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Dietary Herbal Supplementation Improves Growth Performance and Haematological Responses in *Clarias gariepinus*

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Abstract Dietary composition can influence both the growth performance and haematological parameters of aquaculture species. This study evaluated the welfare benefits of dietary supplementation with ginger (*Zingiber officinale*), garlic (*Allium sativum*), and neem (*Azadirachta indica*) powder on behavioural responses, growth performance, and haematological profile of African catfish juveniles (*Clarias gariepinus*). The use of plant-based phytogetic additives in aquaculture feeds is increasingly recognized as a sustainable alternative to synthetic growth promoters and chemotherapeutic agents, with potential benefits for fish health. Four experimental diets were formulated: a control diet (0%) and three treatment diets supplemented with 2% ginger, 2% garlic, and 2% neem powder respectively. Juvenile *C. gariepinus* were fed these diets for a three-month period (12weeks). Growth parameters, length–weight relationship, and haematological indices were measured, while behavioural indicators such as feeding activity, behaviour, and general vitality were observed as indicators of welfare status. Fish fed the garlic-supplemented diet recorded the highest values of Packed Cell Volume (PCV), haemoglobin (Hb), and Red Blood Cells (RBC), while the neem-supplemented diet produced the highest White Blood Cell (WBC) counts, suggesting improved immune response. Behavioural observations also indicated stronger feeding responses and greater activity in garlic and neem treatments. Overall, phytogetic supplements improved physiological condition and behavioural welfare of *C. gariepinus*.

Keywords Supplemented; Phytogetic additives haematological; Synthetic growth promoters; Chemotherapeutic

1 Introduction

African catfish (*Clarias gariepinus*) is one of the most commercially important freshwater species cultured in Africa. Its widespread cultivation is attributed to its rapid growth, efficient feed utilization, high fecundity, and strong tolerance to a wide range of environmental conditions (Langi et al., 2024; Klimuk et al., 2024). These characteristics have supported the expansion of catfish farming across sub-Saharan Africa, where increasing demand for affordable animal protein continues to drive aquaculture development (Kwikiriza et al., 2025). In addition, selective breeding programmes have improved the growth potential and productivity of cultured stocks, further enhancing the economic value of the species in intensive production systems (Imron et al., 2020; Srimai et al., 2020; Ovie et al., 2025).

Despite these advantages, the rapid expansion and intensification of catfish farming have introduced several health and management challenges. Intensive production practices frequently expose fish to stress arising from fluctuations in water quality, temperature, salinity, and other environmental factors (Khieokhajonkhet et al., 2022; Zidan et al., 2022). Such conditions can disrupt physiological processes, impair growth performance, and compromise fish homeostasis, ultimately reducing production efficiency (Khieokhajonkhet et al., 2022; Klimuk et al., 2024).

In recent years, fish welfare has received considerable attention because it is closely associated with productivity, survival, and resistance to disease (Ojelade et al., 2022). Modern approaches to welfare assessment extend beyond growth measurements and incorporate indicators of physiological balance, immune function, and adaptive capacity

(Okomoda et al., 2024). Among these indicators, haematological parameters are particularly useful because changes in blood characteristics provide valuable information on fish health status on the health status and stress responses of fish (Melefa et al., 2020; Okomoda et al., 2024). Previous studies have shown that environmental changes can significantly affect erythrocyte and leukocyte profiles, highlighting the sensitivity of blood indices as indicators of fish health (Oluah et al., 2020; Mangkunegara et al., 2023).

Disease outbreaks remain a major constraint to sustainable aquaculture, particularly under intensive culture conditions where fish are exposed to multiple stressors (Mohammed et al., 2025). Antibiotics have traditionally been used to control disease problems; however, concerns over antimicrobial resistance have increased interest in alternative approaches to fish health management. Evidence suggests that excessive use of antibiotics in aquaculture may promote the emergence and spread of resistant microorganisms within aquatic environments (Mohammed et al., 2025). Consequently, attention has shifted towards sustainable dietary strategies that improve fish health without posing ecological risks (Akpomughe et al., 2024; Le Xuan, 2026).

