



## Effects of Culture System Optimization and Feeding Regimens on Growth, Survival, and Production Efficiency of *Callinectes pallidus* (Rochebrune, 1883) in Indoor Aquaculture Systems

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**Abstract:** This study investigated sustainable indoor culture strategies for the Gladiator Swimming Crab (*Callinectes pallidus*, Rochebrune, 1883) using simple system designs and locally sourced juveniles. The research evaluated the effects of two feeding regimens (trash fish and commercial feed) on growth, survival, and culture efficiency across three indoor systems (a recirculating aquaculture system with UV filtration (System A), a recirculating system without UV (System B), and a flow-through system (System C)). All crabs had an initial mean weight of 1.63 g and were cultured for 2.5 months. Significant differences ( $p < 0.05$ ) were observed among feeding regimens and culture systems. Crabs fed trash fish exhibited superior growth and weight gain across all systems, with System C achieving the highest final mean weight ( $16.45 \pm 0.58$  g), specific growth rate ( $35.50 \pm 1.0\%$ ), and maximum weight gain (18.14 g). Similar trends were observed in carapace dimensions, with System C attaining the largest length ( $31.45 \pm 1.34$  mm) and width ( $52.40 \pm 0.93$  mm). Feed conversion efficiency was highest in System C (FCR = 1.4) and System A (FCR = 1.45), compared to System B (FCR = 3.1). Survival rates followed the same pattern, with System C at 50%. The results demonstrate that combining optimized culture systems with appropriate feeding regimens, particularly trash fish in a flow-through system, significantly enhances growth performance, feed utilization, and survival of *C. pallidus*. These findings provide valuable knowledge for improving the productivity and sustainability of tropical crab aquaculture and show the importance of system design and dietary management in indoor aquaculture operations.

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**Keywords:** Feed conversion ratio (FCR); Flow-through system; Production systems; Recirculating aquaculture system (RAS); Sustainable aquaculture; Ultraviolet filter.

### 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, controlled production of soft-shell swimming crabs has been on the rise due to advances in production technologies and the increase in demand for soft-shell swimming crab farming as 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 (Apine *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

### Location of the Study and Experiment Design

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) were used (Figure 1). 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 *Nitrobacter*

sp. 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).

Juveniles of *Callinectes* spp. were caught from the wild from target areas of high crab activity using a seine net, ensuring minimal environmental disturbance. The crabs were sorted and selected to include 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 and Lovatelli, 2011).

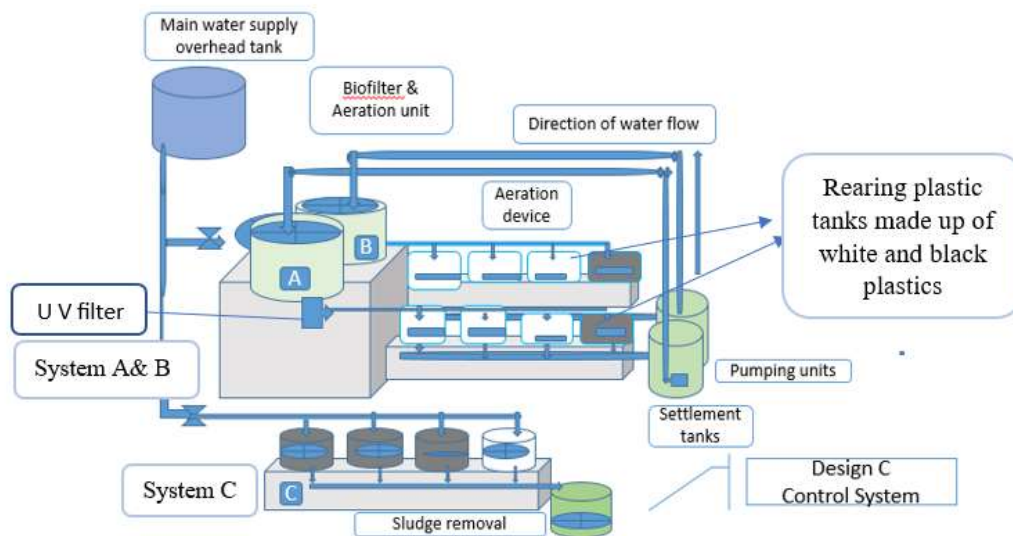


Figure 1: Design view of System A, System B and System C

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 1,20l per system. A total of 72 juvenile crabs with the same average initial weight of 1.63g were randomly distributed across the three systems. Stocked at a rate of 6 crablets per 24-liter container. The crablets were maintained for two and a half months, 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 callipers. Observed features were systematically documented in a standardized data sheet, which included measurements, colouration 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 (*Sardinella maderensis*), and commercial catfish feed (Gouessant) crushed 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 two and a half months (10-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).

## Data Collection

### 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 (Nyadjeu *et al.*, 2021). 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 equation [1] as follows:

$$\text{SGR (\%)} = \frac{(W_t - W_0)}{t} \times 100 \quad \text{equation [1]}$$

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 with four containers (System A, System B, and System C) to compare growth performance across 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.

### iii. 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 equation [2] as follows:

$$\text{Survival rate (\%)} = \frac{\text{Number of live crabs}}{\text{initial number of crabs}} \times 100 \quad \text{equation [2]}$$

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

### iv. Statistical analysis

Experimental data were analyzed using RStudio Desktop (v. 2024.12.1-567). One-way ANOVA was applied to compare treatment means and assess the effects of culture system design and trash fish feeding on the growth and survival of Atlantic blue swimming crabs (*Callinectes* sp.). Results are expressed as means  $\pm$  standard deviation (SD), with statistical significance set at  $p < 0.05$ . To further investigate multivariate relationships among water quality parameters, feeding regimes, and growth performance, Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) were performed using OriginPro 2022.

