ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2026; 8(1): 162-167
www.agriculturaljournals.com
Received: 19-11-2025
Accepted: 21-12-2025

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Growth performance of genetically improved farmed tilapia (*Oreochromis niloticus*) fed diets containing local and imported fish meals in the Saurashtra region

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DOI: https://www.doi.org/10.33545/2664844X.2026.v8.i1c.1136

Abstract
The present study evaluated the growth performance, feed utilization, and physiological responses of genetically improved farmed tilapia (GIFT; *Oreochromis niloticus*) fed diets containing imported and locally manufactured fish meals in the Saurashtra region of Gujarat. Six iso-nitrogenous experimental diets were formulated with graded inclusion levels (15%, 25%, and 35%) of imported fish meal (IF15, IF25, IF35) or locally produced fish meal (LF15, LF25, LF35) and fed to male GIFT fingerlings (initial weight 5.4 g) for 84 days under controlled tank conditions. Growth performance, feed conversion ratio (FCR), protein efficiency ratio (PER), somatic indices, hematological parameters, metabolic oxygen consumption, and water quality were assessed. Fish fed the IF35 diet exhibited the highest final body weight (99.4 g), daily weight gain (1.07 g day^{-1}), and specific growth rate (4.62% day^{-1}), along with improved Food Conversion Ratio (1.62). Comparable growth and feed efficiency were observed in fish fed LF15 and LF25 diets, indicating effective utilization of locally manufactured fish meal at moderate inclusion levels. Haematocrit values and somatic indices increased with higher fish meal inclusion, while metabolic oxygen consumption remained within acceptable physiological limits. Survival was 100% across all treatments, and water quality parameters remained optimal throughout the experiment. Overall, the results demonstrate that locally manufactured fish meal can partially replace imported fish meal in GIFT tilapia diets without compromising growth performance or physiological health, offering a cost-effective and sustainable alternative for tilapia farming in the Saurashtra region, Gujarat.

Keywords: GIFT tilapia, fish meal substitution, growth performance, sustainable aqua feeds

Introduction
Global aquaculture production reached. Continued expansion of aquaculture is essential to meet the growing demand for fish driven by population growth, rising incomes, and increased preference for nutritionally rich diets (Fry *et al.*, 2018) [6]. Asia dominated global aquaculture production. Rapid sectoral growth has resulted in a substantial increase in demand for aquaculture feeds.
A significant portion of global fish harvest is utilized for fish meal and oil production, which remain critical inputs in aqua feed manufacturing (Hecht and Jones, 2009; Tacon and Metian, 2015) [8, 18]. Fish meal is valued for its high digestibility, balanced essential amino acid profile, fatty acids, vitamins, and trace minerals, making it a key ingredient in feeds for finfish and shrimp (Cho and Kim, 2011) [4]. However, reliance on imported fish meal has increased feed costs in many developing aquaculture regions, raising concerns over economic sustainability (Ng and Chong, 2004; Hishamunda *et al.*, 2009) [9, 14].
Considerable research has explored alternative protein sources to reduce dependence on fish meal, including plant- and animal-based ingredients. Nevertheless, nutritional limitations such as amino acid imbalance and anti-nutritional factors often constrain their complete replacement (Gule and Geremew, 2022) [7]. Consequently, fish meal remains a preferred protein source, particularly for high-value species. The level of fish meal inclusion is species-specific, with carnivorous fish requiring higher protein levels than omnivorous species such as tilapia (Tacon and Metian, 2015) [18].
Tilapia plays a crucial role in both rural and commercial aquaculture systems. Genetically Improved Farmed Tilapia (GIFT) is widely adopted due to its rapid growth, environmental tolerance, and market acceptance (Eknath and Hulata, 2009) [5].

In the Saurashtra region, demand for GIFT has increased substantially; however, high feed costs during fingerling production remain a major constraint. Therefore, the present study evaluates the effects of imported and locally produced fish meals on the growth performance of GIFT fingerlings to identify cost-effective feed formulations.

