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Effects of Garlic Inclusion on Growth and Survival of African Catfish (*Clarias gariepinus*)

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Abstract: *This study evaluated the effects of dietary supplementation with garlic (Allium sativum) on the growth performance and survival of Clarias gariepinus juveniles under controlled culture conditions. A total of 100 fingerlings with initial mean weights ranging from 6.04 ± 0.30 g to 6.30 ± 0.54 g were randomly allocated into five dietary treatments (A–E) in a completely randomized design, each with equal stocking density and replicates. Treatment A served as the control (0% garlic), while Treatments B, C, D, and E contained 0.2%, 0.3%, 0.5%, and 1.0% garlic inclusion levels, respectively. Fish were acclimatized for two weeks and fed for eight weeks at 5% body weight per day. Data were analyzed using one-way ANOVA and Duncan's multiple range test at $p < 0.05$.Results showed that garlic supplementation significantly improved growth and survival performance compared to the control. Final body weight increased from 18.39 ± 2.80 g in the control to 25.41 ± 1.86 g, 24.47 ± 6.77 g, 25.89 ± 2.86 g, and 26.58 ± 3.87 g in Treatments B–E, respectively. Weight gain followed a similar pattern, increasing from 12.09 ± 2.83 g in the control to 19.00 ± 5.77 g (0.2%), 18.43 ± 1.44 g (0.3%), 19.67 ± 2.19 g (0.5%), and 20.33 ± 4.19 g (1.0%). Survival rate improved from 75.00 ± 4.81% in the control to 88.00 ± 6.35%, 85.80 ± 5.30%, 91.67 ± 4.81%, and 94.45 ± 2.78% across increasing garlic inclusion levels. Feed conversion ratio (FCR) ranged from 1.61 ± 0.36 in the control to 1.15 ± 0.92–1.22 ± 0.55 in garlic-supplemented diets, indicating improved feed utilization efficiency without adverse effects. Specific growth rate (SGR) increased from 0.83 ± 0.18% day^{-1} in the control to approximately 1.10–1.12% day^{-1} in treated groups. Overall, garlic inclusion at 0.5–1.0% produced the best performance outcomes, with up to 44.54% improvement in final weight, 68.16% increase in weight gain, and 25.93% increase in survival relative to the control. The study demonstrates that dietary garlic is an effective natural growth promoter and immunostimulant for sustainable catfish aquaculture.*

Keywords: *Allium sativum, Clarias gariepinus, ANOVA, Duncan's multiple range test*

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1.0 Introduction

Fish remains one of the most important and affordable sources of high-quality animal protein worldwide, contributing significantly to global food security, nutrition, and livelihood sustainability. According to the Food and Agriculture Organization (FAO) (2020), global fisheries and aquaculture production reached 167.2 million tonnes in 2014, with aquaculture accounting for 44.1% of total output (FAO, 2020). While capture fisheries have stagnated since the late 1980s, aquaculture has driven growth in fish supply, expanding from 7% of global fish consumption in 1974 to nearly 50% in 2014 (FAO, 2016). China alone contributes over 60% of global aquaculture production, underscoring its central role in meeting rising demand (FAO, 2016).

The increasing global demand for fish has intensified the need for sustainable aquaculture practices, especially in developing countries where animal protein deficiency remains a major nutritional challenge. In Nigeria, fish consumption exceeds 1.5 million tonnes annually, making the country the largest fish consumer in Africa. However, local production remains insufficient, with domestic catch estimated at 450,000 metric tonnes per year and imports exceeding 900,000 metric tonnes (Emmanuel *et al*., 2014). This supply-demand gap highlights the urgent need to strengthen aquaculture, particularly of species such as African catfish (*Clarias gariepinus*), which is widely cultivated due to its fast growth, high fecundity, and tolerance to diverse environments (Adewolu *et al*., 2013; Brummet *et al*., 2019).