## 3. Results

### 3.1 Growth Performance and Survival Rate of Crabs across 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) (Table 1). Based on the result, the crabs had a uniform initial average weight of 1.63 g across all systems. After the 10-week experimental period, significant differences ( $p < 0.05$ ) in final average weight were observed among the systems. Crabs in System C exhibited the highest final average weight of  $16.45 \pm 0.58$  g, followed by System A at  $14.00 \pm 0.63$  g, and System B at  $8.45 \pm 0.46$  g. The Specific Growth Rate (SGR) followed a similar trend, with System C given 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  $31.45 \pm 1.34$  mm in System C,  $29.45 \pm 1.16$  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. The flow-through system (System C) showed 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 favourable results.

**Table 1: Overall crab growth performance in the different systems**

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

The result of the Feed Conversion Ratio (FCR) and Survival Rate of blue crabs across the three experimental systems (Table 2) showed that System A had a significantly better feed conversion efficiency (1.45) compared to System B (3.10), while System C (1.40) showed 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 showed the significant impact of trash fish on growth performance (Table 3). 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, shows 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 on dietary regimens (the use of trash fish) for the growth performance and survival of Gladiator swimming crabs reared in the three systems (A, B, and C) revealed that crabs fed trash fish consistently outperformed those fed commercial feed. 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. In System B, the overall growth performance was 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. Crabs fed with commercial feed gained an average of 14.76 g, while those fed with trash fish achieved an impressive 18.14 g.

### 3.3 Effects of Feeding Regimes and Culture Systems on Growth Performance and Weight Gain of Gladiator Swimming Crabs

The regression analysis (Figure 2) showed that the relationship between weight gained (dependent variable) and the feed regimes (type) and system (independent variables) had limited predictive power (Table 2). The intercept was  $5.44 \pm 2.38$  g and statistically significant ( $p = 0.028$ ), indicating a significant baseline weight gain. The slope was  $1.48 \pm 1.50$  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, showing substantial unexplained variation.

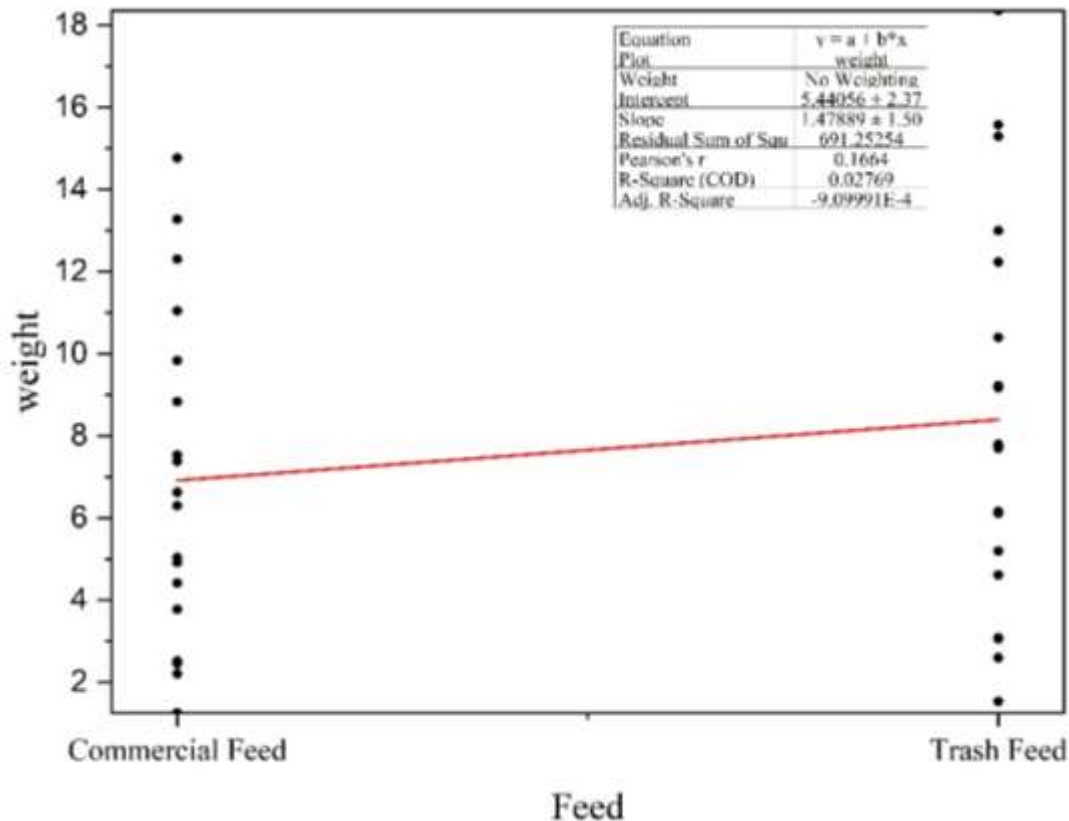
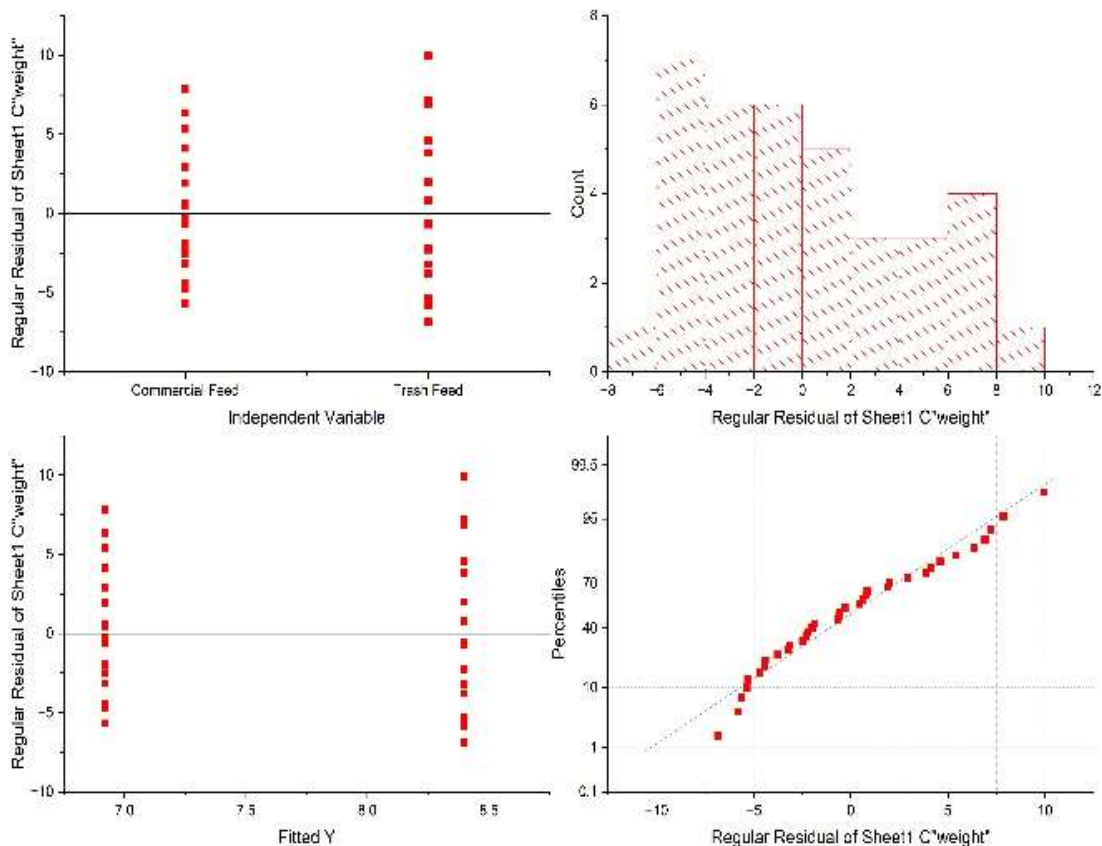


