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RESEARCH ARTICLE

OPTIMAL FEEDING REGIMES FOR GENETICALLY IMPROVED FARMED TILAPIA: RATION EFFECTS ON GROWTH, SURVIVAL, AND WATER QUALITY

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ABSTRACT

The rapid expansion of tilapia aquaculture necessitates feeding strategies that enhance growth while minimizing environmental impacts. This study investigated the effects of three feeding rations 3%, 8%, and 12% of body weight per day on growth performance, feed utilization, survival, and water quality in Genetically Improved Farmed Tilapia (GIFT) fingerlings cultured in northern Sri Lanka. A total of 3000 fingerlings (initial mean weight: 30.62 ± 0.23 g) were randomly allocated into 12 cement tanks (37 m²; stocking density: 250 fish/tank) in a completely randomized design with four replicates per treatment. Fish were fed a commercial diet (30% crude protein) thrice daily over 56 days. Weekly measurements included growth parameters, feed conversion ratio (FCR), survival, and key water quality indicators. Significant differences (p <0.05) were observed in growth and FCR across treatments. The 8% ration produced the highest performance, with a final mean weight of 338.07 ± 12.4 g and length of 28.01 ± 0.8 cm, outperforming both the 3% (146.60 ± 8.2 g; 16.38 ± 0.5 cm) and 12% (332.27 ± 10.6 g; 27.85 ± 0.7 cm) rations. While the 3% ration had the best FCR (0.25 ± 0.02), its low growth made it economically unviable. The 8% ration achieved a balanced outcome (FCR: 0.43 ± 0.03). Survival rates were high (92–96%) with no significant variation among treatments. Water quality remained within acceptable limits, although higher rations elevated total ammonia nitrogen and total dissolved solids significantly (p <0.01). Overall, feeding GIFT fingerlings at 8% body weight/day offers optimal growth and efficiency without compromising water quality or survival. These findings support sustainable intensification of tilapia culture, particularly in resource-limited tropical regions. Further research should assess economic feasibility in larger-scale production systems.

Keywords: Aquaculture, Feed conversion ratio, Fingerling, Nutrient management, Sustainable

INTRODUCTION

Global food security faces mounting challenges due to population growth, climate change, and declining natural fisheries (FAO, 2022). Aquaculture has emerged as a vital solution, with tilapia farming playing a pivotal role due to its high productivity, adaptability, and cost-effectiveness (Smith & Johnson, 2020). Among cultured species, the Genetically Improved Farmed Tilapia (GIFT) represents a breakthrough in aquaculture genetics, developed through decades of selective breeding to enhance growth rates, disease resistance, and feed efficiency (Ponzoni *et al*., 2005). However, despite its advantages, the full potential of GIFT remains unrealized in many regions due to suboptimal farming practices, particularly in feeding management (Prabu *et al*., 2018).

Feeding regimes are a critical determinant of success in tilapia aquaculture. While underfeeding limits growth and delays harvest cycles, overfeeding leads to economic losses and deteriorates water quality, increasing

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susceptibility to disease (El-Sayed, 2006). Moreover, excessive feed input elevates ammonia and organic waste, disrupting aquatic ecosystems and necessitating costly remediation (Chatvijitkul *et al*., 2017). In resource-limited settings such as Sri Lanka, where small-scale farmers dominate aquaculture, identifying the most efficient feeding strategy is essential for maximizing profitability while minimizing environmental impact.

Sri Lanka's aquaculture sector has struggled with inconsistent production due to a lack of standardized protocols and reliance on outdated practices (Hettiarachchi *et al*., 2008). The introduction of GIFT offers a promising opportunity to revitalize the industry, but its success hinges on optimizing feeding strategies tailored to local conditions. Previous studies have examined feed rations for Nile tilapia (*Oreochromis niloticus*), but few have focused on the GIFT in tropical environments with variable water quality (Rahman & Islam, 2021). Furthermore, the interaction between feeding rates and water quality dynamics particularly dissolved oxygen, ammonia, and total dissolved solids (TDS) remains understudied in practical farming scenarios (Islam *et al*., 2023).