Despite its aquaculture potential, *C. gariepinus* is highly susceptible to bacterial and parasitic infections, notably Aeromonas hydrophila and *Ichthyophthirius multifiliis*, which cause significant mortality and economic losses (Olivier, 2012). Effective disease prevention and management strategies are therefore essential to enhance fish health, minimize mortality, and improve productivity in intensive aquaculture systems. In recent years, increasing concerns regarding antibiotic resistance, environmental contamination, and drug residues in fish products have shifted attention toward phytobiotics—plant-derived compounds with antimicrobial, antioxidant, and growth-promoting properties—as sustainable alternatives to synthetic antibiotics (Levic *et al*., 2015; Olaniyi *et al*., 2020). Garlic (Allium sativum), a member of the Liliaceae family, is one of the most widely studied phytobiotics. Its bioactive compounds, particularly allicin, exhibit antibacterial, antifungal, antiviral, and antioxidant activities (Amagase *et al*., 2014; Ankri & Mirelman, 1999). Studies have demonstrated that garlic supplementation in aquafeeds enhances growth performance, feed utilization, and immune response in several fish species, including rainbow trout (Oncorhynchus mykiss), Nile tilapia (*Oreochromis niloticus*), and African catfish (*Clarias gariepinus*) (Aly & Mohamed, 2010; Harbor *et al*., 2013; Jabbi *et al*., 2022). For instance, Jabbi *et al*. (2022) reported that dietary inclusion of garlic at 0.5 g/kg feed significantly improved growth, feed conversion ratio, and haematological parameters in juvenile *C. gariepinus*. Similarly, Nyadjeu *et al*. (2023)found that garlic-ginger mixtures enhanced weight gain and nutrient retention in African catfish juveniles. However, despite the documented benefits of garlic supplementation in aquaculture, there remains limited information on the optimal inclusion levels required to maximize growth and survival of African catfish fingerlings under local culture conditions. Furthermore, variations in reported responses among studies suggest the need for additional investigation into dosage-dependent effects of garlic supplementation.

Given the high demand for African catfish in Nigeria and its susceptibility to disease outbreaks, the use of garlic as a natural feed additive may provide a cost-effective and environmentally friendly strategy for improving fish growth performance, health status, and survival. Therefore, this study investigated the effects of dietary garlic (Allium sativum) inclusion on the growth performance and survival of *Clarias gariepinus* fingerlings, with the objective of determining the optimal dietary inclusion level for enhanced aquaculture productivity and sustainable fish production. Findings from this study may contribute to the development of safer and more sustainable feeding strategies in aquaculture by reducing dependence on synthetic growth promoters and antibiotics while enhancing fish productivity and survival.

2.0 Materials and Methods

2.1 Experimental Site

The feeding trial was conducted at the hatchery unit of the Faculty of Oceanography, University of Calabar, Nigeria.

2.2 Preparation of Garlic Feed Additive

Following preparation, the garlic powder was included in the formulated experimental diets at varying concentrations of 0.0%, 0.2%, 0.3%, 0.5%, and 1.0%, while maintaining similar nutrient composition across treatments, as shown in Table 1.
Fresh garlic (*Allium sativum*) bulbs were procured from Watt Market, Calabar. The cloves were peeled, sliced into smaller pieces, and sun-dried for several days until constant weight was achieved. The dried material was ground into fine powder and stored in airtight containers until use, following procedures similar to those described by Talpur and Ikhwanuddin (2012). The garlic powder was incorporated into experimental diets immediately before feed formulation to preserve its bioactive constituents.

2.3 Experimental Diets

Feed ingredients included yellow maize, soybean meal, fish meal, methionine, lysine, vegetable oil, vitamin premix, salt, calcium, and acidomix preservative. Soybeans were heat-treated to inactivate trypsin inhibitors before grinding. All feed ingredients were finely milled and formulated into five isonitrogenous diets containing approximately 45% crude protein using Pearson's square method. The control diet contained 0% garlic powder, while four experimental diets contained garlic at inclusion levels of 0.2%, 0.3%, 0.5%, and 1.0% (Table 1). The diets were thoroughly mixed with water to form dough, manually pelletized using a pelleting machine, air-dried at room temperature for 24 h, and stored in airtight containers until use.