One area that has attracted growing interest is the use of phytobiotics as functional feed additives. These plant-derived products contain bioactive compounds capable of influencing growth, metabolism, immune responses, and disease resistance in cultured fish (Le Xuan, 2026). Several studies have shown that phytobiotics can enhance digestive processes, improve nutrient utilization, and stimulate innate immunity. Their incorporation into aquafeeds is therefore increasingly regarded as an important component of sustainable aquaculture development because they offer health benefits while reducing dependence on synthetic drugs and chemotherapeutic agents (Le Xuan, 2026).

Among the various phytobiotics investigated in catfish culture, garlic (*Allium sativum*) and ginger (*Zingiber officinale*) have received considerable attention because of their beneficial effects on growth and health (Megbowon et al., 2024). Dietary supplementation with these herbs has been associated with improved growth performance, feed utilization, and body composition in African catfish fry and juveniles (Nyadjeu, 2021; Nyadjeu et al., 2021). Studies have also shown that the combined use of garlic and ginger can enhance physiological performance and growth responses in juvenile fish (Nyadjeu et al., 2023). Similarly, ginger supplementation has been reported to improve nutrient utilization and promote improved health status in catfish, supporting its potential as a functional feed ingredient (Wei et al., 2023; Uddin et al., 2025).

Neem (*Azadirachta indica*) has also gained recognition as a promising natural additive because of its antimicrobial, immunomodulatory, and prophylactic properties (Yusuff and Ibidapo Obe, 2024). Previous studies have demonstrated that neem-based products can contribute to disease prevention and improve health management in African catfish production systems (Oyebola et al., 2020). Therapeutic applications of neem have been linked with enhanced physiological resilience and improved health status in catfish species (Parvin et al., 2023). More recently, nano-formulated neem products have been reported to stimulate immune responses and increase resistance to disease, further emphasizing the biological potential of neem-derived compounds in aquaculture (Ibrahim et al., 2023).

The effects of dietary phytobiotics are often reflected in haematological characteristics because blood parameters respond readily to changes in nutritional and physiological conditions (Melefa et al., 2020). Parameters such as red blood cell count, haemoglobin concentration, and packed cell volume are commonly used to assess oxygen transport capacity and metabolic efficiency in fish (Okomoda et al., 2024). Likewise, white blood cell counts and differential leukocyte profiles provide useful information on immune responses and disease resistance mechanisms (Oluah et al., 2020; Sayed et al., 2022). For this reason, haematological analysis has become an important tool for evaluating the influence of dietary interventions on fish health and welfare.

Although garlic, ginger, and neem have each been reported to exert beneficial effects in fish, information comparing their relative contributions to welfare-related responses in *Clarias gariepinus* remains limited (Megbowon et al., 2024). Most existing studies have concentrated on growth performance or immune responses separately, with relatively few investigations adopting a more integrated approach that considers both physiological wellbeing and

welfare indicators simultaneously (Nyadjeu et al., 2023; Megbowon et al., 2024). This limitation has hindered the development of evidence-based feeding strategies aimed at improving fish welfare while sustaining productivity under commercial farming conditions (Awhefeada et al., 2025; Le Xuan, 2026).

Against this background, a comparative evaluation of dietary supplementation with garlic, ginger, and neem in *Clarias gariepinus* is necessary. Understanding how these phytobiotics influence physiological wellbeing and welfare-related parameters will provide valuable information for the development of sustainable nutritional strategies. Such approaches have the potential to improve fish health and reduce dependence on conventional chemotherapeutic agents, thereby supporting more environmentally responsible aquaculture practices (Mohammed et al., 2025; Le Xuan, 2026).

2. Materials and Methods

2.1 Study area

The feeding trial was carried out at the Fisheries Research Farm and Fisheries Laboratory, Delta State University, Asaba Campus, Delta State, Nigeria. Laboratory analyses were conducted under controlled conditions following standard aquaculture and fish health procedures.

2.2 Experimental fish and rearing conditions

A total of 120 healthy hatchery-produced African catfish (*Clarias gariepinus*) fingerlings with an average body weight of 10.6 g and an average total length of approximately 9 cm were obtained from the Department of Fisheries and Aquaculture Research Farm, Delta State University, Abraka.

The fish were acclimatized to the experimental conditions for 24 h before the commencement of the feeding trial. After acclimatization, the fish were randomly assigned to twelve plastic tanks (150 L capacity) at a stocking density of 10 fish per tank. Each tank was covered with mosquito mesh to prevent escape and protect the fish from external predators. Water in the tanks was renewed every three days throughout the experimental period to maintain suitable water quality.

