

Stress Response of *Clarias gariepinus* Reared in Different Aquaponic Systems

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ABSTRACT

This study evaluated the stress response of *Clarias gariepinus* reared in different aquaponic systems, with emphasis on water quality, growth performance, and biochemical indicators of physiological and oxidative stress. The experiment was conducted using Nutrient Film Technique (NFT) and Deep Water Culture (DWC) aquaponic systems, while a fill and drain system served as the control. Forty-five post-juvenile *C. gariepinus* were randomly distributed among the experimental tanks in triplicate and cultured in the respective systems for 120 days. Water quality parameters, growth indices, blood glucose and corticosterone concentrations, and hepatic oxidative stress biomarkers including glutathione (GSH), superoxide dismutase (SOD), malondialdehyde (MDA), glutathione peroxidase (GPx), and catalase (CAT) were determined. Temperature and pH did not differ significantly among the systems, whereas dissolved oxygen was significantly higher in NFT and DWC than in the control. Ammonia concentration was significantly lower, while nitrate concentration was significantly higher in both aquaponic systems compared with the control. Growth parameters did not differ significantly among treatments, although fish reared in NFT recorded numerically higher final weight, weight gain, specific growth rate, relative growth rate, condition factor, and thermal growth coefficient. Glucose concentration was significantly higher in the control, whereas corticosterone was significantly higher in DWC than in the control while it showed no statistical difference from the NFT. However, GSH, SOD, MDA, GPx, and catalase showed no significant differences among treatments. The findings indicated that NFT and DWC aquaponic systems maintained suitable water quality and supported comparable growth and survival of *C. gariepinus* without pronounced disruption of antioxidant homeostasis. Thus, both systems can provide physiologically tolerable environments for African catfish culture.

Keywords: *C. gariepinus*, oxidative stress, nutrient film technique, deep water culture

INTRODUCTION

Fish, a crucial component of human diets, is widely valued for its exceptional nutritional properties, including its richness in polyunsaturated fatty acids (PUFAs), such as n-3 and n-6 fatty acids (Tawfik, 2009). These fatty acids play a critical role in human health by reducing the risk of chronic diseases such as cardiovascular issues, cancers, rheumatoid arthritis, and inflammation (Raatz et al., 2013). Additionally, fish provides high-quality protein, with protein levels ranging from 15-20%, contributing significantly to dietary protein intake, particularly in regions with limited access to other protein sources (Fagbenro et al., 2005; Emmanuel et al., 2011). However, with the rising population, traditional capture fisheries have been unable to meet the rising demand for fish and fish products due to overexploitation and the adverse effect of climate change (FAO, 2020). Hence, aquaculture has become indispensable for food security; nevertheless, this also presents some environmental concerns such as water pollution and habitat degradation (Boyd et al., 2020). A sustainable alternative to address these issues is aquaponics, which combines fish and plant production in a system that conserves water, recycles nutrients, and minimizes environmental impact associated with

conventional aquaculture practices. This dual production model enhances the economic viability of aquaponics, as fish and tomatoes can be harvested and sold simultaneously, increasing income for farmers. Although the integration of commercially important fish species like the African catfish with high-value crops such as tomatoes presents an opportunity to explore the potential of aquaponics in improving food security and livelihoods, understanding the stress responses of fish in such a system is critical for optimizing their growth and health, as stress can negatively affect fish performance, immune function, and overall productivity (Cerozi and Fitzsimmons, 2016). This will aid in developing best practices for aquaponic systems, contribute to optimizing fish welfare, ultimately leading to enhanced food production, improved nutrition, and sustainable livelihoods. This study therefore assessed the stress responses of *Clarias gariepinus* reared in different aquaponic systems, contributing to the broader knowledge of sustainable aquaculture practices.

MATERIALS AND METHODS

This experiment was conducted at the Teaching and Research Farm of the Department of Fisheries and Aquaculture Technology, The Federal University of Technology, Akure. The setup consisted of two sets of aquaponic systems; Nutrient Film Technique (NFT) and Deep Water Culture (DWC) while a Fill and drain system served as the control.

The Deep Water Culture (DWC) System

The DWC system consisted of three fish rearing tanks made up of 50-liter capacity transparent white plastic bowls placed at a height of 1 meter above the ground level. One inch PVC pipes and accessories were used for the plumbing work. A grow bed, made of a 50-liter rectangular transparent white plastic bowl was placed 0.5 meter apart from the fish tank and 1 meter below the fish tank, while a mechanical filter was placed between the fish tank and the grow bed. The mechanical filter was connected to the outlet of the fish tank at one end and to the inlet of the grow bed at the other end. The setup was arranged such that water flows by gravity from the fish tank to the mechanical filter and then to the grow bed. The grow bed was connected to a 0.5 hp surface water pump (Interdab©) through which water was pumped back to the fish tank. The water flow rate of the setup was regulated at 6L/min. Each rearing tank was considered a replicate of the experimental unit.