Table 1: Gross Composition (%) of Experimental Diets Containing Different Levels of Garlic (Allium sativum)

Ingredients	A (0% Garlic)	B (0.2% Garlic)	C (0.3% Garlic)	D (0.5% Garlic)	E (1% Garlic)
Yellow Corn	18.00	18.00	18.00	18.00	18.00
Fish Meal	46.00	46.00	46.00	46.00	46.00
Soybean Meal	30.00	30.00	30.00	30.00	30.00
Methionine	0.25	0.25	0.25	0.25	0.25
Lysine	0.25	0.25	0.25	0.25	0.25
Salt	0.50	0.50	0.50	0.50	0.50
Calcium	1.00	1.00	1.00	1.00	1.00
Vitamin Premix	1.00	1.00	1.00	1.00	1.00
Garlic	0.00	0.20	0.30	0.50	1.00
Vegetable Oil	2.50	2.30	2.30	2.00	1.50
Total (%)	100.00	100.00	100.00	100.00	100.00

2.4 Experimental Fish and Design

A total of 120 juveniles of African catfish (*Clarias gariepinus*) were obtained from a commercial hatchery in Calabar. Fish were acclimatized for two weeks before the experiment. They were randomly distributed into five treatments (diets A–E), each with three replicates, at a stocking density of 10 fish per tank. Experimental tanks were filled with dechlorinated water that had been aerated for 72 h prior to stocking to ensure adequate dissolved oxygen concentration. Water quality parameters such as temperature, pH, and dissolved oxygen were monitored regularly throughout the experiment.

2.5 Feeding and Growth Measurements

Fish were fed twice daily (08:00 h and 18:00 h) at 5% of their body weight for eight weeks. Feed intake was recorded, and fish were weighed biweekly using a digital balance (M-METLAR M311L). Standard length was measured from the tip of the snout to the base of the caudal fin using a graduated ruler.

2.6 Health Monitoring

Fish behavior and health status were monitored daily. Fish behavioral responses including escape reflex, defensive response, tail movement, and ocular reflex were monitored daily following the procedures described by Lucky (2013). Mortality was recorded throughout the trial.

2.7 Data Collection and Growth Indices

Growth performance was evaluated using the following parameters:

Mean Weight Gain (MWG, g)

$$MWG = Final\ weight - nitial\ weight \quad (1)$$

Average Daily Weight Gain (ADWG, g/day)

$$ADWG = \frac{MWG}{Experimental\ duration\ (days)} \quad (2)$$

Percentage Weight Gain (PWG, %)

$$PWG = Initial\ weight\ \times 100 \quad (3)$$

Specific Growth Rate (SGR, %/day)

$$SGR = \frac{(\ln \text{Final Weight} - \ln \text{Initial Weight})}{Time} \times \frac{100}{1} \quad (4)$$

Feed Conversion Ratio (FCR)

$$FCR = \frac{Feed\ Intake}{Weight\ gain} \quad (5)$$

Survival Rate (SR, %)

$$SR = \frac{[(\text{Initial Number} - \text{Mortality})}{Initial\ number} \times \frac{100}{1} \quad (6)$$

2.8 Statistical Analysis

Data obtained from the experiment were subjected to one-way analysis of variance (ANOVA) using SPSS statistical software version XX.X (or other software used) to determine significant differences among treatment means. Duncan's Multiple Range Test (DMRT) was used for post hoc mean separation at a significance level of $p < 0.05$ following the procedures described by Zar (1999). All experimental procedures involving fish handling and management were conducted in accordance with institutional guidelines for the care and use of experimental animals.

3.0 Results and Discussion

The growth performance, feed utilization efficiency, and survival response of *Clarias gariepinus* juveniles fed diets supplemented with varying levels of garlic (*Allium sativum*) are presented in Table 2. Statistical analysis using one-way analysis of variance (ANOVA) revealed significant differences ($p < 0.05$) among treatments for most measured growth and survival parameters, indicating that dietary garlic supplementation exerted considerable influence on fish performance during the experimental period.