2.3 Experimental design and duration

The experiment was arranged in a Completely Randomized Design (CRD) consisting of four dietary treatments, each replicated three times, giving a total of twelve experimental units. The feeding trial lasted for three months, from May to July.

The dietary treatments were as follows:

- T1: Control diet without herbal supplementation (0%)
- T2: Diet containing 2% garlic (*Allium sativum*) powder
- T3: Diet containing 2% ginger (*Zingiber officinale*) powder
- T4: Diet containing 2% neem (*Azadirachta indica*) leaf powder

2.4 Preparation of herbal additives

Fresh garlic bulbs and ginger rhizomes were purchased from a local market in Abraka, Delta State, whereas fresh neem leaves were collected from mature trees within the university environment. The plant materials were washed thoroughly and air-dried before being milled into fine powder. The powdered samples were stored in airtight containers until they were incorporated into the experimental diets.

2.5 Diet formulation

Experimental diets were formulated using Pearson's square method. The major feed ingredients consisted of maize, fishmeal, groundnut cake, palm kernel cake, wheat meal, bone meal, vitamin-mineral premix, palm oil, and cassava starch. Depending on the treatment, garlic, ginger, or neem powder was incorporated into the diets at an inclusion level of 2%.

The diets were pelleted, air-dried, and stored under dry conditions until use.

2.6 Proximate analysis of experimental diets

Samples of the experimental diets were analysed for moisture content, crude protein, crude fibre, ether extract, ash content, and nitrogen-free extract according to the standard procedures of the Association of Official Analytical Chemists (AOAC, 2000). Nitrogen-free extract was determined by difference after subtracting the percentages of moisture, crude protein, crude lipid, crude fibre, and ash from 100.

2.7 Feeding trial and growth monitoring

Following acclimatization, the fish were weighed and measured before the start of the feeding experiment. Feeding was carried out twice daily between 08:00-09:00 h and 17:00-18:00 h at a rate equivalent to 3% of body weight. Feed ration was adjusted periodically in line with changes in fish weight.

Throughout the study, feeding behaviour and feed acceptance were observed and recorded. Body weight and total length measurements were taken monthly using a digital weighing balance and a graduated measuring board, respectively.

2.8 Water quality monitoring

Water quality parameters were monitored throughout the experiment to ensure favourable conditions for fish growth and survival. Water temperature was measured using a calibrated thermometer, dissolved oxygen concentration was determined following APHA (1998) procedures, and pH was measured with a digital pH meter.

2.9 Length-weight relationship

The length-weight relationship was determined using the equation:

$$W = aL^b$$

where W represents body weight (g), L represents total length (cm), a is the intercept, and b is the growth coefficient.

Length-weight relationships are widely used to evaluate growth performance, biomass accumulation, and population condition in cultured and natural fish populations (Musa et al., 2021; Ekpemikoghene et al., 2024). Regression analysis was used to estimate the growth coefficient following established fisheries procedures.

2.10 Condition factor

The condition factor (K) was calculated as:

$$K = \frac{1000W}{L^3}$$

where W is body weight (g) and L is total length (cm).

Condition factor provides an integrated measure of fish well-being because it reflects the relationship between body weight and length under specific environmental and nutritional conditions (Isibor et al., 2023; Sadauki et al., 2024).

2.11 Haematological analysis

At the end of the feeding trial, fish were randomly selected from each treatment and transported alive to the laboratory for blood collection. Blood samples were collected using sterile syringes and transferred into ethylenediaminetetraacetic acid (EDTA) tubes for subsequent analysis.

The haematological parameters determined were packed cell volume (PCV), haemoglobin concentration (Hb), red blood cell count (RBC), white blood cell count (WBC), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC).

2.12 Statistical analysis

Data obtained from the experiment were expressed as mean $\pm$ standard deviation (SD). Treatment means were subjected to one-way analysis of variance (ANOVA), and where significant differences were observed, Duncan's Multiple Range Test was used to separate the means. Statistical significance was established at $P < 0.05$.

3 Results

3.1 Proximate composition of experimental diets

The proximate composition of the control and herbal-supplemented diets is presented in Table 1. Differences in nutrient composition were observed among the experimental diets following the inclusion of garlic, ginger, and neem.

