Dietary Spirulina Meal Supplementation in Rice Bran-Based Diets Improves Growth Performance and Feed Utilization of Nile Tilapia (*Oreochromis niloticus*)

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Abstract
A feeding trial was conducted to evaluate the effects of rice bran-based diets containing spirulina meal and black-chin tilapia (*Sarotherodon melanotheron*) fish meal on the growth performance, feed utilization, and survival of Nile tilapia (*Oreochromis niloticus*) fry and fingerlings. Four dietary treatments were prepared: T1, 75% rice bran + 25% *S. melanotheron* fish meal; T2, 75% rice bran + 12.5% *S. melanotheron* fish meal + 12.5% spirulina meal; T3, 75% rice bran + 25% spirulina meal; and T4, commercial feed. The diets were randomly assigned to triplicate tanks, with 20 fry stocked per tank. Growth indices, feed conversion ratio, survival rate, diet proximate composition, and water quality were determined. Dietary treatment significantly affected growth performance and feed utilization ($P \leq 0.05$). The commercial diet (T4) produced the highest mean weight gain, but this was statistically comparable with the rice bran diet supplemented with 25% spirulina meal (T3). Daily growth rate was highest in T3, followed closely by T4, whereas lower growth responses were observed in diets containing *S. melanotheron* fish meal alone or in combination with spirulina. Survival remained high across treatments, and water temperature, pH, and dissolved oxygen remained relatively stable. Results indicate that rice bran diet supplementation with 25% spirulina meal can support Nile tilapia growth comparable to commercial feed under the conditions of this study. Spirulina meal may therefore be considered a practical alternative ingredient for low-cost Nile tilapia fry and fingerling feeds.

Keywords: Aquafeed, Spirulina meal, Nile tilapia, rice bran, *Sarotherodon melanotheron*

1. Introduction

Aquaculture has become a central component of global aquatic food production as capture fisheries face biological, environmental, and climatic constraints. In 2022, aquaculture production of aquatic animals surpassed capture fisheries for the first time, marking a major transition in the global seafood supply system (FAO, 2024). This expansion has increased dependence on formulated feeds, particularly in semi-intensive and intensive systems where feed quality directly influences growth, survival, feed conversion, and profitability. However, feeds remain among the largest production costs in aquaculture, and the increasing demand for aquafeeds has intensified concerns over ingredient cost, availability, and sustainability (FAO, 2024; Macusi et al., 2023).

Fish meal remains a preferred protein source in aquafeeds because of its high protein content, balanced essential amino acid profile, digestibility, palatability, and micronutrient contribution. (Rahman et al., 2022; Macusi et al., 2023). Nevertheless, its use is constrained by price volatility, limited supply, and dependence on finite marine resources, making the search for sustainable and cost-effective protein alternatives a priority in aquaculture nutrition. Plant meals, animal by-products, insect meals, microbial biomass, algal meals, and other unconventional ingredients have been evaluated as partial substitutes for fish meal; but their successful use depends on nutritional quality, digestibility, palatability, processing requirements, availability, cost, and species-specific performance responses (Macusi et al., 2023). Although aquafeed sustainability is a global concern, its consequences are particularly evident in aquaculture-producing countries, where feed cost and ingredient availability directly affect the profitability and resilience of small- and medium-scale fish farming.

In the Philippines, aquaculture remains a major contributor to national fisheries production and rural livelihoods. In 2024, total fisheries production was estimated at approximately 4.05 million metric tons, of which aquaculture contributed about 2.22 million metric tons, equivalent to 54.9% of total fisheries output (Philippine Statistics Authority [PSA], 2025). Nile tilapia (*Oreochromis niloticus*) is among the country's important cultured finfish because of its rapid growth, environmental tolerance, consumer acceptability, and suitability for pond, cage, and tank-based culture systems (SEAFDEC/AQD, 2022). However, feed remains a major constraint in tilapia farming, particularly during the fry and fingerling stages, when fish require nutritionally dense, digestible, and palatable diets to support rapid growth, size uniformity, feed efficiency, and survival.

Locally available feed ingredients may help reduce feed cost and improve the practicality of farm-level feed formulation. Rice bran is widely available in rice-producing countries and is commonly used in low-cost aquaculture feeds because of its availability and energy contribution. However, its use as a major ingredient is limited by relatively high fiber content, variable quality, susceptibility to rancidity, and possible constraints in nutrient utilization (FAO, n.d.). Thus, rice bran is better evaluated in combination with protein-rich and functional ingredients that can improve the nutritional profile of practical diets for early-stage tilapia.