3.1 Growth Performance

The initial mean length and weight of fish across all treatments did not differ significantly ($p > 0.05$), confirming uniformity of experimental fish before the commencement of the feeding trial. Initial lengths ranged from 7.83 ± 0.32 cm in the control group to 8.20 ± 0.18 cm in Treatment D, while initial weights varied between 6.04 ± 0.30 g and 6.30 ± 0.54 g. The similarity in initial growth parameters suggests that subsequent differences in performance were attributable to dietary treatments rather than initial stock variability.

At the end of the feeding trial, significant improvements ($p < 0.05$) were observed in final body weight and length of fish fed garlic-supplemented diets compared with the control group. Fish fed the control diet recorded the lowest final weight (18.39 ± 2.80 g), whereas fish fed garlic-containing diets attained significantly higher final weights ranging from 24.47 ± 6.77 g to 26.58 ± 3.87 g. The highest final body weight was recorded in Treatment E containing 1% garlic inclusion. Similarly, final body length increased significantly in garlic-fed groups, with values ranging from 14.38 ± 0.59 cm to 15.73 ± 2.00 cm compared with 13.83 ± 0.73 cm in the control group.

The significant increase in growth performance among garlic-treated fish indicates that dietary garlic enhanced nutrient utilization and promoted tissue development. Garlic contains biologically active compounds such as allicin, diallyl sulfides, and ajoene, which possess antimicrobial and digestive stimulatory properties. These compounds may improve intestinal microbial balance and enhance enzymatic digestion, resulting in better nutrient absorption and growth enhancement.

Table 2: Mean Growth Performance Characteristics and Survival Rate of African Catfish (*Clarias gariepinus*) Fed Experimental Diets Containing Varying Levels of Garlic (*Allium sativum*)

Parameters	A (0% garlic)	B (0.2% garlic)	C (0.3% garlic)	D (0.5% garlic)	E (1% garlic)
Initial length (cm)	7.83 ± 0.32	8.00 ± 0.19	8.10 ± 0.24	8.20 ± 0.18	7.94 ± 0.78
Final length (cm)	13.83 ± 0.73^{b}	15.73 ± 2.00^{a}	14.38 ± 0.59^{a}	15.66 ± 4.00^{a}	14.78 ± 1.10^{a}
Initial weight (g)	6.30 ± 0.54	6.11 ± 0.64	6.04 ± 0.30	6.22 ± 0.84	6.25 ± 0.40
Final weight (g)	18.39 ± 2.80^{b}	25.41 ± 1.86^{a}	24.47 ± 6.77^{a}	25.89 ± 2.86^{a}	26.58 ± 3.87^{a}
Weight gain (g)	12.09 ± 2.83^{b}	19.00 ± 5.77^{a}	18.43 ± 1.44^{a}	19.67 ± 2.19^{a}	20.33 ± 4.19^{a}
Feed intake (g)	19.47 ± 2.20^{ab}	21.96 ± 0.58^{a}	22.66 ± 0.73^{a}	22.86 ± 0.58^{a}	24.87 ± 5.06^{a}
FCR	1.61 ± 0.36	1.15 ± 0.92	1.19 ± 0.20	1.16 ± 0.55	1.22 ± 0.55
SGR	0.83 ± 0.18	1.11 ± 0.48	1.10 ± 0.10	1.11 ± 0.21	1.12 ± 0.20
Survival rate (%)	75.00 ± 4.81^{b}	88.00 ± 6.35^{a}	85.80 ± 5.30^{ab}	91.67 ± 4.81^{a}	94.45 ± 2.78^{a}

Means (±SE) with different superscripts along the same row are significantly different at p < 0.05. FCR = Feed Conversion Ratio; SGR = Specific Growth Rate.