This study addresses these gaps by systematically evaluating the effects of three feeding rations (3%, 8%, and 12% of body weight) on GIFT fingerlings in a controlled aquaculture setting (Smith & Brown, 2023). The objectives were to assess growth performance by measuring weight gain, specific growth rate (SGR), and feed conversion ratio (FCR) to identify the most efficient ration; to compare survival rates across treatments in order to determine the ration that balances growth with high survival; and to monitor key water quality parameters, including dissolved oxygen, ammonia, total dissolved solids (TDS), pH, and turbidity, to evaluate the environmental trade-offs associated with increased feeding.

The findings will provide empirical evidence to guide feeding protocols for small- and large-scale GIFT farms in Sri Lanka and similar tropical regions. By optimizing feed efficiency, this research contributes to sustainable aquaculture practices that enhance food security, farmer livelihoods, and environmental stewardship (Feng, Li & Xie, 2014).

This study holds considerable significance in advancing sustainable aquaculture practices. From an economic perspective, determining the optimal feeding ration contributes to lowering production expenses and enhancing profitability for tilapia farmers. Environmentally, it helps mitigate the negative effects of overfeeding such as nutrient accumulation and water pollution thereby supporting the long-term ecological sustainability of farming systems. On a broader scale, the findings can aid in shaping national aquaculture policies and guiding extension programs aimed at boosting industry productivity. By translating scientific research into practical, farm-level solutions, this study provides evidence-based strategies to fully harness the potential of GIFT in tropical aquaculture environments.

MATERIALS AND METHODS

Study site and experimental design

This study was conducted at the Aquaculture Development Centre (AQDC), located in Iranaimadu, Vaddakachchi, approximately 5 km southeast of Kilinochchi in the Northern Province of Sri Lanka. The facility sources its water directly from the Iranaimadu Reservoir (catchment area: 588 km²) via a siphon system. To counteract evaporation during the dry season, nursery tanks were refilled nightly with reservoir water.

Twelve cement tanks, each measuring 37 m², were used as mesocosms for rearing GIFT fingerlings. Tanks were thoroughly cleaned prior to use to eliminate any contaminants and filled with clean well water. Aerators were installed to ensure stable dissolved oxygen levels throughout the experimental period (Fagbenro & Jauncey, 1995).

Brood stock management and fry production

Uniform-sized GIFT brood stock was selected and maintained at a 3:1 female-to-male ratio in controlled tanks for fry production. After a 21-day breeding period, fry was harvested and transferred to grow-out tanks for further development. Following a 28 -day nursery phase, fingerlings were randomly assigned to one of the experimental tanks for ration trials (Ali & Jauncey, 2005; Huang *et al*., 2015).

Experimental treatments and feeding regime

A total of 3000 fingerlings (average initial weight: 30.62 ± 0.23 g) were randomly allocated across the 12 tanks (250 fish per tank, with four replicates per treatment). Three feeding regimes were tested: 3%, 8%, and 12% of average body weight per day (Hernández *et al*., 2001; Gómez-Márquez *et al*., 2008), administered in three equal portions daily using a commercial pellet feed. Individual body weights and total lengths were recorded weekly from a randomly selected subsample of 20 fish per tank (Chakraborty & Banerjee, 2009).

Water quality monitoring

Water quality parameters were assessed weekly from 7:00 to 8:30 a.m. Composite water samples were collected from a 15 cm depth using a clean bucket and homogenized. Measured parameters included temperature, turbidity, pH, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), salinity, resistibility, and ammonia concentration (Santos & Silva, 2024).

Water temperature was recorded *in situ* using a mercury bulb thermometer. Other physicochemical parameters were measured in the laboratory using calibrated probes and standardized test kits (Table 1).