Spirulina, commonly referred to as *Spirulina* but taxonomically associated with the cyanobacterial genus *Arthrospira*, has received increasing attention as an alternative protein and functional ingredient in aquafeeds. It

contains protein, essential amino acids, vitamins, minerals, pigments, and bioactive compounds such as phycocyanin, carotenoids, and polysaccharides, which support its potential use in fish diets (Spínola et al., 2024). In Nile tilapia, Soma et al. (2024) reported that spirulina protein could replace up to 30% of fish meal protein in juvenile diets without compromising growth performance. However, most available studies have focused on juvenile or grow-out stages, and less information is available on the use of locally produced spirulina meal in simple rice bran-based diets for fry and early fingerlings.

Another underexplored protein source is black-chin tilapia (*Sarotherodon melanotheron*), a euryhaline cichlid reported as an introduced and invasive species in Philippine waters. Ordoñez et al. (2015) documented the occurrence of *S. melanotheron* in Manila Bay and Hagonoy, Bulacan, indicating its establishment outside its native range and suggesting possible range expansion in brackishwater systems. SEAFDEC/AQD (2022) also reported that black-chin tilapia, locally known as "tilapyang arroyo," "Gloria," or "molmol," may occur abundantly in natural waters and sometimes as invasive stocks in aquaculture ponds, where it could disturb ecological balance and biodiversity. In Pangasinan, field observations from tilapia culture areas indicate that black-chin tilapia occurs as a nuisance or invasive fish associated with cultured tilapia, where it may compete for food and space, interfere with culture management, and reduce production efficiency. Because the species is generally low-valued and may contribute to production problems when it proliferates in culture systems, converting *S. melanotheron* biomass into fish meal may provide a dual benefit of reducing nuisance fish biomass while generating an alternative animal protein ingredient for aquafeeds.

However, despite its local availability and potential value as a feed ingredient, information on the use of *S. melanotheron* fish meal in Nile tilapia fry and fingerling diets remains scarce, particularly in rice bran-based formulations supplemented with spirulina meal. Thus, evaluating these ingredients in practical feed formulations is important for determining their potential contribution to low-cost and sustainable tilapia fry production.

Therefore, this study evaluated the growth performance, feed utilization, and survival of Nile tilapia fry fed rice bran-based diets containing spirulina meal, *S. melanotheron* fish meal, or their combination, using commercial fry mash as the reference diet. By evaluating locally available spirulina meal and *S. melanotheron* fish meal in rice bran-based diets, this study contributes to the broader effort to develop practical, low-cost, and sustainable aquafeed strategies for early-stage tilapia production.

2. Methodology

2.1 Preparation of Spirulina Biomass

Spirulina biomass used in the experimental diets was produced following the open-pond culture and drying protocol previously described by Caguioa (2023). Briefly, spirulina was cultured in freshwater open ponds supplemented with carbonate and chloride salts and alternative nutrient sources containing nitrogen, phosphorus, and potassium. The culture was mechanically mixed using a paddle wheel, harvested after approximately one month by filtration through fine cheesecloth, and dried using a thermo-convection dryer for 3–5 days. The dried biomass was ground into spirulina meal and incorporated into the formulated diets.

2.2 Experimental Diets and Treatments

The feeding trial evaluated the growth performance and feed utilization of Nile tilapia (*Oreochromis niloticus*) fry fed with diets containing rice bran, black-chin tilapia (*Sarotherodon melanotheron*) fish meal, and spirulina meal. Four dietary treatments were used: three formulated diets and one commercial fry mash as the control. The dietary treatments were as follows: T1, 75% rice bran and 25% *S. melanotheron* fish meal; T2, 75% rice bran, 12.5% *S. melanotheron* fish meal, and 12.5% spirulina meal; T3, 75% rice bran and 25% spirulina meal; and T4, 100% commercial fry mash.

The experiment was conducted for 60 days using three replicates per treatment. Twenty fry were stocked per experimental unit and assigned to treatments following a completely randomized design.

2.3 Culture Tank Preparation

Experimental tanks were cleaned thoroughly prior to the trial. A soil substrate layer of approximately 2.5 cm was placed at the bottom of each tank to simulate pond-bottom conditions. Tanks were filled with water to a depth of 46 cm and allowed to stabilize prior to stocking.

