2014) reported that dissolved oxygen levels below 5 mg/L can significantly reduce growth performance in aquaculture species, supporting the strong positive association observed in this study. Temperature's influence on growth has also been widely documented, with studies showing that deviations from the optimal range can

reduce metabolic efficiency and compromise growth (Hossain et al., 2019). The moderate influence of pH observed here aligns with findings by Kim et al. (2022), who noted that pH outside the range of 6.5–8.5 can disrupt osmoregulation and enzymatic activity, leading to suboptimal growth performance.

These findings have important implications for aquaculture management. The strong influence of ammonia nitrogen and dissolved oxygen suggests that effective water quality management should prioritize the reduction of ammonia through improved filtration systems or biofilters and the maintenance of optimal oxygen levels through aeration. Monitoring and regulating temperature and pH can further enhance growth performance, particularly for species sensitive to environmental fluctuations. Moreover, the results emphasize the need for site-specific environmental management strategies to optimize aquaculture productivity. Incorporating these findings into system design and management could enhance production efficiency and sustainability, particularly in regions like Cameroon where aquaculture is being developed to diversify protein sources and improve food security.

4. Conclusion

This study contributes to the advancement of sustainable crab aquaculture practices in Cameroon, providing valuable insights into the optimal systems for blue swimming crab culture. It adds to the growing body of knowledge on aquaculture systems and species diversification in Cameroon, with implications for enhancing local food security and reducing dependency on imported frozen fish. The use of trash fish as a supplementary feed also offers a potential cost-effective strategy for crab farmers. The findings of this study highlight the importance of selecting the appropriate aquaculture system for maximizing crab growth and survival. The superior performance of the flow-through system suggests that this could be the most viable option for large-scale crab production in Cameroon. Furthermore, the use of trash fish in feeding regimes could offer sustainable, local solutions for enhancing growth while reducing feed costs. The research also highlights the importance of water quality management in RAS systems, especially regarding the role of UV filtration in maintaining optimal conditions for crab culture.

So, this study provides essential data for the development of sustainable crab aquaculture systems in Cameroon, offering a potential pathway to improving food security and reducing the importation of frozen fish. The results emphasize the role of proper system design, feed management, and water quality control in optimizing blue swimming crab production. Further research is needed to refine these systems and explore their scalability, ensuring that they can be adapted to the broader context of marine aquaculture in the region.

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Author contributions

Morfow Nkeze Paul: wrote the original manuscript, Benedicta O. M: Critically commented on the first draft of the manuscript Friday E.O.: Formatted and critically revised and follow-up of the final manuscript before submission. Nor Azman Kasan: commented and approved the final revision of manuscript.

Conflict of interest

The authors declare no conflict of interest

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