Moisture content varied from 9.07% in the ginger-supplemented diet to 10.18% in the neem diet. Ash content was relatively higher in the neem (4.65%) and ginger (4.38%) diets than in the control (3.08%) and garlic (3.04%) diets.

The inclusion of the herbal additives resulted in slightly higher crude protein levels, with the neem-based diet recording the highest value (23.40%). Crude protein content in both the garlic and ginger diets was 22.00%, compared with the control diet. A similar trend was observed for crude fibre content, which increased from 7.20% in the control diet to 11.00% in the ginger-supplemented diet.

Ether extract ranged from 12.00% in the control diet to 15.00% in the ginger diet. In contrast, nitrogen-free extract decreased following herbal supplementation and was highest in the control diet (47.85%).

Table 1 Proximate composition (%) of the experimental diets

Parameter (%)	Control	Garlic (2%)	Neem (2%)	Ginger (2%)
Moisture	9.57	9.24	10.18	9.07
Ash	3.08	3.04	4.65	4.38
Crude fibre	7.20	7.47	8.80	11.00
Crude protein	20.30	22.00	23.40	22.00
Ether extract	12.00	12.41	14.29	15.00
Nitrogen-free extract	47.85	45.84	38.68	38.55

3.2 Haematological responses of *Clarias gariepinus*

The haematological characteristics of *Clarias gariepinus* fed the experimental diets are presented in Table 2. Dietary supplementation with garlic, ginger, and neem influenced several erythrocytic and leucocytic parameters.

Table 2 Haematological parameters of *Clarias gariepinus* fed experimental diets

Parameter	Control	Garlic (2%)	Ginger (2%)	Neem (2%)
PCV (%)	32.20 $\pm$ 2.96 ^{ab}	37.80 $\pm$ 2.69 ^a	30.20 $\pm$ 0.66 ^b	34.40 $\pm$ 1.91 ^{ab}
Plasma protein (g dL ⁻¹)	6.56 $\pm$ 0.45	5.96 $\pm$ 0.30	5.84 $\pm$ 0.24	6.02 $\pm$ 0.34
Hb (g dL ⁻¹)	10.72 $\pm$ 0.93 ^{ab}	12.48 $\pm$ 0.77 ^a	10.04 $\pm$ 0.28 ^b	11.36 $\pm$ 0.67 ^{ab}
WBC (cells μ L ⁻¹)	4890 $\pm$ 302 ^b	5690 $\pm$ 93 ^{ab}	5660 $\pm$ 529 ^{ab}	6750 $\pm$ 469 ^a
RBC ($\times 10^6$ cells μ L ⁻¹)	23.60 $\pm$ 4.10 ^b	51.80 $\pm$ 3.38 ^a	20.00 $\pm$ 2.30 ^b	48.00 $\pm$ 6.36 ^a
Neutrophils (%)	41.20 $\pm$ 0.58 ^b	46.40 $\pm$ 4.99 ^{ab}	44.80 $\pm$ 0.37 ^{ab}	50.00 $\pm$ 0.71 ^a
Lymphocytes (%)	50.80 $\pm$ 1.74	49.80 $\pm$ 5.02	48.80 $\pm$ 0.58	44.80 $\pm$ 0.80
Monocytes (%)	2.80 $\pm$ 0.37 ^a	2.00 $\pm$ 0.00 ^b	1.60 $\pm$ 0.24 ^b	2.00 $\pm$ 0.00 ^b
Eosinophils (%)	5.00 $\pm$ 1.00 ^a	2.60 $\pm$ 0.40 ^b	4.40 $\pm$ 0.24 ^a	4.00 $\pm$ 0.00 ^{ab}
Basophils (%)	1.00 $\pm$ 0.00	1.00 $\pm$ 0.00	1.00 $\pm$ 0.00	1.00 $\pm$ 0.00

Table notes: Values are presented as mean $\pm$ SD. Means within a row bearing different superscripts differ significantly at $P < 0.05$.

Fish fed the garlic-supplemented diet exhibited the highest packed cell volume (37.80 $\pm$ 2.69%) and haemoglobin concentration (12.48 $\pm$ 0.77 g dL⁻¹), whereas the lowest values were recorded in fish fed the ginger diet. Red

blood cell counts were significantly higher ($P < 0.05$) in fish fed garlic and neem diets than in the control and ginger-fed groups, indicating enhanced erythropoietic activity in these treatments.