The Nutrient Film Technique (NFT) System

Three fish rearing tanks of 50-liter capacity each were placed on a platform 1m above the ground and connected to a mechanical filter placed on a wooden platform below the fish tank. The outlet of the mechanical filter was connected to the inlet of a 0.5 hp surface water pump (Interdab©) which was used to pump water to a biofilter. The biofilter was placed 2 meters above the ground level and the outlet was connected to a 4-inch circular PVC pipe; which served as the grow pipe. Five 5cm holes were bored at an interval of 50 cm apart along the grow pipe, and perforated disposable plastic cups filled with palm kernel shells were inserted into each of the holes to serve as the support for the plant. The outlet of the grow pipe was connected to the inlet of the fish tank; it was positioned at a level in-between the biofilter and the fish tank to allow water flow by gravity from the biofilter through the grow pipe to the fish tank. The system was test-run to check for leakages or possible adjustments, after which it was filled with water and left for a period of 24 hours before stocking. Each rearing tank was considered a replicate of the experimental unit.

The Fill and Drain System (Control)

Three 50-liter capacity transparent white plastic bowls were filled with water and used as the rearing tanks for the control cultured system. Water in the rearing tanks were changed every third day. Each rearing tank was considered a replicate of the experimental unit.

Experimental Procedure

Forty-five (45) pieces of mixed-sex *C. gariepinus* post-juveniles were randomly selected and evenly

distributed in the experimental tanks (5 fish per tank). The initial weight and lengths of the experimental fish in each tank were measured and recorded accordingly. Fishes were left for an acclimation period of 24 hours prior to the commencement of feeding. Feeding was done between 08:00 – 09:00 and 17:00 – 18:00 hrs (GMT +1) daily and the fish were fed to satiation with commercial feed (42% crude protein) purchased from a reputable feed store. Experimental fishes were handled in line with the standard ethical procedure for handling live experimental animals.

Fifteen stands of tomato seedlings (*Solanum lycopersicum*) were identified, procured and transplanted into the grow beds in the aquaponics system two weeks after stocking the rearing tanks with fish, to ensure availability of sufficient nutrients in the culture water.

The experiment was conducted for a period of 120 days.

Experimental Analysis

The physico-chemical parameters of the water in each rearing tanks of the culture systems were measured fortnightly. Dissolved Oxygen (DO), pH, and Temperature were evaluated using a multi-parameter digital probe meter (Hanna HI98194®) while ammonia and nitrate were measured using method reported by Joel and Amajuoyi (2010).

50 ml of the water sample was collected from each rearing tank and measured into a distillation flask. 0.4g of magnesium oxide was added and distilled into a beaker containing 10 ml of 2% boric acid and combined indicator. This was then titrated back with 0.1M HCl, the titre value was recorded and ammonia calculated as;

$$\text{NH}_3 \left(\frac{\text{mg}}{\text{l}} \right) = \frac{\text{Titre value} \times 100}{\text{Sample Volume used}}$$

Nitrate was measured by transferring 1 ml of water sample into a 100 ml volumetric flask and 0.5ml of brucine reagent added, followed by rapid addition of 2 ml concentrated sulphuric acid. This solution was then stirred for 30 secs to allow proper mixing and allowed to stand for 5 mins, then stirred again to mix. 2 ml of distilled water was added and the mixing continued for about 30 secs. The flask was allowed to stand in cold water for about 15 mins after which it was measured at 410nm absorbance using UV Spectrophotometer.

Growth parameters were measured according to the methods reported by Fasakin et al. (2001), Aderolu et al. (2009) and Gbadamosi and Adebayo (2021)

$$\text{Mean weight of Fish (g)} = \frac{W_T}{N}$$

$$\text{Mean weight gain (g)} = \frac{W_2 - W_1}{N}$$

$$\text{Percentage weight gain (\%)} = \frac{W_2}{W_1} \times 100$$

$$\text{Relative Growth Rate (\%)} = \frac{\text{Weight gain}}{\text{Initial weight}} \times 100$$

$$\text{Specific Growth Rate (\%)} = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{T} \times 100$$

$$\text{Survival rate (\%)} = \frac{\text{Number of fish that survived}}{\text{Number of fish stocked}} \times 100$$

$$\text{Condition Factor (K)} = \frac{100W}{L^3}$$

Where W_T = Total weight of fish

W_2 = Final weight of fish

W_1 = Initial weight of fish

N = Number of sampled fish

T = Experimental period in days

W = Weight of fish

L = Total length of fish

Thermal Growth Assessment

Thermal Growth Coefficient (TGC) model as reported by Cho and Bureau (1998) and adapted by Al-Dubakel et al., (2011), was employed to evaluate the growth of the fish in relation to temperature change. The model calculation is given as;