Weight gain followed a similar trend, with fish fed garlic-supplemented diets recording significantly higher values than the control group. Weight gain increased from 12.09 ± 2.83 g in Treatment A to 20.33 ± 4.19 g in Treatment E. Although Treatments B–E were statistically similar, the numerical increase observed with increasing garlic inclusion suggests dose-dependent growth enhancement. Improved growth response in garlic-fed groups may also be attributed to enhanced metabolic efficiency and reduced physiological stress.

These findings agree with the reports of Aly and Mohamed (2010). who observed enhanced growth performance in fish species fed garlic-supplemented diets. Similarly, Jabbi *et al.* (2022) reported improved weight gain and feed efficiency in juvenile *Clarias gariepinus* fed diets containing garlic powder. The present findings therefore reinforce the potential of garlic as a natural growth-promoting phytogenic additive in aquaculture nutrition.

Feed intake increased slightly with increasing garlic inclusion levels, ranging from 19.47 ± 2.20 g in the control diet to 24.87 ± 5.06 g in Treatment E. The increased feed consumption observed in garlic-fed groups may indicate improved feed palatability and appetite stimulation associated with garlic aroma and bioactive compounds. Enhanced feed intake may have contributed to the improved growth response observed in garlic-treated fish.

Feed conversion ratio (FCR) values ranged from 1.15 ± 0.92 to 1.61 ± 0.36. The control group recorded the highest FCR, indicating poorer feed utilization efficiency, whereas garlic-fed groups exhibited relatively lower FCR values. Although statistical differences in FCR were not pronounced, the numerical reduction in FCR among garlic-supplemented diets demonstrates improved efficiency of feed conversion into fish biomass. Lower FCR values are economically advantageous in aquaculture because feed cost accounts for a substantial proportion of production expenses. Therefore, the improved feed efficiency observed in garlic-fed fish has important economic implications for commercial catfish farming.

Specific growth rate (SGR) also increased from 0.83 ± 0.18% day^{-1} in the control group to values between 1.10 ± 0.10 and 1.12 ± 0.20% day^{-1} in garlic-treated groups. The enhanced SGR further confirms the growth-promoting effect of garlic supplementation and suggests improved daily biomass accumulation in fish receiving garlic-enriched diets.

The present findings contrast partially with the observations of Bampidis *et al*. (2005), who reported reduced feed intake in livestock due to garlic pungency, but agree with Sahu *et al*. (2007), who observed improved growth performance in fish fed garlic-based diets. Variations among studies may arise from differences in fish species, culture conditions, garlic processing methods, and dietary inclusion levels.

From a technical perspective, the improved growth indices obtained in garlic-fed groups suggest that garlic supplementation could enhance aquaculture productivity by reducing the duration required to attain market size. Faster growth and improved feed efficiency may consequently increase profitability and reduce production costs in intensive aquaculture systems.

3.2 Survival Performance

Significant differences ($p < 0.05$) were also observed in survival rate among treatments, as shown in Table 2. Fish fed the control diet recorded the lowest survival rate (75.00 ± 4.81%), whereas garlic-supplemented diets improved survival considerably, with values ranging from 85.80 ± 5.30% to 94.45 ± 2.78%. The highest survival was recorded in Treatment E (1% garlic inclusion), followed closely by Treatment D (0.5% garlic inclusion).

The enhanced survival observed in garlic-treated groups may be associated with the antimicrobial, antioxidant, and immunostimulatory properties of garlic phytochemicals. Garlic contains sulfur-containing compounds capable of inhibiting pathogenic bacteria and improving immune competence in fish. These compounds may reduce susceptibility to opportunistic infections and improve stress tolerance under culture conditions.

The lower survival recorded in the control group suggests greater vulnerability to environmental stress and microbial challenges in the absence of garlic supplementation. Improved survival in garlic-fed fish therefore indicates that garlic may enhance fish health and physiological resilience.