Materials and Methods

Raw materials

Imported fish meal originating from Indonesia was procured through a commercial supplier, while locally produced fish meal and fish oil were obtained from a domestic manufacturer. The local fish meal was prepared from fish-processing by-products generated by the export-oriented raw fish industry. Soybean meal, coconut poonac, wheat flour, maize grain, wheat bran, dicalcium phosphate (DCP), carboxymethyl cellulose (CMC), DL-methionine, L-lysine, and a vitamin–mineral premix were sourced from certified local feed ingredient suppliers.

Experimental diet formulation

Six experimental diets were formulated to contain graded inclusion levels of imported or locally produced fish meal at 20%, 30%, and 40%, designated as IF15, IF25, IF35 and LF15, LF25, LF35, respectively. Diets were designed to meet the nutritional requirements of genetically improved farmed tilapia (*Oreochromis niloticus*) and were formulated using WinFeed software. Ingredient proportions for each diet are presented in Table 1.

Imported fish meal diets contained 19–38% fish meal, while local fish meal diets incorporated 20–40% locally sourced fish meal. Soybean meal served as the primary plant protein source, with levels adjusted inversely to fish meal inclusion. All diets contained fixed levels of fish oil (1%), vitamin–mineral mixture (1–1.1%), methionine (0.3%), lysine (0.3–0.4%), and DCP (0.5–0.51%).

Feed preparation

All ingredients were finely ground to pass through a 0.5 mm sieve and weighed according to formulation specifications. Dry ingredients were thoroughly mixed to ensure homogeneity, after which water was added to form a uniform dough. The mixture was pelleted using a mechanical pelletizer fitted with a 2 mm die. Pellets were dried in a forced-air dryer at 50 °C for 48 h and subsequently stored in airtight polyethylene bags at approximately 4 °C until use.

Experimental design and feeding management

The feeding trial was conducted for 84 days using male GIFT fingerlings obtained from a government hatchery. The experiment was carried out in 21 concrete tanks (3 m × 1.5 m × 0.5 m) supplied with dechlorinated freshwater and continuous aeration. Each tank was stocked with 20 fish (initial mean weight: 5.4 g), and treatments were arranged in a completely randomized design with three replicates per diet.

Fish in treatments IF15, IF25 and IF35 received imported fish meal–based diets, whereas those in LF15, LF25 and LF35 were fed diets formulated with local fish meal. A commercial tilapia feed was used as the control diet. Fish were hand-fed three times daily at decreasing feeding rates adjusted according to biomass. Uneaten feed and faecal matter were removed by siphoning twice weekly, and evaporative water loss was replenished. Tank walls and bottoms were cleaned regularly to control algal growth.

Water quality monitoring

Water temperature and dissolved oxygen were monitored using a portable dissolved oxygen meter, while pH was measured twice weekly using a digital pH meter. Total ammonia nitrogen was determined weekly using a commercial colorimetric test kit. Water quality parameters were maintained within suitable ranges for tilapia culture throughout the experiment.

Sampling and growth measurements

Fish were starved for 24 h prior to sampling. Body weight, total length, and standard length were recorded at fortnightly intervals. At the start of the trial, representative fish were sampled for baseline whole-body proximate composition. At the end of the experiment, five fish per tank were randomly collected for final biometric measurements and proximate analysis.

Oxygen consumption

Metabolic oxygen consumption was measured at the end of the feeding trial using a static respirometry system. Four fish per treatment were placed in sealed respirometer chambers, and dissolved oxygen depletion was recorded continuously for 14 min using a dissolved oxygen meter. Oxygen consumption was calculated on a body-weight basis following standard procedures.

Hematological analysis

Blood samples were collected from five randomly selected fish per treatment after a 24 hrs fasting period. Fish were anesthetized with tricaine methanesulfonate (MS-222; 0.3 g L^{-1}), and blood was drawn from the caudal vein into EDTA coated microtubes. Packed cell volume was determined by centrifugation of heparinized capillary tubes at 6000 rpm for 30 min.