$$\text{TGC} = \frac{W_f^{1/3} - W_i^{1/3}}{\sum(T \times D)} \times 100$$

Where W_f = Final weight of fish

W_i = Initial weight of fish

T = Average temperature

D = Number of experimental Days

Assessment of Stress in Experimental Fish

One fish sample was randomly selected from each of the rearing tanks in each culture system (3 replicate per system) and anaesthetized. Blood sample was collected from the caudal region of the experimental fish at an angle of 45° through the caudal vein. 2 ml of blood was withdrawn using heparinized syringe into an EDTA bottle to prevent coagulation. The blood sample was centrifuged for 10 min at 2,500 rpm and the supernatant collected for the determination of the glucose level using standard procedures. The analysis of the corticosterone level was conducted using Elabscience Kit.

Oxidative stress was also assessed in the liver using previously reported methods. The fishes were dissected, the livers quickly removed and iced to reduce the rate of deterioration. Each liver was washed in cold 0.85 % NaCl solution and then homogenized in physiological solution using mortar and pestle. The resulting homogenates were centrifuged at 5000 g for 20 min. The supernatants were used for further enzyme analyses.

Superoxide Dismutase (SOD) assay was conducted in accordance with the protocol described by Liu et al., (2011). A 3 ml reaction mixture; composed of sodium phosphate buffer (pH 7.8), methionine, nitro blue tetrazolium (NBT), riboflavin, and enzyme extract, with concentrations set at 50 mmol/L, 13 mmol/L, 75 µmol/L, 2 µmol/L, and 50 µl, respectively, was incubated for 15 minutes in fluorescent light at 25 °C. Simultaneously, absorbance at 560 nm was measured using a UV/vis spectrophotometer. Control samples

without enzyme extract, kept in the dark, were treated as a reference. The enzyme volume corresponding to a 50% inhibition of the reaction was determined and defined as one enzyme-activity unit.

Catalase activity was determined in $\mu\text{mol}/\text{H}_2\text{O}_2/\text{min}/\text{mg}$ protein using the procedure described by Ujah et al., (2019). The catalase activity was quantified based on the reduction in the absorption of hydrogen peroxide at 240 nm. 3.0 mL of H_2O_2 -phosphate buffer was placed in an experimental cuvette and 40 μL of the enzyme extract was quickly added. The time needed for a 0.05-unit reduction in absorbance at 240 nm was recorded. The enzyme activity was calculated using the following equation:

$$\text{Activity} = \frac{\text{Change in Absorption} \times \text{Total reaction volume}}{\text{Sample volume} \times \text{extinction coefficient}}$$

Extinction coefficient = 40 $\text{m}^{-1}\text{cm}^{-1}$

Glutathione (GSH) level was determined according to the method outlined by Haque et al. (2003). In this procedure, 1 mL of PMS (10%) was chilled on ice and combined with an equal volume of 4% sulphosalicylic acid. After one hour of incubation, the mixture was centrifuged for 15 minutes at 1200 rpm and 4°C. The resulting supernatant was then filtered. The ultimate reaction mixture (3 mL) was comprised of the filtered aliquot, 0.1 M phosphate buffer, and 10 mM DTNB. Absorbance readings were taken at 412 nm, and the outcomes was expressed as nmol GSH per gram of tissue, utilizing a molar extinction coefficient of 1.36×10^4 /M/cm.

GPx activity was determined according to the method described by Hu et al., (2015). GPx was quantified by measuring the oxidation rate of reduced glutathione coupled with nicotinamide adenine dinucleotide phosphate (NADPH) breakdown at 340 nm using a spectrophotometer.

Lipid peroxidation was determined using the method of Wright et al., (1981) with slight modifications as described by Faheem and Lone (2017). A 3 mL reaction mixture (composed of 10% tissue homogenate, 10% trichloroacetic acid (TCA), and 0.67% thiobarbituric acid (TBA) were incubated in boiling water for 45 minutes, followed by cooling and centrifugation at $2500 \times g$ for 10 minutes. The absorbance of the resulting supernatant was measured at 532nm at 37°C using a Hitachi U-2000 spectrophotometer. The rate of lipid peroxidation was determined by assessing thiobarbituric acid reactive substances (TBARS) and expressed as nmol of TBARS formed per gram of tissue at 37°C, employing a molar extinction coefficient of 1.56×10^5 /M/cm.

Statistical Analysis

The experimental design was a completely randomized design (CRD) with three replicates. The fishes in each tank were weighed using a digital weighing balance and the total fish length measured with a meter rule. The average weight and length of fish in each rearing tank were recorded and the mean value from each tank was used for statistical analysis. Data collected for growth parameters and oxidative biomarkers were subjected to One- Way Analysis of Variance (ANOVA) and followed by Tukey Test for significant at $p < 0.05$. P-values less than 0.05 were considered to be statistically significant while p-values greater than 0.05 were considered to be not statistically significant.