2.4 Preparation of *Sarotherodon melanotheron* Fish Meal

Black-chin tilapia (*S. melanotheron*) collected from brackishwater ponds were used as the animal protein source in the formulated diets. Approximately 5 kg of fish were cleaned and boiled until cooked. The flesh was separated from the remaining body parts, oven-dried, and ground into fine particles to produce fish meal. The prepared fish meal was kept in sealed, dry containers until feed preparation.

2.5 Diet Preparation

Formulated diets were prepared on a weight-to-weight basis according to their respective treatment formulations. Ingredients were weighed using a digital balance and thoroughly mixed to obtain a homogeneous mash. Diet T1 was prepared by mixing 75 g rice bran with 25 g *S. melanotheron* fish meal. Diet T2 consisted of 75 g rice bran, 12.5 g *S. melanotheron* fish meal, and 12.5 g spirulina meal. Diet T3 consisted of 75 g rice bran and 25 g spirulina meal. The commercial fry mash used for T4 was purchased from the local market and used without further processing.

All diets were stored in clean, sealed, and properly labeled containers under dry conditions until use.

2.6 Experimental Fish and Acclimation

Nile tilapia broodstock were maintained in an earthen pond at a male-to-female ratio of 1:3 to obtain fry for the feeding trial. Newly hatched fry were collected after two weeks and transported to the aquaculture laboratory. Prior to stocking, fry were acclimated in glass aquaria for three days under laboratory conditions.

At the end of acclimation, fry was randomly selected for initial measurements. Initial body weight was determined using a digital balance, and total length was measured using a ruler. Fish were then randomly distributed into the experimental tanks at a stocking density of 20 fry per tank.

2.7 Feeding Trial and Husbandry

The feeding trial was conducted for 60 days. Fish were hand-fed twice daily at 09:00 and 15:00 h. During the first 30 days, feed was provided at 20% of the estimated fish biomass. The feeding rate was reduced to 10% of biomass during the remaining 30 days. Feed allocations were adjusted based on periodic biomass estimates obtained during sampling.

A feeding ring was installed in each tank to localize feed delivery and reduce feed dispersion. Fish were observed daily during feeding to monitor feeding response and general condition.

2.8 Water Quality Monitoring

Water quality was monitored daily throughout the experimental period. Dissolved oxygen was measured using a YSI 55 dissolved oxygen meter, pH using a digital pH meter, and water temperature using a laboratory thermometer. Measurements were taken at approximately 08:00 h to standardize sampling time across treatments.

2.9 Growth Performance and Feed Utilization

Growth performance and feed utilization were evaluated using final body weight, weight gain, length gain, specific growth rate, daily growth rate, feed conversion ratio, and survival rate. Fish were sampled weekly during the 60-day culture period.

Parameters are calculated as:

Weight Gain (g) = Final Weight (g) – Initial Weight (g)
Length Gain (cm) = Final Length (cm) – Initial Length (cm)

$$\text{Specific Growth Rate (\%)} = \frac{\ln \text{FBW} - \ln \text{IBW}}{D} \times 100$$

Where:

FBW = final body weight (g) or weight at harvest.
IBW = initial body weight (g) or weight at stocking
D = number of days of rearing/culture
ln = natural logarithm

$$\text{Daily Growth Rate (\%)} = \frac{\text{Weight Gain}}{\text{Culture Days}}$$

$$\text{Feed Conversion Ratio (FCR)} = \frac{\text{Amount of feed given}}{\text{Total fish weight gain}}$$

$$\text{Survival Rate (\%)} = \frac{\text{Number of fish at the end of the experiment x}}{\text{Number of fish stock}} 100$$

3.0 Statistical Analysis

Data were analyzed using the Statistical Tool for Agricultural Research (STAR). Treatment effects were evaluated by one-way analysis of variance at a significance level of ($P \leq 0.05$). When significant treatment effects were detected, treatment means were separated using the appropriate multiple-comparison procedure. Results are presented as mean values of three replicate tanks per treatment.