Proximate composition analysis

Proximate composition of fish meals, experimental diets, and whole body fish samples was determined following standard AOAC procedures (Horwitz, 2010) [10], including moisture, crude protein, crude lipid, crude fiber, and ash content.

Growth performance and nutrient utilization

Growth performance and feed utilization were evaluated using final body weight, daily weight gain, specific growth rate, feed conversion ratio, protein efficiency ratio, protein retention efficiency, hepato-somatic index, viscero-somatic index, survival rate, haematocrit value, and metabolic oxygen consumption. Calculations were performed using standard equations.

Specific Growth Rate (SGR)

SGR % = [(ln final body weight - ln Initial body weight) × 100 /days]

Feed Conversion Efficiency (FCR)

FCR =Total feed Intake (g) / Total live weight gain (g)

Protein Retention Efficiency (PRE)
PRE = [Total final body weight × Final carcass protein - Total initial body weight x Initial carcass protein) / Total protein intake] ×100

Survival rate (s)
(Final number of fish / Initial number of fish) × 100

Viscero somatic index (VSI)
VSI% = [Final visceral weight (g) / Final body weight (g)] ×100

Hepato-somatic index (HSI)
HSI % = 100× [Final liver weight (g) / Final body weight (g)]

Individual metabolic oxygen consumption (MO_2)
MO_2 = (O_2 consumed / time) × Volume of the water (L) / Body mass of the fish (Kg)

Statistical analysis
Data were expressed as mean±standard deviation. Statistical analyses were conducted using Minitab software (version 17). Normality and homogeneity of variance were assessed prior to one-way ANOVA. Differences among dietary treatments were identified using Tukey's multiple comparison test at $P < 0.05$. Proximate composition of imported and local fish meals was compared using Student's *t*-test ($P < 0.05$).

Results

Proximate composition of fish meals and experimental diets: The proximate composition of imported and locally produced fish meals and the formulated experimental diets is presented in Tables 2. Diet moisture content varied across treatments, with values ranging from 8.6% in IF35 to 13.8% in LF25. Crude protein levels increased with increasing fish meal inclusion and ranged from 34.9% (LF15) to 38.1% (IF35). Imported fish meal based diets consistently exhibited higher crude protein and energy content than their locally formulated counterparts.
Crude lipid content ranged from 7.4% in IF15 to 9.6% in IF35, while local fish meal diets showed lipid levels between 8.1% and 8.7%. Crude fibre content remained below 6.5% in all experimental diets, with the lowest value observed in IF35 (3.3%) and the highest in LF25 (6.2%). Ash content increased with increasing fish meal inclusion, reaching maximum values in IF35 (12.9%) and LF35 (12.6%). Gross energy content ranged from 3680 kcal kg^{-1} in IF15 to 4185 kcal kg^{-1} in IF35, whereas local fish meal diets showed comparatively lower energy values (3700–3890 kcal kg^{-1}).

Growth performance, feed intake, and feed utilization
No mortality was recorded in any treatment or control group, resulting in 100% survival throughout the 84-day feeding trial (Table 4). Mean daily feed intake varied among treatments, with the highest intake recorded in IF35 (1.94 g $fish^{-1}$ day^{-1}), and followed by LF15 (1.91 g $fish^{-1}$ day^{-1}) and IF25 (1.88 g $fish^{-1}$ day^{-1}). The lowest feed intake was observed in the control group (1.34 g $fish^{-1}$ day^{-1}).
Final body weight differed among dietary treatments. Fish fed IF35 attained the highest final weight (99.4 g), followed closely by LF15 (97.9 g) and IF25 (91.8 g), whereas the lowest final weight was recorded in the control group (85.2 g). Correspondingly, daily weight gain ranged from 0.86 g in IF15 to 1.07 g in IF35. Specific growth rate followed a similar trend, with the highest SGR recorded in IF35 (4.62% day^{-1}), followed by LF15 (4.59% day^{-1}), while the lowest SGR was observed in IF15 (4.33% day^{-1}).
Feed conversion ratio improved with increasing fish meal inclusion, with the most efficient FCR observed in IF35 (1.62), followed by LF15 (1.64). The highest FCR among experimental diets was recorded in IF15 (1.83), whereas the control diet showed the lowest FCR (1.36). Protein efficiency ratio ranged from 1.55 in IF15 to 1.69 in LF15, while the control diet exhibited the highest PER (3.0).