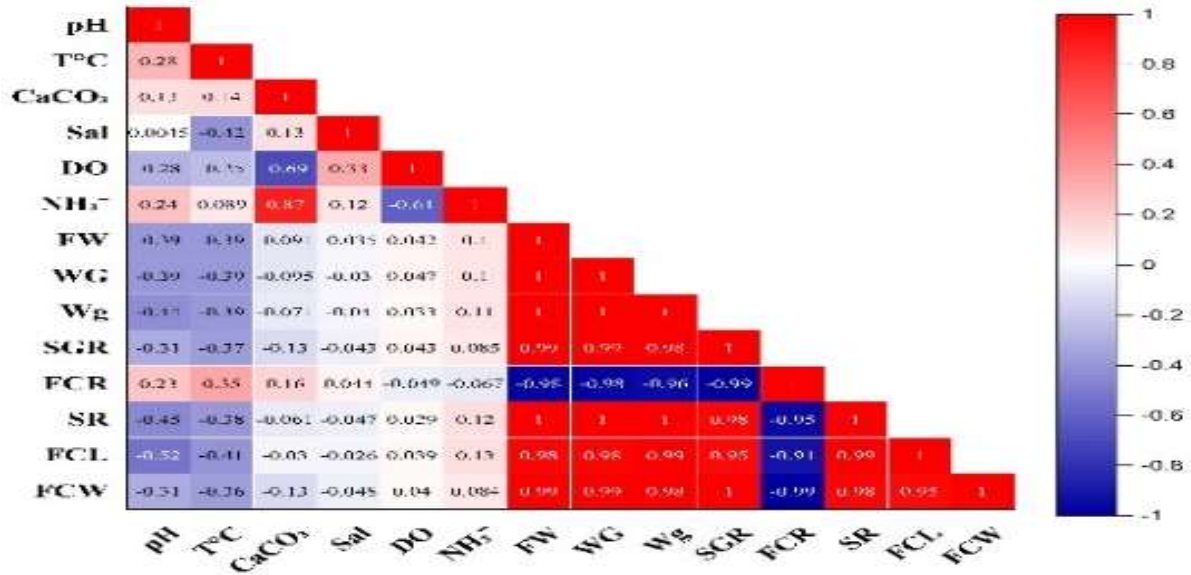
Figure 2: Fitted curve plot of regression analysis showing the relationship between weight gain (dependent variable) and the feed type (independent variables)

The residuals versus independent variable plot (Figure 3) indicates that the residuals are dispersed randomly around zero for both feed types, indicating that there is no evident pattern or systematic bias in the residuals associated with either type of feed (Figure 3). 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 shows 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.