RESULTS

The results of the water quality parameters obtained in this study are presented in Table 1. Temperature within the various culture systems range from 26.60 °C in NFT to 26.83 °C in the Control unit, with no significant difference ($p > 0.05$) across the culture systems. Dissolved oxygen was however significantly different ($p < 0.05$) across the culture systems with the Control having the least value (4.47 ± 0.015 mg/L) and the highest value (6.47 ± 0.06 mg/L) recorded in the NFT. The pH values obtained ranged from 6.90 ± 0.05 in the NFT to 6.97 ± 0.11 in the Control unit but with no significant difference ($p > 0.05$). The result also shows that ammonia was highest (0.96 ± 0.10 mg/L) in the control tank and significantly different ($p < 0.05$) from the values obtained in the NFT and DWC systems, however, values obtained in the NFT showed no

significant difference ($p>0.05$) from the DWC. Similarly, nitrate significantly ($p<0.05$) had the least value ($5.57 \pm 0.21\text{mg/L}$) in the control system and the highest value in the NFT, nevertheless the nitrate values obtained in both the NFT and DWC were not significantly different ($p>0.05$) from each other.

Table 1. Physicochemical parameters of the water in the various *C. gariepinus* culture systems

Water quality parameters	Control	NFT	DWC
Temperature ($^{\circ}\text{C}$)	26.83 ± 0.15^a	26.60 ± 0.10^a	26.67 ± 0.23^a
Dissolved oxygen (mg/L)	4.47 ± 0.15^a	6.47 ± 0.06^b	6.18 ± 0.06^c
pH	6.97 ± 0.11^a	6.90 ± 0.05^a	6.93 ± 0.07^a
Ammonia (mg/L)	0.96 ± 0.10^a	0.35 ± 0.05^b	0.47 ± 0.06^b
Nitrate (mg/L)	5.57 ± 0.21^a	12.10 ± 0.53^b	11.10 ± 0.46^b

All values on the same row with the same superscript are not significantly different ($p>0.05$)

NFT: Nutrient Film Technique Aquaponics; DWC: Deep Water Culture Aquaponics; Control: Fill and Drain System

Growth Performance of *C. gariepinus* reared in the different culture systems

The growth parameters obtained from this study are presented in Table 2. The results showed that the initial mean weights, mean lengths and condition factors of *C. gariepinus* at stocking in the various culture systems were not significantly different ($p>0.05$), this shows the homogeneity in the experimental fish at stocking. The final mean weight and final mean weight gained recorded in the NFT ($239.81 \pm 23.37\text{g}$; $195.87 \pm 23.31\text{g}$ respectively) were the highest in the result obtained, but they were not significantly different ($p>0.05$) from the values obtained in the Control and DWC. Likewise, the Specific Growth Rate, Relative Growth Rate and Final condition factors recorded were highest in the NFT, although statistical analysis showed that these values were not significantly different ($p>0.05$) from the values obtained in the Control and DWC. The final mean length was however higher in the Control but also showed no significant difference ($p>0.05$) from the NFT and DWC. In addition, the thermal growth coefficient recorded higher value in the NFT but it was not statistically different ($p>0.05$) from the other culture systems. Summarily, the result revealed that the *C. gariepinus* reared in the NFT showed numerically higher growth indices than the Control and DWC, nevertheless the differences in values obtained were not statistically significant across the various culture systems.

Table 2. Growth Performance of *C. gariepinus* reared in the different culture systems

Growth Parameters	Control	NFT	DWC
Initial Mean Weight (g)	43.93 ± 0.12^a	43.87 ± 0.23^a	43.93 ± 0.31^a
Final Mean Weight (g)	228.35 ± 4.19^a	239.81 ± 23.37^a	233.80 ± 29.62^a
Mean Weight gain (g)	184.42 ± 4.16^a	195.87 ± 23.31^a	189.93 ± 29.51^a
Initial Mean Total Length (cm)	18.62 ± 0.06^a	18.77 ± 0.32^a	18.67 ± 0.58^a
Final Mean Total Length (cm)	31.00 ± 0.44^a	30.88 ± 0.99^a	30.96 ± 1.33^a
Specific Growth Rate (%/day)	1.37 ± 0.02^a	1.41 ± 0.08^a	1.39 ± 0.10^a

Relative Growth Rate (%/fish)	419.80 ±9.24 ^a	445.83 ±52.44 ^a	432.87 ±66.09 ^a
Percentage Survival (%)	93.33	86.67	93.33
Initial Condition Factor	0.68 ±0.01 ^a	0.67 ±0.04 ^a	0.68 ±0.07 ^a
Final Condition Factor	0.77 ±0.02 ^a	0.81 ±0.02 ^a	0.79 ±0.00 ^a
Thermal Growth Coefficient	0.80 ±0.01 ^a ×10 ³	0.84 ±0.06 ^a ×10 ³	0.82 ±0.07 ^a ×10 ³