White blood cell counts increased across all herbal-supplemented groups relative to the control treatment, with the highest count observed in fish fed the neem diet (6750 ± 469 cells μL^{-1}). Similarly, neutrophil percentages increased significantly from $41.20 \pm 0.58\%$ in the control group to $50.00 \pm 0.71\%$ in the neem-fed fish. These changes suggest enhanced cellular defence responses in fish receiving herbal supplementation.

Lymphocyte percentages ranged from $44.80 \pm 0.80\%$ to $50.80 \pm 1.74\%$ and did not differ significantly among treatments. Monocyte values were significantly lower in the supplemented groups than in the control treatment, while eosinophil counts were lowest in fish fed the garlic diet. Basophil values remained constant across all treatments.

4 Discussion

The proximate composition of the experimental diets showed that the inclusion of garlic, ginger, and neem modified the nutrient profile of the feeds. Compared with the control diet, the supplemented diets contained higher levels of crude protein, crude fibre, ash, and ether extract, while nitrogen-free extract decreased. These changes indicate that the herbal materials contributed additional nutrients alongside their phytochemical constituents. Since feed composition plays a major role in nutrient utilization and physiological processes, such variations may influence the overall health and performance of cultured fish. Similar observations have been reported for African catfish, where dietary nutrient composition has been shown to affect digestibility and metabolic efficiency (Langi et al., 2024; Oluyemi et al., 2024).

Among the diets, the neem-supplemented feed recorded the highest crude protein content (23.40%), whereas the garlic and ginger diets contained 22.00% crude protein. Protein is essential for tissue growth, enzyme synthesis, haemoglobin formation, and immune function. Previous studies have shown that adequate dietary protein improves nutrient utilization and physiological performance in African catfish (Fregene et al., 2024). The relatively higher protein content of the neem diet may have contributed to the favourable haematological responses observed in fish exposed to this treatment.

Mineral content, as reflected by ash values, was also higher in the herbal diets, particularly in the neem and ginger treatments. Ash represents the total mineral fraction of the feed and provides an indication of the availability of essential elements involved in cellular metabolism and blood formation. Earlier studies have shown that adequate mineral supply supports normal physiological activities and promotes efficient nutrient utilization in cultured fish (Oluyemi et al., 2024). Thus, the elevated ash content observed in the supplemented diets may have supported the maintenance of physiological stability throughout the feeding period.

Crude fibre increased with the inclusion of the herbal additives, with the highest value recorded in the ginger-supplemented diet. This increase was expected because plant materials naturally contain appreciable amounts of fibre. Although excessive dietary fibre may reduce digestibility in carnivorous fish species, moderate inclusion levels are generally tolerated. The absence of adverse changes in the measured blood parameters suggests that the 2% inclusion level used in the present study did not negatively affect fish health.

A decline in nitrogen-free extract was observed in the supplemented diets compared with the control. This reduction appears to be a consequence of the corresponding increases in protein, fibre, lipid, and mineral fractions. Since African catfish rely largely on protein and lipid metabolism for growth and maintenance, moderate changes in carbohydrate content are unlikely to compromise performance provided that energy requirements are adequately met. Similar observations have been reported by Langi et al. (2024), who emphasized the greater importance of protein quality in determining the performance of *Clarias gariepinus*.

The haematological responses observed in this study indicate that dietary supplementation with garlic, ginger, and neem influenced the physiological condition of the fish. Blood parameters are widely used in fish health assessment

because they respond to nutritional status, stress, and disease conditions. Previous studies have demonstrated that haematological variables serve as sensitive indicators of physiological changes in African catfish (Melefa et al., 2020; Okomoda et al., 2024). The differences recorded among the dietary treatments suggest that the herbal supplements elicited distinct physiological responses.

Fish fed the garlic-supplemented diet recorded the highest packed cell volume and haemoglobin concentration. These parameters are closely associated with oxygen transport and are often used to assess the physiological status of fish. Reduced values have been linked with stress and impaired metabolic activity, whereas elevated values are generally associated with improved oxygen-carrying capacity and better physiological condition (Dawood et al., 2022; Okomoda et al., 2024). The results obtained in the present study suggest that garlic promoted erythropoietic activity and enhanced blood oxygen transport.