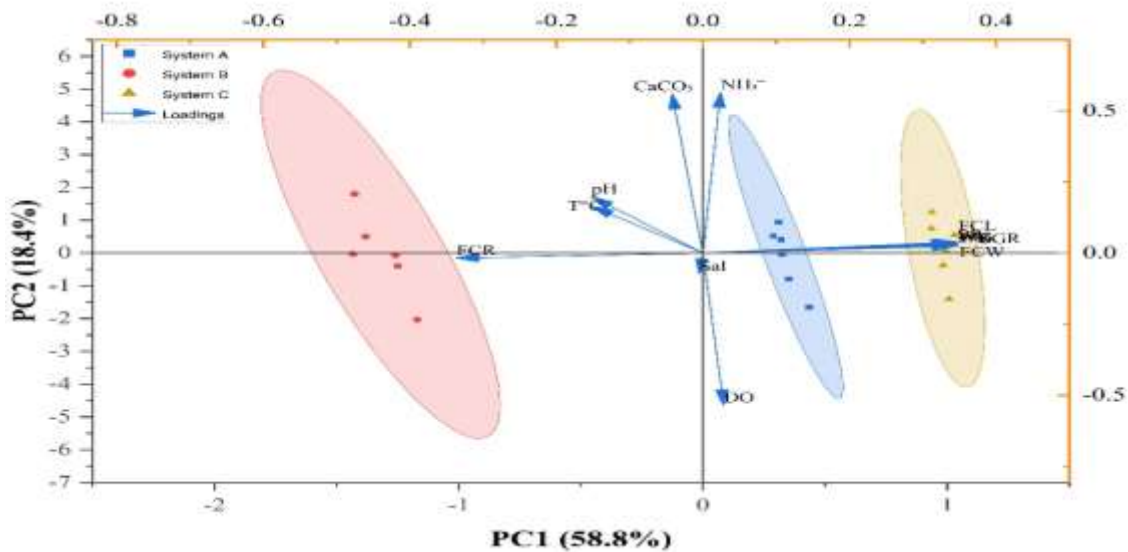


**Figure 3: Residual plot of Feed Regimes and Systems**

The correlation analysis between water quality parameters and growth performance metrics revealed several significant relationships (Figure 4). pH showed a weak positive correlation with final weight ( $r=0.39$ ), weight gain ( $r=0.39$ ), and specific growth rate ( $r=0.31$ ), while demonstrating a moderate negative correlation with survival rate ( $r=-0.45$ ). Temperature exhibited weak negative correlations with growth metrics such as final weight ( $r=-0.39$ ) and weight gain ( $r=-0.39$ ). Additionally, temperature showed a weak positive correlation with food conversion ratio ( $r=0.35$ ). Dissolved oxygen (DO) was weakly positively correlated with survival ( $r=0.04$ ) and growth metrics. Ammonia nitrogen ( $\text{NH}_3^-$ ) displayed strong correlations with growth metrics such as final weight ( $r=0.10$ ) and weight gain ( $r=0.10$ ). However, a negative correlation between ammonia and dissolved oxygen ( $r=-0.61$ ) was observed. The growth metrics themselves, including final weight, weight gain, weight gain percentage, and specific growth rate, were highly positively correlated ( $r > 0.99$ ), reflecting their interconnected nature as measures of production efficiency. Specific growth rate was strongly negatively correlated with food conversion ratio ( $r=-0.99$ ). Survival rate demonstrated strong positive correlations with weight gain ( $r=0.99$ ) and final carapace length ( $r=0.99$ ).



**Figure 4:** Correlation matrix between water quality parameters and growth parameters  
 Principal Component Analysis (PCA) was used to explore the relationships between water quality parameters and growth performance metrics across the three systems (Figure 5). The analysis revealed that the first principal component (PC1) explained 8.23% of the total variance, primarily driven by pH, which exhibited a strong negative loading (-0.15242). The second principal component (PC2) accounted for 2.57% of the variance, with temperature (T°C) emerging as a key contributor (-0.15255). Among the water quality parameters, DO had a strong negative loading in PC2 (-0.53481). NH<sub>3</sub><sup>-</sup> exhibited a significant positive loading in PC2 (0.56578). Regarding growth metrics, weight gain (WG) and specific growth rate (SGR) showed positive loadings in PC2 (0.34766 and 0.34421, respectively), which showed strong correlations with ammonia nitrogen levels. Feed conversion ratio (FCR) displayed a negative loading in PC2 (-0.33703), signifying its inverse relationship with other growth performance indicators. System clustering revealed distinct groupings based on water quality and growth performance. System A is clustered separately, influenced by its association with pH and dissolved oxygen levels. System B was linked to temperature and moderate growth performance, clustering near intermediate values of ammonia nitrogen. System C, characterized by higher ammonia nitrogen levels, demonstrated superior growth performance metrics, including WG, SGR, and survival rate, clustering distinctly due to its optimized efficiency.



**Figure 5:** Principal Component Analysis of water quality and growth performance

### 3.4 Physicochemical Properties of Water Across the Three Culture Systems for Gladiator Swimming Crab

The physicochemical properties of water across the three culture systems, i.e., System A (recirculating aquaculture system with UV filtration), System B (recirculating aquaculture system without UV filtration), and System C (flow-through system), were monitored throughout the experimental period to assess their stability and management efficiency. The pH values across the systems remained in a slightly alkaline range but varied slightly among treatments (Figure 6). At the start of the experiment, System B recorded the highest pH (7.30), followed by System A (7.21) and System C (7.16). As the culture period progressed, System B generally maintained higher pH levels, while System A showed a gradual increase, reaching a peak of 7.79 before stabilizing towards the end of the experiment. System C consistently recorded lower pH values throughout the study, ending at 7.33 (Figure 2). Thus, pH fluctuations stayed within acceptable limits for aquatic organisms, indicating that the culture environments across the three systems maintained suitable acid–base conditions.

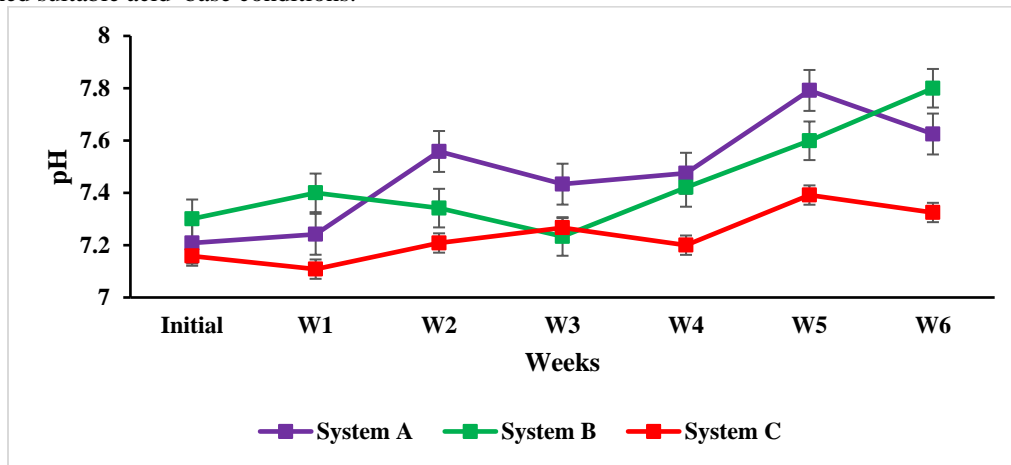


Figure 6: pH variation across the three systems

Temperature across the systems showed minor variations during the experimental period (Figure 7). Initial temperatures were similar, ranging from 25.1°C in System A to 25.5°C in System C. Systems A and C maintained stable temperature profiles throughout, whereas System B experienced a temporary rise to 29.5°C before stabilizing within a comparable range. Despite this fluctuation, temperature values across all systems generally stayed within the optimal range for aquaculture operations.