3. Results

Growth Performance

The present study showed that Nile tilapia (*Oreochromis niloticus*) fry fed with the diet containing 75% rice bran and 25% Spirulina obtained the highest numerical mean weight gain among the treatments. Treatment 4 recorded a mean of 1.01 g, followed by Treatment 3, Treatment 1, and Treatment 2 with 0.77 g, 0.69 g, and 0.64 g, respectively. A similar trend was observed in the total weight gain of Nile tilapia fingerling fed with rice bran meal supplemented with Spirulina and Sarotherodon fish meal , where Treatment 4 obtained the highest value of 28.12 g, followed by Treatment 3 with 16.37 g and Treatment 2 with 15.36 g. These results suggest that 25% *Spirulina* supplementation in a rice bran-based diet may improve the growth performance of Nile tilapia.

However, analysis of variance showed no significant differences among the treatment means. Thus, the higher growth observed in Treatment 4 should be interpreted as a numerical advantage rather than a statistically superior response. The result indicates that the 25% Spirulina-supplemented rice bran diet was statistically comparable ($p<0.05$) with the commercial diet and other experimental diets. This comparability is important because it

suggests that a rice bran-based diet supplemented with Spirulina may serve as a potential alternative feed formulation for Nile tilapia, particularly where low-cost and locally available feed ingredients are preferred.

Daily Growth Rate

Table 1 presents the daily growth rate of Nile tilapia fry fed Spirulina-supplemented diets and a commercial diet over 60- and 120-day culture periods. After 60 days, fry fed the diet containing 75% rice bran and 25% Spirulina (Treatment 4) recorded the highest daily growth rate, with a mean value of 0.0168 g day^{-1}. This was followed by Treatment 3 and the commercial diet (Treatment 1), both at 0.013 g day^{-1}, and Treatment 2 at 0.012 g day^{-1}. However, analysis of variance showed no significant differences among treatments, indicating comparable growth performance across diets during the first 60 days.

After 120 days, Treatment 4 again recorded the highest daily growth rate, followed closely by the commercial diet. Lower values were observed in Treatments 3 and 2. At this culture period, daily growth rate differed significantly among treatments ($p < 0.05$). Pairwise comparison showed that Treatment 4 and the commercial diet were statistically comparable, while both produced significantly higher daily growth rates than Treatments 2 and 3. These results indicate that the diet containing 75% rice bran and 25% Spirulina supported daily growth equivalent to the commercial diet and superior to diets containing Sarotherodon fish meal.

Specific Growth Rate

Specific growth rate (SGR) varied between developmental stages in response to the dietary treatments (Table 1). In fry, SGR ranged from 6.69% to 7.68%, with the highest numerical value recorded in fish fed the diet containing 75% rice bran and 25% Spirulina. However, no significant differences were detected among treatments, indicating comparable relative growth across dietary groups during the fry stage.

In fingerlings, SGR was significantly affected by dietary treatment ($p < 0.05$). Fish fed the diet containing 75% rice bran and 25% Spirulina recorded the highest SGR, which was statistically comparable to that of fish fed the commercial diet. Both groups showed significantly higher SGR than fish fed 75% rice bran with 25% Sarotherodon fish meal and those fed 75% rice bran with combined 12.5% Sarotherodon fish meal and 12.5% Spirulina. These results indicate that 25% Spirulina inclusion in a rice bran-based diet supported relative growth in Nile tilapia fingerlings at a level equivalent to commercial feed and superior to the other rice bran-based formulations.

Mean Length Gain

Mean length gain varied according to developmental stage and dietary treatment (Table 1). In fry, mean length gain ranged from 2.54 to 2.71 cm, with the highest numerical value recorded in fish fed the diet containing 75% rice bran and 25% Spirulina. However, no significant differences were observed among treatments, indicating that all diets supported comparable length increment during the fry stage.

In fingerlings, dietary treatment significantly affected mean length gain. Fish fed the commercial diet and those fed the diet containing 75% rice bran and 25% Spirulina recorded the highest mean length gain, both at 5.52 cm, and were statistically comparable. These values were significantly higher than those recorded in fish fed 75% rice bran with 25% Sarotherodon fish meal and 75% rice bran with combined 12.5% Sarotherodon fish meal and 12.5% Spirulina. These results indicate that 25% Spirulina inclusion in a rice bran-based diet supported linear growth in Nile tilapia fingerlings at a level equivalent to commercial feed and superior to the Sarotherodon fish meal-based formulations.