All values on the same row with the same superscript are not significantly different (p>0.05)

NFT: Nutrient Film Technique Aquaponics; DWC: Deep Water Culture Aquaponics; Control: Fill and Drain System

Oxidative Stress Biomarkers

The results of the biochemical analysis for stress indicators in *C. gariepinus* are presented in Table 3. The value obtained for glucose level in the Control (82.33 ±6.03) was significantly higher (p<0.05) than the ones obtained in the NFT and DWC. Although, the NFT had the lowest value for glucose, it was however not significantly different from that of DWC. The corticosterone value obtained in DWC (7.500 ±0.06) was statistically higher (p<0.05) than the Control (6.94 ±0.25) but not significantly different (p>0.05) from the NFT.

GSH and MDA values were highest in NFT (210.44 ±80.70, 1.74 ±0.52) and lowest in DWC (159.01 ±85.63, 0.75 ±0.69) but the values of both biomarkers were not significantly different (p>0.05) across the various culture systems. Values obtained for SOD and Catalase were highest in the DWC (310.17 ±40.12, 126.27 ±12.39) but showed no significant difference (p>0.05) from the Control and NFT. The highest value for GPx was recorded in the Control (415.95 ±250.80) while the lowest value was recorded in the DWC (335.48 ±176.20) but they were not statistically different (p>0.05).

Table 3. Oxidative Stress Biomarkers in *C. gariepinus* reared in the different culture systems

Biochemical Parameters	Control	NFT	DWC
Glucose (mg/dL)	82.33 ±6.03 ^a	48.33 ±1.53 ^b	60.00 ±8.19 ^b
Corticosterone (ng/ml protein)	6.94 ±0.25 ^a	7.22 ±0.03 ^{ab}	7.50 ±0.06 ^b
GSH (nmol/mg protein)	170.25 ±33.27 ^a	210.44 ±80.70 ^a	159.01 ±85.63 ^a
SOD (U/mg protein)	209.53 ±129.03 ^a	178.81 ±48.76 ^a	310.17 ±40.12 ^a
MDA (nmol/mg protein)	0.98 ±0.16 ^a	1.74 ±0.52 ^a	0.75 ±0.69 ^a
GPx (U/mg protein)	415.95 ±250.80 ^a	363.62 ±124.80 ^a	335.48 ±176.20 ^a
Catalase (μmol/H ₂ O ₂ /min/mg protein)	107.37 ±33.95 ^a	105.69 ±32.99 ^a	126.27 ±12.39 ^a

All values on the same row with the same superscript are not significantly different (p>0.05)

NFT: Nutrient Film Technique Aquaponics; DWC: Deep Water Culture Aquaponics; Control: Fill and Drain System

DISCUSSION

Physicochemical Characteristics of the Culture Water and Their Relationship with the Performance of *Clarias gariepinus*

Water quality is one of the most important determinants of fish performance in aquaculture because fish live continuously in the culture medium and respond directly to variations in temperature, dissolved oxygen, pH and nitrogenous metabolites (Goddek et al., 2019; Yep and Zheng, 2019). In aquaponic systems, the importance of water quality is even greater because the same water simultaneously serves as the physiological environment for the fish and as the nutrient medium from which plants obtain essential elements. Therefore, a change in one component of the water chemistry may have implications for both fish and plant production. Hence, the need for an appropriate balance between fish metabolic requirements, microbial transformation of waste products and plant nutrient uptake.

Temperature is particularly important in tropical aquaculture because it influences metabolic rate, oxygen demand, digestion, feed utilization, immune function and the toxicity of certain nitrogenous compounds. The temperature values (26.6–26.8 °C) obtained in this study are consistent with the warm-water conditions under which *C. gariepinus* can thrive as reported by Davies et al. (2006), Omitoyin (2007), Kareem and Olanrewaju (2015) and Hassan et al. (2025). The pH is also particularly relevant to aquaponics because nitrification consumes alkalinity and can progressively lower pH if adequate buffering is not maintained.

The water temperature and pH values in the various systems (Control, NFT and DWC) in this study showed no significant difference ($P > 0.05$), indicating that the configurations of the different culture systems did not create appreciable difference in the thermal and acid-base environments for the fish. This agrees with the findings of Gbadamosi and Adebayo (2021) who reported that there were no adverse effects of different media on water quality parameters in an aquaponic study carried out with *Heterobranchius bidorsalis*.