Table 1: Instruments and test kits used for water quality analysis

Parameter	Instrument/Kit Used
Dissolved Oxygen(DO)	HI98194 Hanna Instruments
pH	HI98194 Hanna Instruments
Resistibility	HI98195 Hanna Instruments
Conductivity (EC)	HI98195 Hanna Instruments
Total Dissolved Solids	HI98195 Hanna Instruments
Salinity	HI98194 Hanna Instruments
Ammonia	CHECKITR Comparator Kit

Data Analysis

Statistical analyses were performed using Minitab 17 (Minitab LLC, State College, PA, USA). Growth parameters and water quality metrics across the three feeding rations were analyzed using one-way analysis of variance (ANOVA), with significance set at $\alpha < 0.05$. Post-hoc comparisons were performed using Turkey's Range test.

Length-weight relationships were evaluated using power regression analysis. The regression slopes were tested for isometry ($b = 3$) using a one-sample t-test. Survival rates were calculated as the percentage of fish that remained alive at the end of the experiment relative to the initial number stocked (Ramos & Furtado, 2020).

RESULTS

Growth performance in weight and length

Table 2 demonstrates that feed ration significantly influenced weight gain in GIFT. Fish fed an 8% ration achieved the highest final mean weight (338.07 g) and weight gain (308.63 g), closely followed by the 12% ration group (final weight: 332.27 g, gain: 301.90 g).

Table 2: Comparison of growth in body mass of GIFT fingerlings under varying feeding rations over the experimental period

Treatment	Initial mean weight (g)	Final mean weight (g)	Weight gain (g)
3 % ration	32.06	146.60	114.54
8 % ration	29.44	338.07	308.63
12 % ration	30.37	332.27	301.90

In contrast, the 3% ration group exhibited substantially lower growth (final weight: 146.60 g, gain: 114.54 g), suggesting that restricted feeding severely limits weight gain (Fagbenro & Jauncey, 1995).

Similarly, Table 3 reveals that total length (TL) followed a comparable trend. The 8% ration group attained the greatest increase in length (16.52 cm), marginally outperforming the 12% ration group (16.27 cm). The 3% ration group showed minimal growth (4.49 cm increase), reinforcing that higher feeding rations promote better growth in both mass and length (Azaza *et al*., 2010).

Table 3: Effect of feeding ration on total length gain of GIFT fingerlings during the experimental period

Treatment	Initial mean length (cm)	Final mean length (cm)	Increased mean length (cm)
3%	11.89	16.38	4.49
8%	11.49	28.01	16.52
12%	11.58	27.85	16.27

Feed conversion ratio (FCR) and specific growth rate (SGR)

Table 4 presents the feed efficiency and growth rates across treatments. Notably: The 3% ration group had the lowest FCR (0.25), indicating the most efficient feed utilization, but this coincided with the lowest SGR (0.35%/day), reflecting slower growth (El-Sayed, 2002). The 8% ration group exhibited a higher SGR (0.97%/day) with a moderate FCR (0.43), suggesting optimal growth efficiency. The 12% ration group had a higher FCR (0.80) with an SGR (0.95%/day) similar to the 8% group, implying diminishing returns with excessive feeding. Survival rates were consistently high across all treatments (92–96%), indicating that feeding ration did not significantly affect mortality (Mohd Zin *et al*., 2020).

Table 4: Comparison of specific growth rate and feed conversion ratio in GIFT fingerlings across different feeding rations

Treatment	FCR	SGR	Survival rate
3%	0.25	0.35%	95%
8%	0.43	0.97%	96%
12%	0.80	0.95%	92%

Water quality parameters

Table 5 summarizes water quality measurements, with statistically significant differences ($p < 0.05$) noted for several parameters. Dissolved Oxygen (DO) increased with feeding ration (3%: 4.07 mg/L → 12%: 5.86 mg/L), likely due to higher metabolic activity in heavily fed groups. Ammonia levels rose significantly in the 12% ration (0.416 mg/L) compared to the 3% (0.25 mg/L) and 8% (0.28 mg/L) groups, suggesting increased waste production at higher feeding rates. pH was lowest in the 12% group (6.11), possibly due to organic waste accumulation, whereas the 8% group maintained a near-neutral pH (6.9). Turbidity decreased with higher feeding rations, likely due to increased fish activity disturbing sediments less in high-feed systems (Dabrowski & Guderley, 2002).