Somatic indices, haematology, and oxygen consumption
Hepato-somatic index values increased with higher fish meal inclusion, with the highest HSI recorded in IF35 (2.04%) and the lowest in IF15 (1.41%). Viscero-somatic index varied among treatments, with the highest VSI observed in IF35 (8.7%) and LF15 (7.9%), while the lowest value was recorded in the control group (5.8%).
Haematocrit values ranged from 31% to 42% among experimental treatments. The highest haematocrit value was observed in IF35 (42%), followed by LF15 (40%), whereas the control group showed the lowest value (30%). Metabolic oxygen consumption varied from 348 mg kg^{-1} h^{-1} in IF15 to 431 mg kg^{-1} h^{-1} in IF35. Fish fed local fish meal diets showed intermediate oxygen consumption rates, while the lowest value was observed in the control group (312 mg kg^{-1} h^{-1}).

Water quality parameters
Water quality parameters remained stable throughout the experimental period and did not differ among treatments (Table 5). All measured parameters remained within acceptable limits for tilapia culture, ensuring that observed differences in growth and feed utilization were attributable to dietary treatments rather than environmental variation.

Discussion

Feed cost remains the dominant expenditure in aquaculture production systems, accounting for a major proportion of operational costs, particularly in tilapia culture (Hishamunda *et al.*, 2009; Tacon and Metian, 2008) [9, 18]. Fish meal continues to be one of the most expensive feed ingredients due to increasing global demand and limited supply (Ng and Chong, 2004; Chiu *et al.*, 2013; Luhur *et al.*, 2021) [3, 11, 14]. In this context, evaluating locally manufactured fish meal as a partial or complete replacement for imported fish meal is critical for improving economic sustainability in tilapia farming.
In the present study, imported and locally manufactured fish meal–based diets differed in proximate composition, particularly in crude protein, lipid, ash, and energy content. Diets formulated with imported fish meal exhibited higher protein (up to 38.1%) and energy levels (up to 4185 kcal kg^{-1}) compared with local fish meal–based diets. Variations in nutrient composition are largely attributable to differences in raw material sources used for fish meal production, as reported previously (Hecht and Jones, 2009; Chiu *et al.*, 2013; Ahmad and Ibrahim, 2016) [2, 3, 8]. Locally manufactured fish meal in this study was derived primarily from processing by-products, which typically contain higher ash and lower lipid fractions due to the inclusion of bones,

skin, and viscera (Tacon and Metian, 2008; Abdur *et al*., 2017) [1, 18].

The protein levels of all experimental diets (34.9–38.1%) met or exceeded the dietary protein requirement recommended for tilapia fingerlings (30–35%) (Ahmad and Ibrahim, 2016; Zeng *et al*., 2021) [2, 19]. Growth performance results indicated that increasing fish meal inclusion enhanced feed intake, weight gain, and specific growth rate. Fish fed IF35 exhibited the highest final body weight, daily weight gain, and SGR, confirming the positive role of higher dietary protein and lipid availability in promoting growth. Similar trends have been reported in tilapia and other omnivorous fish species when dietary protein and energy levels are optimized (Chiu *et al*., 2013; Mosha *et al*., 2020) [3, 12].