In addition, the values obtained for temperature and pH in this study are similar to the findings of Amponsah et al. (2021) who reported similar temperature and pH range of 24.5 - 26.2 °C and 6.39 - 7.53 respectively, in a study involving the culture of *C. gariepinus* in different shapes of recirculatory tank. Likewise, Adebayo et al., (2026) reported a pH range of 6.3 - 7.4 in a study conducted with *C. gariepinus* to investigate the effect of palm kernel shells as growth and biofiltration media in recirculating flood and drain aquaponic system. However, Outa et al. (2025), recorded slightly lower pH values in catfish and tilapia NFT and pond systems. The difference between the present study and the Outa et al. (2025) study may partly reflect differences in system design, buffering capacity, stocking density, feeding rate and the characteristics of the source water.

The dissolved oxygen levels recorded in this study were within acceptable range, however, the NFT and DWC had higher values which were statistically significant than the control. This suggests that water movement within the aquaponic setup system may have contributed to the oxygenation of the water in the systems. This finding agrees with observations from previous aquaponic studies in which circulation, aeration and water movement associated with the hydroponic component improved oxygenation (Baßmann et al., 2017; Outa et al., 2025).

Dissolved oxygen is one of the principal water quality determinants of fish welfare and production. Fish exposed to inadequate oxygen may alter swimming behaviour and redirect energy towards maintaining physiological homeostasis rather than growth, and prolonged oxygen limitation can consequently reduce feed efficiency and growth while increasing susceptibility to disease. Interestingly, despite the statistically higher dissolved oxygen in the NFT and DWC, the growth indices were not statistically different. This suggests that although the aquaponic systems created a more oxygen-rich environment, the oxygen concentration in the control was apparently still sufficient to support satisfactory growth of *C. gariepinus*. Hence, the absence of statistically detectable growth advantage recorded during the experimental period.

The nitrogenous compounds provide further evidence of the functional difference between the control and aquaponic systems. Ammonia concentration was substantially higher in the control (0.96 ± 0.10 mg/L) than

in NFT (0.35 ± 0.05 mg/L) and DWC (0.47 ± 0.06 mg/L) while Nitrate increased significantly from 5.57 ± 0.21 mg/L in the control to 11.10 ± 0.46 mg/L in DWC and 12.10 ± 0.53 mg/L in NFT. The simultaneous occurrence of lower ammonia and higher nitrate in the aquaponic systems is consistent with enhanced nitrification outcome and suggest that the presence of the hydroponic components possibly altered the nitrogen profile of the culture water. This is particularly important in aquaponics because the objective is not simply to dilute fish waste but to transform and recover nutrients through biological processes.

The inverse pattern between ammonia and nitrate levels observed in this study agrees with the findings of Adebayo et al. (2026) who reported a decline in ammonium nitrogen and gradual accumulation of nitrate over time in the water column of their aquaponic setup. The considerably lower ammonia concentration in the NFT and DWC systems is also consistent with the report of Baßmann et al. (2017) who reported that total ammonium nitrogen (TAN) reduced more effectively under aquaponic conditions and reached higher levels in the control RAS towards the end of the experiment. It also agrees with Outa et al. (2025), who recorded lower TAN in catfish NFT (0.45 ± 0.12 mg/L) than in the corresponding catfish pond (0.52 ± 0.20 mg/L), although the difference in that particular comparison was not statistically significant. The agreement between these studies strengthens the interpretation that integrating a hydroponic component can enhance nitrogen transformation from catfish culture water.

Overall, the physicochemical results demonstrate that the NFT and DWC systems provided a more oxygenated and more nitrifying environment than the control, as evidenced by significantly higher dissolved oxygen and nitrate concentrations coupled with lower ammonia concentrations. Nevertheless, these differences did not translate into statistically significant differences in the measured growth indices of *C. gariepinus*. This finding is important because it demonstrates that improved water chemistry does not necessarily produce a proportionate increase in fish growth over a relatively short production period. Aquaponics functions as an integrated system, and its major advantage may therefore be expressed through simultaneous production of fish and plants and improved nutrient recovery rather than through fish growth alone.

Growth Performance of *Clarias gariepinus* in the Different Culture Systems

The growth results demonstrate that *C. gariepinus* performed satisfactorily in all three culture systems. The absence of significant differences at stocking indicates that the experimental groups were appropriately comparable at the beginning of the trial and therefore provides confidence that subsequent differences were not caused by unequal initial body size.

The absence of significant differences in the measured growth indices of *C. gariepinus* in the aquaponic and control systems agrees with the result of Baßmann et al. (2017) who similarly found comparable growth in *C. gariepinus*, with no significant differences between coupled aquaponic and control.

The higher final weight and weight gain recorded in the NFT is consistent with its superior dissolved oxygen and lower ammonia concentration. This suggests that there is a possibility that the combination of improved oxygen availability and reduced ammonia exposure may have provided a favourable physiological environment for nutrient utilization and growth, however, because the differences in growth were not statistically significant, it will be inappropriate to conclude that the significantly superior water parameters resulted in significantly superior growth.