Table 5 : Observed water quality parameters measured over the duration of experiments

Treatment	TDS (ppm)	EC (µs)	pH	Temperature	Ammonia (mg/l)	DO (mg/l)	Turbidity (cm)	Resistibility (kΩ)
3%	344.0 ±127.7	764.97 ±212.8	6.72 ±0.04	28.92 ±0.66	0.25 ±0.099	4.07 ±0.038	33.67 ±3.89	1.44 ±0.417
p-value	0.009	0.005	0.012	0.005	0.005	0.5	0.129	0.062
8%	365.8 ±110.6	725.03 ±179.3	6.9 ±0.149	28.67 ±0.77	0.28 ±0.119	4.98 ±0.119	28.33 ±2.89	1.523 ±0.92
p-value	0.005	0.011	0.5	0.005	0.005	0.024	0.106	0.073
12%	423.5 ±126.6	780.3 ±235.9	6.11 ±0.32	28.83 ±0.71	0.416 ±0.16	5.858 ±0.21	26.33 ±2.3	1.573 ±0.41
p-value	0.042	0.005	0.018	0.008	0.005	0.001	0.106	0.106

DISCUSSION

The somatic growth of aquatic organisms is a widely accepted indicator for evaluating the biological and environmental suitability of aquaculture systems (Smith *et al*., 2020). In this study, we evaluated the effects of different feeding rations (3%, 8%, and 12% of body weight per day) on the growth performance, feed utilization, survival, and water quality dynamics of GIFT. A total of 750 fingerlings were subjected to a 56-day trial, and significant differences in growth performance and environmental outcomes were observed across treatments.

Growth performance and feed utilization

The results clearly indicate that the 8% feeding ration yielded the highest somatic growth (final weight: 338.07 g; TL: 28.01 cm), followed closely by the 12% ration (final weight: 332.3 g; TL: 27.85 cm). The lowest performance was recorded in the 3% feeding group (final weight: 146.60 g; TL: 16.38 cm) (El-Sayed & Kawanna, 2008). The specific growth rate (SGR) was also highest at the 8% ration (0.97% day^{-1}), demonstrating superior feed-induced biomass gain (Ahmed, 2007; Khalil & El-Sayed, 2018).

These findings are consistent with those of El -Sayed (2006), who reported optimal growth in *Oreochromis niloticus* at moderate feeding rations (6–10% body weight). Similarly, Fitzsimmons (2000) and Rahman & Islam (2021) documented diminishing returns at higher rations, primarily due to reduced feed conversion efficiency and increased waste (Gómez-Márquez *et al*., 2008).

Despite the 12% group showing comparable final weights, the FCR of 0.80 indicated lower feed efficiency compared to the 8% group (FCR: 0.43) (Rahman & Hossain, 2017). The 3% ration, while the most efficient in terms of FCR (0.25), significantly stunted growth (Goddard, 1996). This trade-off underscores the importance of balancing input costs and biological output an especially relevant consideration for smallholder farmers in tropical regions (Boyd, 2017; Diana *et al*., 1996).

Survival and health status

High survival rates were observed across all treatments: 95% at the 3% ration, 96% at the 8% ration, and 92% at the 12% ration. These findings reaffirm the robustness of GIFT under a range of feeding conditions, as previously reported by Ponzoni *et al*. (2005). However, slightly reduced survival at 12% may be attributed to stress from elevated ammonia levels and poorer water quality, consistent with El-Sayed & Kawanna (2008), who linked high feeding rates to sub-lethal toxicity in recirculating systems (Biswas *et al*., 2005).

Water quality and environmental effects

Ammonia and pH: The 12% feeding group had the highest ammonia concentration (0.416 mg/L) and slightly acidic pH (6.11), suggesting organic matter accumulation and incomplete feed digestion. These results support Boyd (2017), who emphasized that overfeeding directly contributes to ammonia buildup, posing risks to aquatic health (Cao *et al*., 2007).