Notably, fish fed LF15 and LF25 diets achieved growth performance comparable to those fed higher levels of imported fish meal, indicating that locally manufactured fish meal can effectively support tilapia growth when included at appropriate levels. This finding supports previous reports suggesting that local fish meals with moderate protein levels are suitable for omnivorous species such as tilapia, carp, and catfish (Luhur *et al*., 2021) [11]. Although growth was marginally lower in LF diets compared to IF35, the differences were not substantial enough to negate their practical applicability under cost-sensitive farming conditions.

Feed utilization indices further supported these observations. Lower FCR values were recorded in IF35 and LF15 diets, reflecting improved feed efficiency at higher fish meal inclusion levels. While the control diet showed the lowest FCR and highest PER, this result must be interpreted cautiously, as FCR alone does not account for differences in feed composition, protein quality, or carcass nutrient deposition (Fry *et al*., 2018) [6]. The PER values observed in experimental diets were within the range reported for tilapia-based feeds (Ogunji *et al*., 2008) [16], confirming adequate protein utilization across treatments.

Somatic indices responded positively to increased dietary fish meal levels. Higher VSI and HSI values in IF35 and LF15 diets suggest enhanced nutrient assimilation and lipid deposition, consistent with earlier findings in tilapia fed protein- and energy-rich diets (Zeng *et al*., 2021) [19]. The HSI values observed in the present study fall within acceptable physiological ranges and indicate no adverse effects on liver health. Lower VSI and HSI values in the control diet may reflect reduced lipid availability and visceral fat deposition.

Hematological parameters further supported the nutritional adequacy of fish meal–based diets. Elevated haematocrit values in IF35 and LF15 treatments indicate improved physiological condition and oxygen-carrying capacity, which are commonly associated with enhanced growth and metabolic activity (Ogunji *et al*., 2008) [16]. Oxygen consumption rates did not differ significantly among treatments, suggesting that dietary fish meal source did not impose additional metabolic stress. However, slightly higher oxygen consumption observed in faster-growing groups may be attributed to increased metabolic demand associated with enhanced growth performance.

Water quality parameters remained within optimal ranges for tilapia culture throughout the experimental period and did not differ among treatments, confirming that dietary treatments had no adverse effects on the rearing environment (Ngugi *et al*., 2007; Mosha *et al*., 2020) [12, 15]. This further strengthens the conclusion that observed differences in growth and feed utilization were driven primarily by dietary composition rather than environmental variation.

Overall, the findings of the present study demonstrate that locally manufactured fish meal can effectively replace imported fish meal in diets for GIFT tilapia fingerlings without compromising growth performance, feed utilization, or physiological health. Given the substantially lower cost of locally produced fish meal, its inclusion offers a practical strategy for reducing feed costs and improving the economic sustainability of tilapia farming. Further investigations under commercial farm conditions and across different life stages are recommended to validate the broader applicability of locally manufactured fish meal in aqua feed formulations.

Table 1: Ingredient composition of experimental diets (g/100 g dry matter)

Ingredient	IF15	IF25	IF35	LF15	LF25	LF35
Fish meal (imported)	19	28	38	0	0	0
Fish meal (local)	0	0	0	20	30	40
Soybean meal	40.3	24.92	11.49	42.55	31.18	18.9
Coconut poonac	6	7	7	5.35	5.72	6
Wheat flour	20.1	20	22	19	20	20.5
Corn grain	5.5	5.88	7	5	5	5.5
Fish oil	1	1	1	1	1	1
Vitamin–mineral mix	1	1	1.1	1	1	1
Methionine	0.3	0.3	0.3	0.3	0.3	0.3
Lysine	0.3	0.3	0.4	0.3	0.3	0.3
DCP	0.5	0.5	0.51	0.5	0.5	0.5
Wheat bran	6	5.1	5.1	5	5	6

Note: IF, imported fish meal–incorporated diets; LF, locally manufactured fish meal–incorporated diets.