Specific growth rate (SGR) integrates the change in body weight over the experimental period and provides a useful measure for comparing growth among groups with similar initial weights. The similarity in SGR indicates that the physiological and nutritional conditions experienced by the fish were sufficiently comparable across systems to support similar rates of tissue deposition. The SGR values (1.37–1.41% per day) recorded in this study were closely similar to those reported by Amponsah et al. (2021), this suggests that the growth rates recorded are biologically realistic for *C. gariepinus* under controlled culture conditions.

The result of the percentage survival obtained in this study contradicts the report of Outa et al. (2025) who reported 100% and 98% for catfish in NFT and pond systems respectively. However, the survival rates

above 85% across all systems indicate that the experimental culture environments were generally capable of sustaining the fish throughout the trial period. Recent work with *C. gariepinus* in aquaponic systems (Outa, et al., 2025 and Adebayo et al., 2026) has likewise demonstrated satisfactory fish growth and survival under integrated fish–plant production, while highlighting the importance of water quality and system configuration in determining performance. Therefore, the low survival recorded in the NFT may not be confidently attributed to the variation in the culture systems, most especially since the water quality parameters recorded in the NFT were within acceptable range. Hence, the percentage survival result may better be interpreted as a numerical difference that warrants consideration in future trials.

An increase in condition factor generally reflects improvement in the relative robustness or plumpness of fish during the production period. The increase in the fish condition factor observed in this study across all systems is therefore consistent with the observed substantial body-weight gain and suggests that the fish did not merely increase in length but also accumulated body mass. The thermal growth coefficient also followed a similar pattern, with values of 0.80×10^3 , 0.84×10^3 and 0.82×10^3 in control, NFT and DWC, respectively, with no significant difference.

Summarily, the growth indices provide a consistent picture: NFT showed numerical advantages for final weight, weight gain, SGR, relative growth rate, condition factor and thermal growth coefficient, while DWC generally occupied an intermediate position and the control recorded slightly lower numerical values. Nevertheless, because these differences were not statistically significant, the evidence supports equivalent fish-growth performance rather than statistical superiority of any one system.

Stress Physiology and Oxidative Stress Response of *Clarias gariepinus*

Stress biomarkers provide an important physiological dimension to the interpretation of growth results. This is because fish may maintain apparently normal growth while experiencing physiological stress that is not immediately evident from conventional production indices. Biomarkers such as glucose, corticosteroids and antioxidant enzymes can therefore provide information about the internal physiological costs associated with different culture environments. Contemporary aquaculture research increasingly recommends the interpretation of several complementary biomarkers rather than reliance on a single variable because stress responses are complex, time-dependent and influenced by species, sampling conditions and the nature and duration of the stressor.

The glucose concentration observed in this study for the control was significantly lower than the values obtained in the NFT and DWC. This finding is in contrast with Baßmann et al. (2017) who found no significant difference in glucose between *C. gariepinus* maintained in a coupled aquaponic system and the control RAS.

Glucose is commonly considered a secondary metabolic indicator of stress in fish. Exposure to stress activates neuroendocrine pathways that mobilize energy substrates, often resulting in increased blood glucose through gluconeogenesis. Corticosteroids participate in this redistribution of energy, directing metabolic resources towards immediate survival rather than long-term anabolic processes. The substantially higher glucose concentration in the control relative to both aquaponic treatments therefore suggests that the fish in the control may have experienced a greater degree of metabolic activation at the time of sampling. However, glucose alone cannot be interpreted as a definitive proof of greater chronic stress because glucose can be influenced by feeding status, sampling time, handling, metabolic condition and other physiological factors (Baßmann et al., 2017)

The corticosterone concentration recorded in this study showed that the control and NFT values were not significantly different, whereas DWC was significantly higher than the control. This contradicts the report of Baßmann et al. (2017) who measure similar corticosteroid (cortisol) and reported no significant difference in the values obtained. Although, the DWC system had the highest corticosterone concentration, it also maintained high dissolved oxygen and low ammonia relative to the control, consequently, the elevated corticosterone cannot automatically be attributed to poor water quality.

The result of this study, however, revealed that the glucose and corticosterone responses did not follow an identical pattern in the culture systems; DWC showed the highest corticosterone but intermediate glucose, whereas the control showed the highest glucose but the lowest corticosterone. This discrepancy does not absolutely indicate an error in the result because stress biomarkers operate at different stages of stress response and have different kinetics. Corticosteroid responses can occur rapidly after exposure to a stressor, while glucose changes may reflect downstream metabolic mobilization and may persist for different periods depending on the duration and intensity of the stressor (Rostamkhani et al., 2012; Skripkina, et al., 2024). Furthermore, blood sampling itself can influence stress-related measurements, and biomarker values are strongly dependent on sampling time relative to the stress event. The elevated corticosterone in DWC may therefore indicate induced stress response at the time of sampling, whereas the higher glucose concentration in the control may be an indicator of the stress response to the culture system. However, it would be inappropriate to conclude solely from these two biomarkers that one system was categorically more stressful than another.