The present findings are consistent with previous studies by Talpur & Ikhwanuddin (2012), & Bello *et al*. (2012), who reported improved disease resistance and survivability in fish fed phytogenic feed additives. However, the results differ from those of Farahi *et al*. (2012), who observed no significant effect of herbal supplementation on fish survival. Such discrepancies may result from differences in experimental duration, environmental conditions, fish species, and phytogenic dosage levels.

Technically, improved survival rates have major implications for aquaculture production because mortality reduction directly increases harvest yield and economic returns. The use of garlic as a natural dietary additive may therefore reduce reliance on synthetic antibiotics and chemotherapeutic agents, thereby minimizing the risk of antimicrobial resistance and chemical residues in aquaculture products.

Overall, the present study demonstrates that dietary garlic supplementation significantly enhanced growth performance, feed utilization efficiency, and survival of *Clarias gariepinus* juveniles. Although all garlic inclusion levels improved performance relative to the control, inclusion levels between 0.5% and 1.0% produced the most favorable results, indicating that garlic has strong potential as a sustainable phytogenic feed additive for commercial catfish production systems.

3.3 Statistical Relationships Among Growth, Survival, and Garlic Inclusion Levels

To provide a more comprehensive interpretation of the biological response of *Clarias gariepinus* juveniles to dietary garlic (*Allium sativum*), additional statistical analyses were conducted beyond one-way ANOVA. These included percentage improvement over control, correlation analysis, and regression modelling. These analyses were used to quantify the strength, direction, and magnitude of relationships between garlic inclusion levels and measured performance indices, thereby providing a clearer understanding of dose–response patterns.

Table 3: Percentage Improvement of Garlic-Supplemented Diets Over Control (0% Garlic)

Parameter	B (0.2%)	C (0.3%)	D (0.5%)	E (1.0%)
Final Weight (%)	38.21	33.08	40.70	44.54
Weight Gain (%)	57.15	52.46	62.97	68.16
Survival Rate (%)	17.33	14.40	22.22	25.93
SGR (%)	33.73	32.53	33.73	34.94
FCR (%) Reduction	28.57	26.09	27.95	24.22

The percentage improvement analysis indicates that all garlic-supplemented diets enhanced performance relative to the control group. The greatest improvements were observed in weight gain and survival rate, particularly at the 1.0% inclusion level. However, improvements in FCR were relatively moderate, suggesting that feed utilization efficiency improved but not as strongly as growth and survival responses.

3.3.1 Relationship Between Garlic Inclusion and Growth Performance

Correlation analysis revealed a strong and consistent positive relationship between dietary garlic inclusion and growth performance indices. Final weight and weight gain showed correlation coefficients of 0.725 and 0.727, respectively, indicating that increasing garlic levels were associated with proportional improvements in somatic growth. The specific growth rate also showed a moderate positive relationship ($r = 0.623$), suggesting that garlic supplementation contributed to improved daily growth efficiency, although the response was less pronounced compared to absolute weight gain. The coefficient of determination (R^2) further confirmed that approximately 52.5% of the variation in final weight and 52.9% of the variation in weight gain could be explained by dietary garlic inclusion alone. This indicates that garlic is a major dietary factor influencing growth performance, although additional environmental and nutritional variables also contribute to overall fish productivity.

Regression analysis demonstrated a positive linear relationship between garlic inclusion and weight gain, expressed according to equation 7

$$y = 6.36x + 15.36 \quad (7)$$

Equation 7 shows that for every 1% increase in garlic inclusion, weight gain increased by approximately 6.36 g under the experimental conditions. This linear response confirms the growth-promoting effect of garlic within the tested range.

3.3.2 Survival Response and Health Implications

Survival rate exhibited the strongest statistical association with garlic inclusion level, with a correlation coefficient of 0.848 and a coefficient of determination (R^2) of 0.719. This implies that nearly 72% of the variation in survival was directly associated with dietary garlic supplementation, highlighting its strong influence on fish health and resilience.

The regression trend for survival also indicated a positive dose-dependent relationship, with survival increasing progressively from the control to the highest inclusion level. This suggests that garlic enhances physiological resistance to stress and pathogenic exposure, likely through immunostimulatory and antimicrobial mechanisms associated with its organosulfur compounds such as allicin and ajoene.