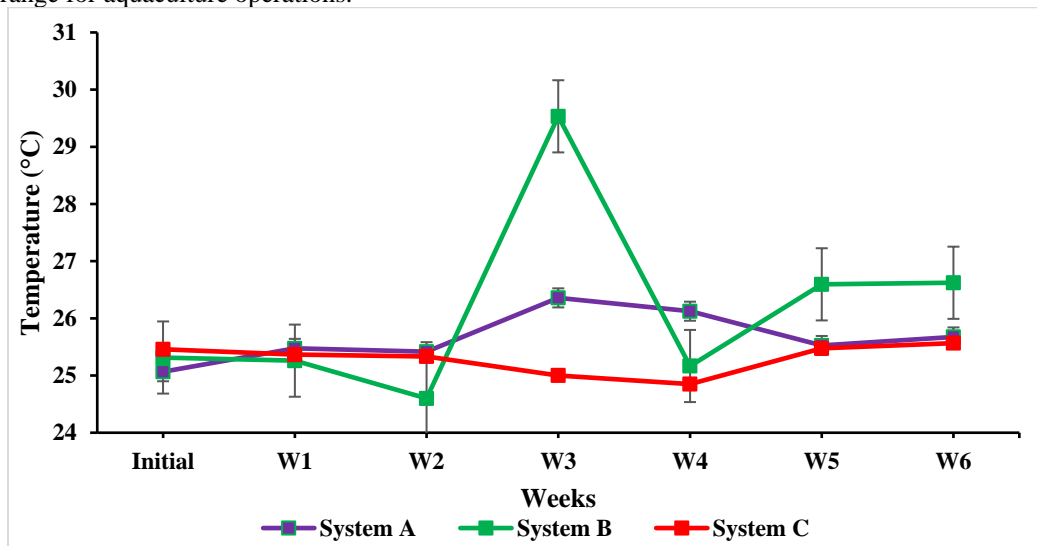


Figure 7: Temperature variation across the three systems

Alkalinity levels varied among the systems, revealing differences in buffering capacity and water quality regulation (Figure 8). At the beginning of the experiment, alkalinity values were similar across the systems, indicating uniform baseline conditions. As the study progressed, increases in alkalinity were observed, particularly in Systems B and C, while System A exhibited a more gradual rise. Toward the end of the experimental period, System C recorded the highest alkalinity value (119.6 mg/L), whereas Systems A and B maintained relatively stable values close to 102 mg/L. These variations reveal differences in carbonate buffering dynamics among the systems.

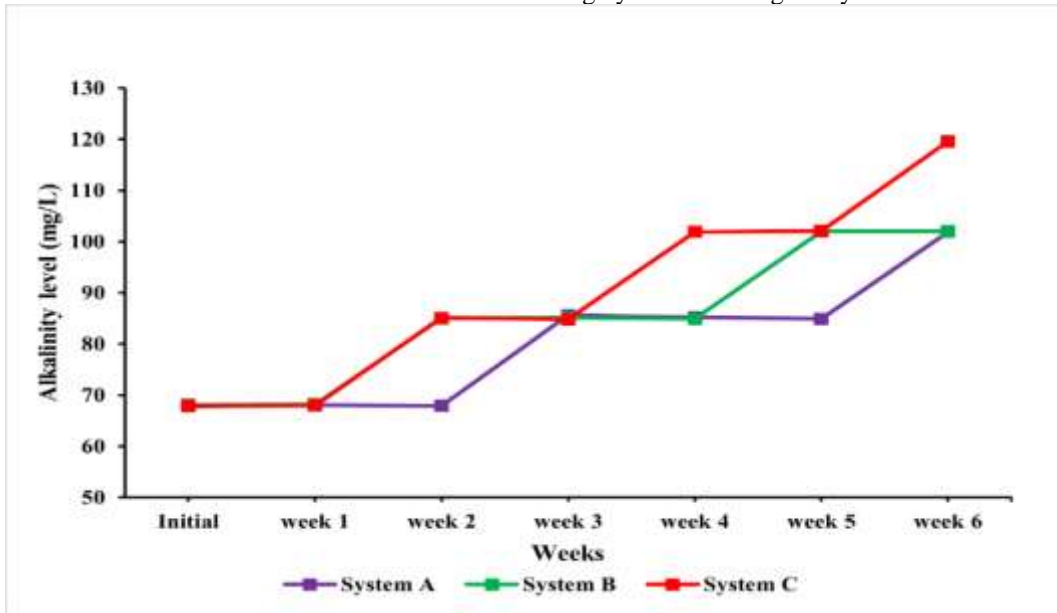


Figure 8: Alkalinity variation across the three systems

Salinity remained generally stable across the three systems during the study period (Figure 9). Initial salinity values ranged from 32.5 to 32.8 ppt and showed only minor fluctuations over time. Although System B exhibited a slight increase at one stage, the total salinity levels across all systems remained relatively consistent, with values ranging between approximately 32.1 and 33.4 ppt. This stability indicates that salinity was effectively maintained within the appropriate range for crab culture.