Table 2: Proximate composition of experimental diets (%)

Parameter	IF15	IF25	IF35	LF15	LF25	LF35
Moisture	10.4	9.2	8.6	11.3	13.8	13.1
Crude protein	35.2	36.6	38.1	34.9	35.7	36.9
Crude lipid	7.4	8.9	9.6	8.7	8.3	8.1
Crude fibre	4.8	4.4	3.3	5.1	6.2	3.8
Ash	8.1	10.6	12.9	9.4	11.8	12.6
Energy (kcal/kg)	3680	4025	4185	3890	3745	3700

Note: IF, imported fish meal–incorporated diets; LF, locally manufactured fish meal–incorporated diets.

Table 3: Growth performance of GIFT tilapia (84-day trial)

Parameter	IF15	IF25	IF35	LF15	LF25	LF35	Control
Feed intake (g/fish/day)	1.76	1.88	1.94	1.91	1.86	1.81	1.34
FCR	1.83	1.71	1.62	1.64	1.73	1.79	1.36
PER	1.55	1.61	1.66	1.69	1.6	1.56	3
HSI (%)	1.41	1.69	2.04	1.88	1.56	1.49	1.53
VSI (%)	6.5	7.3	8.7	7.9	7.2	6.7	5.8
Hematocrit (%)	31	36	42	40	38	34	30
Oxygen consumption (mg kg^{-1} h^{-1})	348	374	431	418	370	355	312

Note: IF, imported fish meal–incorporated diets; LF, locally manufactured fish meal–incorporated diets.

Table 4: Feed utilization and physiological indices

Parameter	IF15	IF25	IF35	LF15	LF25	LF35	Control
Initial weight (g)	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Final weight (g)	82.6	91.8	99.4	97.9	92.1	88.3	85.2
Daily weight gain (g)	0.86	0.98	1.07	1.05	0.99	0.94	0.89
SGR (%/day)	4.33	4.48	4.62	4.59	4.46	4.39	4.36
Survival (%)	100	100	100	100	100	100	100

Note: IF, imported fish meal–incorporated diets; LF, locally manufactured fish meal–incorporated diets.

Table 5: Water quality parameters

Treatment	Temperature (°C)	Dissolved oxygen (mg L^{-1})	pH	Ammonia (mg L^{-1})	Total alkalinity (mg L^{-1} as $CaCO_3$)
IF15	25.8±0.42	6.3±0.21	8.1±0.06	< 0.02	118.4±3.6
IF25	26.0±0.38	6.4±0.18	8.2±0.05	< 0.02	121.7±4.2
IF35	26.2±0.41	6.5±0.22	8.2±0.04	< 0.02	124.9±3.1
LF15	26.1±0.39	6.4±0.19	8.2±0.05	< 0.02	122.3±3.8
LF25	25.9±0.36	6.3±0.20	8.1±0.04	< 0.02	119.6±4.0
LF35	26.3±0.44	6.6±0.25	8.3±0.06	< 0.02	126.8±4.5
Control	26.0±0.40	6.4±0.23	8.2±0.03	< 0.02	120.5±2.9

Note: IF, imported fish meal–incorporated diets; LF, locally manufactured fish meal–incorporated diets.

Conclusions

The present study demonstrates that both imported and locally manufactured fish meal–based diets can effectively support the growth, feed utilization, and physiological health of GIFT tilapia fingerlings when formulated to meet their nutritional requirements. Diets containing higher inclusion levels of imported fish meal produced the highest growth and feed efficiency; however, comparable performance was achieved with moderate inclusion levels of locally manufactured fish meal.

Despite lower protein and energy content, locally manufactured fish meal supported satisfactory growth, feed conversion, somatic indices, and hematological responses, without adversely affecting water quality or metabolic activity. These findings indicate that locally manufactured fish meal is a viable and nutritionally adequate alternative to imported fish meal in diets for GIFT tilapia fingerlings.

The use of cost-effective, locally available fish meal has the potential to reduce feed production costs and enhance the economic sustainability of tilapia farming in the Saurashtra region. Further validation under field conditions and across different life stages of tilapia is recommended to confirm its broader applicability in commercial aquaculture.

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