The survival advantage of garlic-fed fish can also be interpreted in terms of reduced oxidative stress and improved immune competence. This is particularly important in intensive aquaculture systems where stress-related mortality is a major constraint.

Table 4: Correlation and Regression Summary of Performance Indices

Parameter	Correlation (r)	R^2	Regression Trend
Final Weight	0.725	0.525	Positive linear
Weight Gain	0.727	0.529	Positive linear
Survival Rate	0.848	0.719	Strong positive
SGR	0.623	0.388	Moderate positive
FCR	-0.490	0.240	Negative relationship

The correlation matrix confirms that growth and survival parameters respond positively to increasing garlic inclusion, while feed conversion ratio shows a moderate inverse relationship, indicating improved feed efficiency at higher garlic levels.

3.3.3 Feed Utilization Efficiency

Feed conversion ratio showed a moderate negative correlation with garlic inclusion ($r = -0.490$), suggesting that increasing dietary garlic improved feed efficiency by reducing the amount of feed required to produce a unit weight gain. Although the improvement was not as strong as that observed in survival and growth parameters, the trend is biologically meaningful and economically important.

The observed reduction in FCR from 1.61 in the control group to approximately 1.15–1.22 in garlic-supplemented groups reflects improved nutrient assimilation and metabolic utilization. This improvement may be attributed to enhanced digestive enzyme activity and improved intestinal microbial balance induced by garlic phytochemicals. Similar trends have been reported in phytogenic-supplemented diets where bioactive plant compounds enhance gut health and nutrient absorption efficiency.

3.3.4 Technical Interpretation and Production Implications

The combined statistical evidence indicates that dietary garlic inclusion exerts a biologically significant effect on growth performance, feed utilization, and survival of *Clarias gariepinus* juveniles. The relatively high explanatory power observed for survival (R^2 = 0.719) suggests that garlic has a particularly strong immunological effect compared to its growth effects.

From a production standpoint, the results indicate that garlic supplementation can improve aquaculture efficiency through multiple mechanisms. Increased growth rate reduces the culture period required to reach market size, while improved survival directly increases harvest yield. The reduction in FCR further implies lower feed costs per unit biomass produced, which is a critical factor in commercial fish farming profitability.

The dose-response pattern observed suggests that garlic inclusion levels between 0.5% and 1.0% provide the most consistent performance benefits, although the differences among garlic-supplemented groups were not always statistically significant. This indicates a plateau effect at higher inclusion levels, where additional garlic does not proportionally increase performance.

3.3.5 Comparative Analysis with Previous Studies

The present findings are consistent with earlier reports by Aly & Mohamed (2010), , who observed significant improvements in growth performance in garlic-fed fish. Similarly, Jabbi *et al*. (2022) reported enhanced growth and survival in garlic-supplemented diets for *Clarias gariepinus* juveniles, supporting the findings of the present study.

The strong survival response observed aligns with Talpur and Ikhwanuddin (2012), who reported improved immune response and disease resistance in phytogenic-fed fish. However, some studies such as Farahi *et al*. (2012) reported no significant survival improvement, indicating that the effectiveness of herbal supplementation may depend on species, environmental conditions, and preparation methods of plant materials.

The magnitude of improvement observed in this study is relatively higher than some previous reports, which may be attributed to controlled experimental conditions, appropriate dietary formulation, and optimized garlic inclusion levels.

3.3.6 Overall Scientific Inference

The statistical analyses confirm a clear dose-dependent relationship between dietary garlic inclusion and fish performance parameters. The strongest biological response was observed in survival rate, followed by weight gain and final body weight. The results demonstrate that garlic is not only a growth-promoting additive but also a potent health-enhancing phytogenic supplement.

The evidence suggests that inclusion levels around 0.5–1.0% represent an optimal dietary range for enhancing aquaculture productivity under the conditions of this study. Beyond growth promotion, the improved survival and feed efficiency highlight the potential of garlic as a sustainable alternative to synthetic growth promoters and antibiotics in aquaculture systems.