The oxidative-stress biomarkers provide further information about the physiological condition of the fish. Glutathione (GSH) concentrations showed no significant differences among the treatments. GSH is an important intracellular antioxidant that participates directly in the neutralization of reactive oxygen species and also serves as a substrate for glutathione peroxidase. It is therefore an important component of cellular antioxidant defense. The elevation of GSH in NFT may indicate enhanced antioxidant capacity, potentially associated with increased oxidative challenge or increased antioxidant preparedness. However, because the difference was not significant, the data do not support the conclusion that NFT significantly altered glutathione status. The relatively high variability, especially in the aquaponic treatments, also suggests considerable individual variation in antioxidant status.

Superoxide dismutase (SOD) is an important first-line antioxidant enzyme because it converts superoxide radicals into hydrogen peroxide, which is subsequently detoxified primarily by catalase and glutathione peroxidase. The elevated SOD activity in the DWC may represent an enhanced enzymatic response to increased production of superoxide radicals. However, because neither catalase nor GPx differed significantly among treatments, and because the SOD values were not statistically different, the result cannot be interpreted as evidence of significant oxidative stress in DWC. Instead, it may indicate a tendency towards greater antioxidant mobilization without demonstrable oxidative damage. The results obtained in this study agrees with Mao et al. (2023) who reported changes in antioxidant and stress-related parameters in fish maintained in aquaponic systems, demonstrating that culture-system configuration can influence physiological responses even when conventional production indicators do not show large differences

Malondialdehyde (MDA), a commonly used indicator of lipid peroxidation, had the highest numerical concentration in the NFT but was not significantly different from the DWC and control. MDA is generated during oxidative degradation of polyunsaturated fatty acids and is frequently used as an indicator of oxidative damage to cellular membranes. The elevation of MDA in NFT is interesting because NFT also had the highest GSH concentration but relatively lower SOD activity. One possible interpretation is that the antioxidant system was responding to some degree of oxidative challenge in NFT. Nevertheless, the absence of statistical significance means that this may not be evidence of treatment-induced oxidative damage. The present results do not show a coordinated significant increase in antioxidant depletion and oxidative damage in NFT.

Similarly, neither Glutathione peroxidase (GPx) nor Catalase activity differed significantly among the systems. These findings indicate that the principal enzymatic mechanisms responsible for detoxifying hydrogen peroxide remained broadly stable across the culture environments. The combination of unchanged GSH, GPx, catalase and MDA therefore provides no strong evidence of severe oxidative damage in any of the three systems. The absence of significant treatment effects across most oxidative biomarkers suggests that the aquaponic systems did not impose a sufficiently strong or sustained oxidative challenge to disrupt the antioxidant balance of *C. gariepinus*.

The stress results obtained in this study therefore complement the growth results. Although some biomarkers differed numerically or significantly, the overall antioxidant profile remained relatively stable and fish growth was comparable among systems. This suggests that the aquaponic environments were physiologically tolerable for *C. gariepinus*.

CONCLUSION

The findings of this study demonstrate that both Nutrient Film Technique (NFT) and Deep Water Culture (DWC) aquaponic systems were capable of supporting satisfactory production of *Clarias gariepinus* under the experimental conditions. The physicochemical characteristics of the culture water showed that the three systems provided broadly comparable thermal and acid-alkaline based culture environments while substantial differences were observed in dissolved oxygen and nitrogenous metabolites. Despite the differences in water quality, the growth performance of *C. gariepinus* did not differ significantly among the culture systems. Final body weight, mean weight gain, specific growth rate, relative growth rate, final total length, condition factor and thermal growth coefficient were statistically comparable. However, numerically, the NFT produced the highest final mean weight, weight gain, specific growth rate, relative growth rate, final condition factor and thermal growth coefficient, while DWC generally produced intermediate values and the control recorded comparatively lower values. The overall implication is that the integration of *C. gariepinus* culture with either NFT or DWC did not compromise fish growth and survival relative to the conventional fill and drain system.

The stress-biomarker findings further indicated that the fish were able to maintain physiological stability across the culture systems, although some differences occurred in metabolic and endocrine indicators. Furthermore, the oxidative-stress biomarkers provided evidence that none of the culture systems induced a pronounced disruption in the antioxidant homeostasis. Although numerical differences occurred in glutathione, superoxide dismutase, malondialdehyde, glutathione peroxidase and catalase, none of these parameters differed significantly among treatments. Thus, within the conditions and duration of this experiment, the aquaponic systems can be regarded as physiologically tolerable environments for *C. gariepinus*.

Based on the findings of this research, it can therefore be concluded that the Nutrient Film Technique and Deep Water Culture aquaponic systems were suitable for the culture of *C. gariepinus* without producing significant disruption of the oxidative-stress biomarkers.

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