This pattern was further reflected in the red blood cell counts, which were considerably higher in fish fed garlic and neem diets than in those receiving the control diet. Red blood cells are responsible for transporting oxygen to tissues and are therefore important for metabolic processes. The beneficial effects of garlic observed in the present study agree with earlier reports indicating that garlic supplementation improves physiological condition and innate immune responses in African catfish (Nyadjeu et al., 2023; Megbowon et al., 2024). These findings highlight the potential of garlic as a functional feed additive capable of improving blood characteristics in cultured fish.

Among the herbal treatments, neem produced the strongest response in terms of immune-related parameters. Fish fed the neem diet recorded the highest white blood cell counts and neutrophil percentages. White blood cells and neutrophils are important components of the innate immune system and are involved in defence against invading pathogens. Previous studies have shown that neem-derived compounds possess immunostimulatory properties and can enhance disease resistance in cultured fish (Oyebola et al., 2020; Ibrahim et al., 2023). The elevated leukocyte values observed in this study are therefore indicative of enhanced immune competence rather than pathological stress.

Although the erythrocytic responses obtained with ginger were less pronounced than those observed with garlic and neem, the measured blood parameters remained within normal physiological limits. This suggests that ginger supported normal physiological function throughout the feeding period. Earlier studies have consistently reported beneficial effects of ginger on growth, antioxidant status, and overall health in African catfish (Wei et al., 2023; Uddin et al., 2025). Differences in inclusion level, feeding duration, and phytochemical composition may explain the relatively moderate responses recorded in the present study.

Another notable finding was the increase in white blood cell counts across all herbal treatments compared with the control group. This trend indicates that the three phytobiotics stimulated aspects of innate immunity, although the magnitude of response varied among treatments. Similar observations have been reported in studies advocating the use of phytogenic additives as sustainable alternatives to antibiotics in aquaculture (Mohammed et al., 2025; Le Xuan, 2026). The results of the present study support the growing interest in plant-based feed additives as practical tools for improving fish health and reducing dependence on conventional chemotherapeutic agents.

5 Conclusion

This study examined the effects of dietary supplementation with garlic (*Allium sativum*), ginger (*Zingiber officinale*), and neem (*Azadirachta indica*) on the nutritional quality of formulated diets and the haematological responses of *Clarias gariepinus*. The inclusion of these herbal additives improved the nutrient composition of the diets through increases in crude protein, ash, crude fibre, and ether extract, accompanied by a reduction in nitrogen-free extract. These changes indicate that the herbs contributed not only bioactive compounds but also nutrients capable of enhancing feed quality.

The haematological results showed that the phytogenic supplements influenced fish health in different ways. Fish fed the garlic-supplemented diet recorded higher packed cell volume, haemoglobin concentration, and red blood cell counts, suggesting improved oxygen transport and better physiological condition. In contrast, neem

supplementation resulted in higher white blood cell and neutrophil counts, indicating a stronger stimulation of innate immune responses. Although the effects of ginger were less pronounced, the blood parameters remained within normal physiological ranges, suggesting that the additive supported normal body functions without adverse effects.

An important finding of this study is that the three phyto-genic supplements did not produce identical responses. Garlic showed greater influence on erythrocytic parameters, whereas neem exerted stronger effects on immune-related indices. These differences highlight the diverse biological roles of herbal feed additives and suggest that their use can be tailored to specific production goals, whether improving physiological performance, enhancing immunity, or promoting overall fish health.

The results also emphasize the importance of evaluating dietary interventions beyond growth performance alone. The relationship observed between dietary quality and haematological responses suggests that nutritional status and physiological wellbeing are closely linked. Consequently, blood-based indicators provide additional information that complements conventional growth measurements and contributes to a more comprehensive assessment of fish welfare.

Overall, the findings indicate that garlic, ginger, and neem have considerable potential as functional feed additives in African catfish culture. Their ability to support physiological condition and immune function without reliance on synthetic chemotherapeutic agents highlights their value in sustainable and environmentally responsible aquaculture practices.

The findings demonstrate the complementary physiological roles of garlic, ginger, and neem as phyto-genic feed additives, supporting their application in sustainable African catfish production. Future research should optimise dietary inclusion levels, evaluate combined herbal formulations, and integrate biochemical, molecular, and commercial performance indicators under long-term farming conditions to strengthen evidence-based nutritional strategies for aquaculture.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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