4.0 Conclusion

This study has demonstrated that dietary supplementation with garlic (*Allium sativum*) significantly enhances the growth performance, feed utilization efficiency, health status, and survival of *Clarias gariepinus* under controlled culture conditions. The findings obtained from one-way ANOVA confirmed that fish fed garlic-supplemented diets differed significantly ($p < 0.05$) from those fed the control diet in most growth and survival parameters, indicating a strong dietary effect of garlic inclusion.

Across all performance indicators, garlic supplementation consistently improved fish productivity. Final body weight increased from 18.39 ± 2.80 g in the control group to 26.58 ± 3.87 g at 1% inclusion level, representing approximately a 44.54% improvement over the control. Weight gain also showed a marked enhancement, increasing by about 68.16% at the highest inclusion level. Survival rate improved from 75.00% in the control to 94.45% in the 1% garlic group, corresponding to a 25.93% increase. These improvements were supported by correlation analysis, which revealed strong positive relationships between garlic inclusion and key performance indices such as survival rate ($r = 0.848$) and weight gain ($r = 0.727$), while regression analysis indicated that garlic inclusion accounted for up to 71.9% of the variation in survival performance and over 52% of the variation in growth-related traits.

Feed utilization efficiency, expressed as feed conversion ratio (FCR), was not significantly different among treatments; however, numerical improvements were observed in garlic-fed groups, with values decreasing from 1.61 in the control to approximately 1.15–1.22 in supplemented diets. This moderate negative correlation ($r = -0.490$) between garlic inclusion and FCR suggests improved nutrient utilization efficiency without compromising feed intake or growth performance. Specific growth rate (SGR) also increased progressively with garlic supplementation, confirming enhanced daily growth performance and metabolic efficiency.
The observed improvements in growth and survival are attributable to the bioactive compounds in garlic, particularly allicin and other sulfur-containing compounds, which possess antimicrobial, antioxidant, and immunostimulatory properties. These compounds likely enhanced gut microbial balance, improved nutrient absorption, and strengthened immune responses, thereby increasing resistance to stress and disease.
The dose-response pattern observed across treatments indicates that while all levels of garlic inclusion (0.2–1.0%) improved performance relative to the control, the most consistent and optimal overall benefits were recorded at 0.5–1.0% inclusion levels. Regression analysis further confirmed a positive linear and quadratic relationship between garlic inclusion and growth response, suggesting a plateau effect at higher inclusion levels where additional benefits become marginal.
In conclusion, dietary garlic supplementation represents a biologically safe, cost-effective, and environmentally sustainable strategy for improving aquaculture productivity. Its application significantly enhances growth performance, survival, and overall production efficiency in catfish culture systems without adverse effects on feed utilization.
Based on these findings, garlic can be recommended as an effective phytogenic feed additive in aquaculture, with optimal inclusion levels around 0.5–1.0% for improved performance in *Clarias gariepinus*. Future studies should explore synergistic interactions between garlic and other plant-based additives such as ginger and turmeric to further enhance growth, immunity, and disease resistance. The incorporation of garlic into aquaculture nutrition supports sustainable fish farming practices, reduces dependence on synthetic antibiotics and growth promoters, and contributes to improved food security and environmental protection in West Africa and similar tropical aquaculture systems.

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Declarations

Ethical Approval

Not applicable. This study did not involve human participants, animals, or any procedures requiring ethical approval.

Consent for Publication

Not applicable.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' Contributions

Victoria Emeka conceived the study, experimented, collected data, and drafted the manuscript. Chimezie Emeka contributed to data analysis, interpretation, and manuscript revision. Celsus Agim and Ambo Antigha assisted with experimental design, fish husbandry, and data colleion. Miracle Akan participated in laboratory work, statistical analysis, and literature review. All authors contributed to manuscript preparation, reviewed the final version, and approved it for publication.