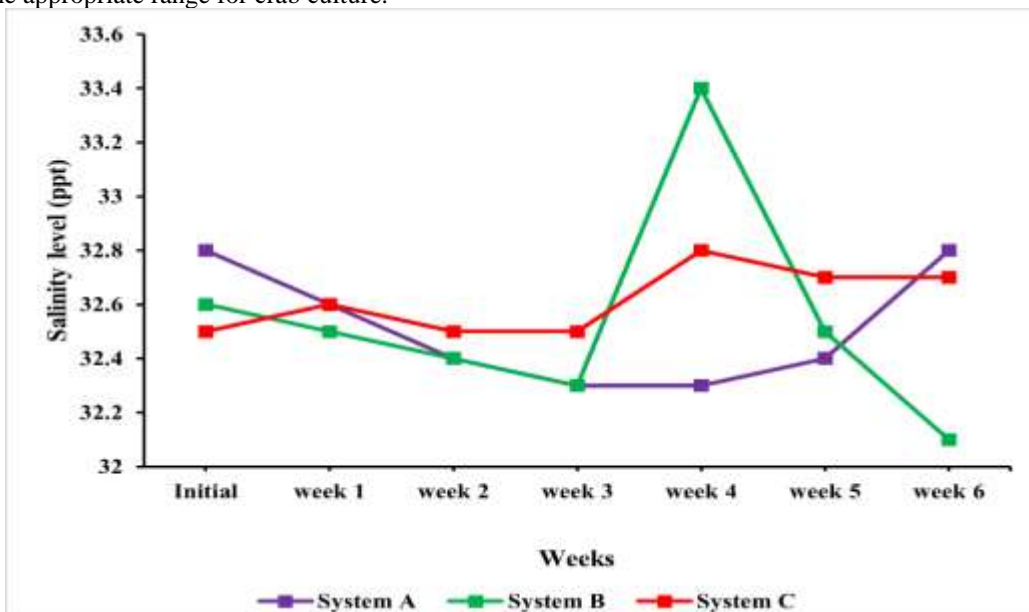
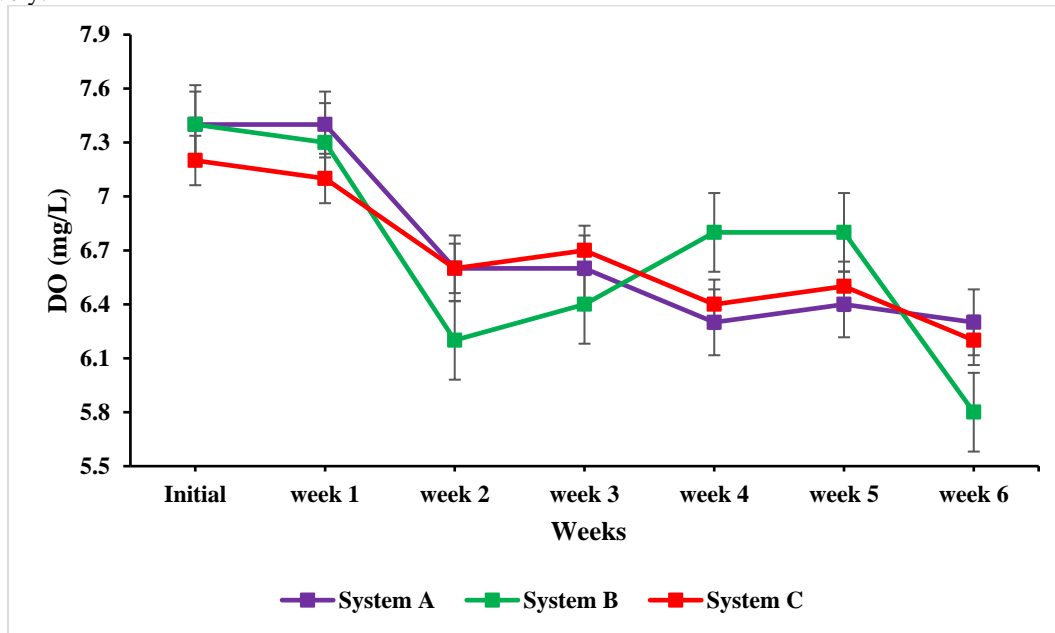


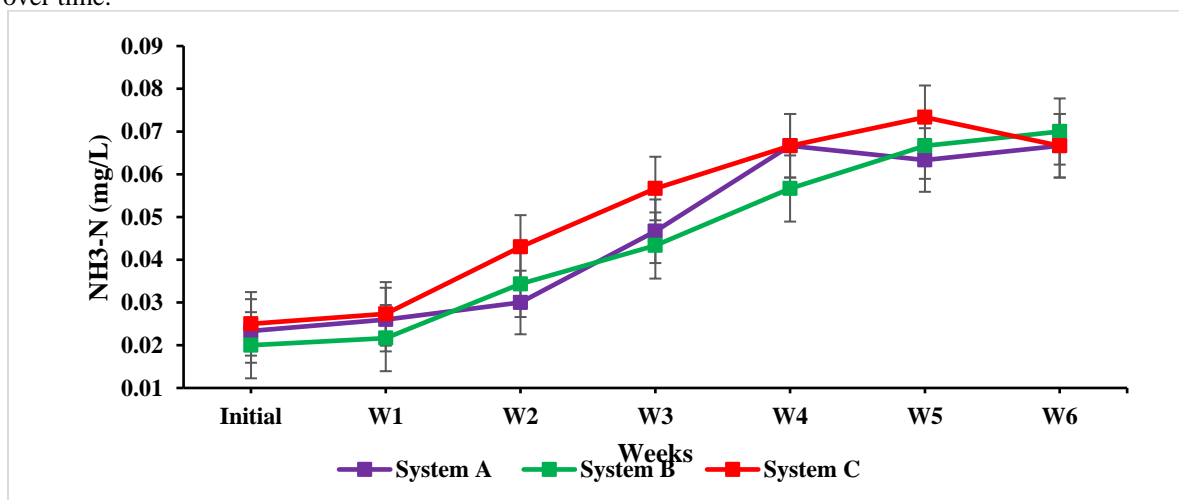
Figure 9: Salinity variation in the three systems

Dissolved oxygen (DO) concentrations showed a gradual decline over the experimental period across all systems (Figure 10). Initial DO levels were relatively high and similar among the systems, with values ranging from 7.2 to 7.4 mg/L. As the experiment progressed, reductions in DO were observed, although the magnitude of decline differed among the systems. System B recorded a more pronounced decrease at certain stages, while Systems A and C maintained relatively comparable oxygen levels. By the end of the experiment, System B exhibited the lowest DO concentration (5.8 mg/L), whereas Systems A and C recorded slightly higher values of 6.3 mg/L and 6.2 mg/L, respectively.



**Figure 10:** Dissolved Oxygen (DO) variation across the three systems

Ammonia nitrogen ( $\text{NH}_3\text{-N}$ ) concentrations were initially low and comparable among the three systems (Figure 11). Over the course of the experiment,  $\text{NH}_3\text{-N}$  levels increased with observable fluctuations across treatments. While early measurements showed minimal differences among systems, a noticeable increase occurred in System B during the later stages of the experiment. In contrast, Systems A and C maintained relatively lower ammonia concentrations for most of the experimental period. By the end of the study,  $\text{NH}_3\text{-N}$  concentrations increased across all systems, reaching similar values. These trends indicate progressive accumulation of metabolic waste in the culture systems over time.