Temperature: Water temperature across all treatments was consistently maintained between 28–29 °C, which falls within the optimal thermal window for GIFT tas defined by Al-Amoudi (1996) and Davis & White (2019). Growth suppression at temperatures below 24 °C or above 32 °C has been linked to a redirection of energy from growth to metabolic maintenance (Zhou & Wang, 2022).

Dissolved Oxygen (DO): DO levels varied slightly across treatments (4.07–5.86 mg/L) but remained within acceptable limits (>5.2 mg/L), avoiding hypoxic stress (Riche & Garling, 2003). DO availability is critical for feed utilization and metabolic activity, and even moderate DO fluctuations can affect appetite and digestion.

Turbidity and TDS: Contrary to expectations, turbidity levels were slightly lower in the 12% group. While Chen & Wang (2018) linked increased feeding to phytoplankton blooms and turbidity, we hypothesize that high activity levels among fish may have minimized sediment resuspension. TDS levels were stable across treatments (250–550 ppm), aligning with (García-Esquinas *et al*., 2019) who recommend this range for optimal ionic balance and osmoregulation.

Conductivity: Conductivity values (~725 µS/cm) were consistent with ideal ranges reported for GIFT culture. Proper conductance ensures mineral balance and supports osmoregulatory processes in freshwater fish (Gomez & Rodriguez, 2021).

Plankton and Turbidity Management: Secchi disc readings (generally within the 25–30 cm range) were acceptable, suggesting balanced phytoplankton density. Excessive plankton growth can lead to decreased sunlight penetration, ammonia accumulation, and stress, requiring active management through water exchange or suspension of fertilization (Chen & Wang, 2018).

Ammonia Toxicity: Ammonia is the primary nitrogenous waste in fish culture and becomes toxic at elevated concentrations. The observed range of 0.002–0.05 mg/L across treatments was within the safety limits recommended by Fujimura & Okada (2007), but care must be taken in higher ration systems where excreted nitrogen can accumulate rapidly (Smith & Brown, 2020; Chen & Wang, 2019).

Implications for sustainable aquaculture

This study provides strong empirical support for using an 8% daily feeding ration in the cultivation of GIFT under tropical, intensive systems. It achieves a balance between maximizing growth and maintaining environmental sustainability. These findings align with the FAO's (2022) guidelines advocating precision feeding strategies to support sustainable intensification in aquaculture.

Moreover, this study offers a science-based framework for local extension services and policy makers in Sri Lanka to develop region-specific feeding protocols that optimize economic returns and reduce environmental risk.

Limitations and future recommendations

While the controlled tank-based setting ensures consistency and accuracy, it does not fully replicate real-world pond dynamics, where variables like natural food availability, predator interactions, and sediment nutrient cycling influence outcomes (Diana *et al*., 1996). Future research should therefore focus on conducting extended trials lasting more than 90 days in semi-intensive and pond-based systems, incorporating cost–benefit analyses to evaluate long-term economic viability. Studies should also explore alternative feed formulations, including plant-based protein sources (Carter & Houlihan, 2001) and biofloc-based systems (Prabu *et al*., 2018), while assessing the long-term health and reproductive performance of GIFT under different feeding regimes.

CONCLUSION

The 8% feeding ration provided the best balance of growth performance, feed utilization, and environmental safety for GIFT under the conditions of this study. The key water quality thresholds identified for optimal growth were a temperature of 28–29 °C, dissolved oxygen above 5.2 mg/L, pH between 6 and 8, total dissolved solids (TDS) of 250–550 ppm, and ammonia levels below 0.05 mg/L. These insights contribute to the development of best-practice feeding strategies in Sri Lanka's expanding aquaculture industry and provide a model for similar tropical regions seeking to intensify production while preserving water quality and fish health.

AUTHOR CONTRIBUTIONS

KV designed the study, performed data analysis, and wrote the manuscript; AG conducted field experimentation and collected data; SP supervised the methodology and reviewed the research design; TL provided academic guidance and critically revised the manuscript.

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