**Figure 11:** Ammonia nitrogen variation across the three systems

## 4. Discussions

### 4.1 Growth Performance and Survival Rate of Crabs across Different Systems

The growth performance of Gladiator swimming crabs varied significantly across the three aquaculture systems. System C, the flow-through system, achieved the highest final average weight ( $16.45 \pm 0.58$  g) compared to System A ( $14.00 \pm 0.63$  g) and System B ( $8.45 \pm 0.46$  g). The superior growth in System C is likely due to continuous water exchange, which maintained optimal environmental conditions such as higher dissolved oxygen and lower ammonia levels, both critical for crab development (Keene *et al.*, 2017; Boyd, 2015; Sallenave, 2019). Larger final carapace length and width were also observed in System C ( $31.45 \pm 1.34$  mm and  $52.40 \pm 0.93$  mm), showing the positive effect of stable water conditions on morphological growth (Romano and Zeng, 2013; Boyd, 2020).

System A, the RAS with UV filtration, performed better than System B, achieving a final weight of  $14.00 \pm 0.63$  g and SGR of  $29.67 \pm 0.9\%$ , though it did not match the flow-through system. UV filtration improved water quality by reducing microbial contamination and ammonia, yet the recirculating nature of RAS posed challenges in maintaining consistent oxygen levels and preventing metabolic waste accumulation (Udayakumar *et al.*, 2025). System B, the RAS without UV filtration, exhibited the lowest growth metrics, likely due to elevated ammonia and nitrate levels impairing feeding efficiency and physiological performance (Aich *et al.*, 2020; Rahman *et al.*, 2020; Boyd, 2020).

Survival rates mirrored growth performance, with System C recording the highest survival (50%), followed by System A (37.5%) and System B (12.5%). The high survival in System C was associated with reduced toxic waste accumulation through continuous water exchange, whereas poor water quality and higher microbial loads contributed to the low survival in System B (Rahman *et al.*, 2020; Aich *et al.*, 2020). Feed conversion ratio (FCR) was lowest in System C (1.4) and System A (1.45), indicating efficient feed utilization, while System B recorded a higher FCR of 3.1, showing stress-induced inefficiency in feed conversion (Heugens *et al.*, 2001; Goodrich and Clark, 2023).

### 4.2 Effect of Trash Fish and Commercial Feed on the Survival and Growth Performance of Blue Crabs

The study indicated that feed type, including trash fish and commercial feed, interacts with water quality to influence crab survival and growth. Crabs in systems with optimal water conditions and effective feed

(System C and System A) achieved better growth and feed conversion efficiency than those in System B. Efficient feed utilization in Systems A and C can be attributed to the combination of high-quality feed and stable environmental conditions, which reduced stress and allowed crabs to allocate energy to growth (Goodrich and Clark, 2023).

In contrast, System B's poor performance in both growth and survival suggests that suboptimal water quality, compounded by the feeding regime, negatively affected nutrient absorption and metabolic processes. High ammonia and nitrate levels, resulting from limited water exchange and lack of UV filtration, may have reduced the crabs' ability to convert feed into biomass efficiently, regardless of feed type (Romano and Zeng, 2013; Boyd, 2020). This demonstrates that although feed composition is important, its effects on growth and survival are significantly influenced by water quality and system management practices.

### 4.3 Effects of Feeding Regimes and Culture Systems on Growth Performance and Weight Gain of Gladiator Swimming Crabs

The analysis of growth metrics revealed that weight gain in Gladiator swimming crabs was closely associated with feeding regimes under the environmental conditions of each system. Strong positive correlations were observed between weight, carapace length, and carapace width, indicating interrelated growth patterns typical of crustaceans (Chang *et al.*, 2012). Ammonia levels ( $\text{NH}_3\text{-N}$ ) correlated positively with weight (0.88), carapace length (0.96), and width (0.96), suggesting that crabs could efficiently utilize feed under controlled nitrogen levels, likely due to nitrification processes mitigating toxicity (Colt, 2006; Kuhn *et al.*, 2010; Martins *et al.*, 2010).

Dissolved oxygen showed a strong negative correlation with growth (-0.7 to -0.81), highlighting the importance of aerobic conditions for effective feed utilization and weight gain (Chen *et al.*, 2015; Ciji and Akhtar, 2021; Marković *et al.*, 2023). Alkalinity also correlated positively with growth (0.87 to 0.92), indicating its role in maintaining optimal physiological conditions that support nutrient absorption and shell development (Boyd *et al.*, 2016).

Multivariate analyses, including PCA and canonical correlation, confirmed that environmental parameters such as ammonia, DO, temperature, and pH interact with feeding regimes to influence weight gain. System C, which combined flow-through water management with consistent feeding, achieved the highest weight gain, while System B's combination of poor water quality and feeding conditions resulted in the lowest gains (Boyd and Tucker, 2016; Ekasari *et al.*, 2015;

Bossier *and* Ekasari, 2017). These findings show that weight gain in Gladiator swimming crabs is determined not only by feed type and quantity but also by the environmental conditions that regulate metabolic efficiency and nutrient assimilation.

#### 4.4 Physicochemical Properties of Water Across the Three Culture Systems for Gladiator Swimming Crab

Water quality is a critical determinant of productivity and sustainability in aquaculture systems because physicochemical conditions directly influence the physiological performance, metabolism, and survival of cultured organisms. The variations observed among the three culture systems, i.e. System A (RAS with UV filtration), System B (RAS without UV filtration), and System C (flow-through system), show the influence of system design and water management on environmental stability within aquaculture facilities. The pH values recorded across the systems remained within a slightly alkaline range, which is generally considered suitable for most aquatic organisms (Jafari *et al.*, 2024). However, differences in pH trends among the systems show variations in microbial activity and buffering processes. Recirculating aquaculture systems often experience fluctuations in pH due to nitrification processes occurring within biofilters, where ammonia is oxidized to nitrite and nitrate, releasing hydrogen ions that can gradually reduce pH levels if buffering capacity is insufficient (Espinal and Matulić, 2019). The relatively higher pH levels observed in System B compared with the other systems indicate differences in biological filtration efficiency or buffering dynamics. However, the relatively stable pH levels recorded in System A and the slightly lower values in the flow-through system show that filtration and water exchange processes contributed to maintaining more stable acid-base conditions (Mao, 2016; Ende *et al.*, 2024).

Temperature across the systems showed relatively minor variation throughout the experimental period, indicating that environmental conditions were generally stable. Temperature stability is essential in aquaculture because it influences metabolic activity, feeding behaviour, and oxygen consumption of aquatic organisms (Volkoff and Rønnestad, 2020; Mugwanya *et al.*, 2022). Although a temporary increase in temperature occurred in System B, the overall range remained within acceptable limits for aquaculture operations. Similar observations have been reported in intensive culture systems where temperature fluctuations are moderated through system design and water circulation (Mugwanya *et al.*, 2022; Mihaila *et al.*, 2024).

The variations observed in alkalinity among the systems show differences in buffering capacity and carbonate chemistry (Hammer, 2020). Alkalinity plays

an important role in stabilizing pH and supporting nitrification processes in aquaculture systems (Maoxiao *et al.*, 2023; Amjad *et al.*, 2025). In recirculating aquaculture systems, nitrification consumes alkalinity as ammonia is converted into nitrate, which can lead to gradual reductions in buffering capacity unless alkalinity is replenished (Espinal and Matulić, 2019; Ni *et al.*, 2023). The relatively higher alkalinity levels observed toward the end of the study in the flow-through system showed continuous water replacement, which can introduce additional bicarbonates and carbonates that enhance buffering capacity.

Salinity remained relatively stable across all systems, with only minor fluctuations during the study period. Stable salinity conditions are essential in crustacean aquaculture because sudden changes in ionic concentration can induce osmotic stress and negatively affect physiological processes such as moulting, growth, and survival (Wang *et al.*, 2023; Guo *et al.*, 2024). The minimal variation observed in this study indicates that salinity control was effectively maintained across the three systems.

Dissolved oxygen (DO) concentrations showed a gradual decline during the culture period across all systems, although the magnitude of decline varied among treatments. Oxygen availability is a key environmental factor in aquaculture systems because it directly influences respiration, metabolism, and waste oxidation (Timmons and Ebeling, 2013). The observed decline in DO may be associated with increasing biological oxygen demand resulting from metabolic activities of cultured organisms and microbial decomposition of organic matter. The comparatively lower DO levels observed in System B, therefore, indicate increased oxygen demand or reduced aeration efficiency within that system.

Ammonia nitrogen (NH<sub>3</sub>-N) concentrations increased progressively throughout the experimental period across the three systems. This pattern is typical in aquaculture environments, as ammonia is continuously produced through the excretion of nitrogenous waste and the decomposition of uneaten feed and organic matter (Ip and Chew, 2010). In recirculating aquaculture systems, the accumulation of ammonia is normally mitigated through biological filtration, where nitrifying bacteria convert ammonia into nitrite and nitrate (Timmons and Ebeling, 2013). The noticeable increase in ammonia concentration in System B during the later stages of the study may therefore show differences in filtration efficiency or microbial activity compared with the other systems.

## 5. Conclusion

This study demonstrates that aquaculture system design and diet significantly influence the growth performance, feed utilization efficiency, and survival of Gladiator swimming crabs (*Callinectes* spp.). Among the three systems evaluated, the flow-through system (System C) consistently produced superior performance indicators. Crabs reared in System C achieved the highest final average weight ( $16.45 \pm 0.58$  g), the highest Specific Growth Rate ( $35.50 \pm 1.0\%$ ), the best Feed Conversion Ratio (1.40), and the highest survival rate (50%). In comparison, the RAS with UV filter (System A) recorded moderate performance (final weight:  $14.00 \pm 0.63$  g; SGR:  $29.67 \pm 0.9\%$ ; FCR: 1.45; survival: 37.5%), while the RAS without UV filter (System B) showed significantly lower growth (final weight:  $8.45 \pm 0.46$  g; SGR:  $16.24 \pm 0.7\%$ ; FCR: 3.10; survival: 12.5%) ( $p < 0.05$ ).

Morphometric growth parameters followed similar trends, with System C producing the greatest final carapace length ( $31.45 \pm 1.34$  mm) and width ( $52.40 \pm 0.93$  mm), compared to System A ( $29.45 \pm 1.16$  mm;  $51.70 \pm 0.95$  mm) and System B ( $26.88 \pm 0.97$  mm;  $47.50 \pm 1.10$  mm). These findings confirm that improved water exchange and quality management enhance somatic growth and morphological development.

Dietary treatment further influenced performance. Trash fish consistently resulted in higher weight gain across systems (System C: 18.14 g; System A: 15.53 g; System B: 9.30 g) compared to commercial feed (System C: 14.76 g; System A: 13.38 g; System B: 7.61 g), indicating superior nutrient utilization and growth stimulation from natural feed sources.

Although regression analysis showed limited predictive power ( $R^2 = 0.0277$ ;  $p = 0.33$ ), multivariate analyses revealed strong environmental influences. Ammonia nitrogen exhibited strong positive correlations with weight ( $r = 0.88$ ), carapace length ( $r = 0.96$ ), and width ( $r = 0.96$ ), while dissolved oxygen showed strong negative correlations with growth indicators ( $r = -0.70$  to  $-0.81$ ). Canonical correlation analysis indicated that the first canonical variate explained 64.43% of total variation (canonical correlation = 0.96619;  $p = 0.09197$ ), confirming ammonia nitrogen and dissolved oxygen as dominant drivers of growth variability. Therefore, the results establish that optimal water exchange, effective filtration, stable water quality parameters, and high-quality feed are critical determinants of crab production efficiency. The flow-through system (System C), particularly when combined with trash fish feeding, provides the most favourable conditions for maximizing growth, feed efficiency, and survival. These findings show the importance of integrated water quality management

and diet optimization strategies for sustainable and commercially viable swimming crab aquaculture.

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