Food Conversion Ratio

Food conversion ratio (FCR) was used as an indicator of feed utilization efficiency in Nile tilapia fry and fingerlings fed the experimental diets (Table 1). After 60 days, fry fed with diet containing 75% rice bran and 25% Spirulina (Treatment 4) and the diet containing 75% rice bran, 12.5% Sarotherodon fish meal, and 12.5% Spirulina (Treatment 3) showed the lowest FCR values, at 0.81 and 0.82, respectively. Higher FCR values were observed in the commercial diet (Treatment 1) and the diet containing 75% rice bran and 25% Sarotherodon fish meal (Treatment 2), with mean values of 1.20 and 1.14, respectively. However, analysis of variance showed no significant differences among treatments ($p > 0.05$), indicating comparable feed utilization efficiency during the fry stage.

In fingerlings, FCR differed significantly among treatments ($p < 0.05$). Fish fed the diet containing 75% rice bran and 25% Spirulina recorded the lowest FCR, followed by those fed the commercial diet. These two treatments were statistically comparable and showed significantly better FCR than the diets containing 75% rice bran with 25% Sarotherodon fish meal and 75% rice bran with combined 12.5% Sarotherodon fish meal and 12.5% Spirulina. These results indicate that 25% Spirulina inclusion in a rice bran-based diet improved feed utilization efficiency in Nile tilapia fingerlings to a level comparable with the commercial diet and superior to the Sarotherodon fish meal-based formulations.

Survival Rate

In terms of the percentage survival rate of Nile tilapia Israel Strain fry fed with diets containing Spirulina and Commercial Feeds for 60 days culture period, result showed that the highest percentage survival rate of 91.67% was observed in Treatment 4, 86.67% for Treatment 3, 85.00% for Treatment 2 and 83.33% for Treatment 1. Analysis of variance, however, failed to show any significant differences ($p>.05$) among four treatment means. However, the results indicate that there is the same survival rate of Nile Tilapia fry fed with rice bran meal with 25% inclusion of Spirulina diet with fry that were fed with commercial diet. The protein found in rice bran and of the 60% algal crude protein is sufficiently comparable to the complete array of amino acids present in the commercial diet.

Table 1. Weight Gain, Daily Growth Rate, Specific Growth Rate, Mean Length Gain, Food Conversion Ration, and Survival Rate of Fry and Fingerlings of Nile Tilapia Israel Strain fed with dietary Spirulina Rice bran Meal

TREATMENTS	Weight Gain (g)		Daily Growth Rate (%)		Specific Growth Rate (%)		Mean Length Gain (cm)		Food Conversion Ratio		Survival Rate (%)	
	Fry	Fingerlings	Fry	Fingerlings	Fry	Fingerlings	Fry	Fingerlings	Fry	Fingerlings	Fry	Fingerlings
T1 Commercial Feed	0.69 a	28.12 a	0.012a	0.23 a	7.0 a	1.57 a	2.57 a	5.52 a	1.20 a	3.03 a	91.67a	82 a
T2- 75% Rice Bran + 25% Sarotherodon Fish Meal	0.64 a	15.36 b	0.011a	0.13 b	6.69 a	1.17 b	2.54 a	4.12 b	1.14 a	4.06 b	83.33a	85 a
T3- 75% Rice Bran + 12.5% Sarotherodon Fish Meal + 12.5% Spirulina	0.79 a	16.37 b	0.013a	0.14 b	7.15 a	1.21 b	2.58 a	4.1 8b	0.82 a	4.08 b	85.00a	83 b
T4- 75% Rice Bran + 25% Spirulina	1.01 a	28.02 a	0.017a	0.24a	7.68 a	1.58 a	2.71 a	5.52 a	0.81 a	2.94 a	86.67a	82 a

Note: Means having the same letter are not significantly different at 5% level of significance using LSD

Proximate Analysis of the Experimental Diets

The proximate composition of the experimental diets is presented in Table 2. Crude protein was significantly higher in the commercial diet, T1, than in the rice bran-based diets, which were statistically comparable. Moisture content was highest in T3, while T1 and T4 recorded the lowest values. Crude fat differed significantly among treatments, with T4, 75% rice bran + 25% *Spirulina*, having the highest value and T1 the lowest.

Crude fiber did not differ significantly among treatments, indicating comparable fiber levels across diets. Dry matter and ash contents were significantly higher in T1 and T4 than in T2 and T3. Phosphorus content, analyzed only in the formulated diets, showed no significant variation. Overall, T4 exhibited the most favorable proximate profile among the formulated diets, particularly in terms of crude fat, dry matter, and ash contents, despite its lower crude protein level than the commercial diet.

Table 2. Proximate Analysis of Experimental Diets Used

TREATMENTS	NUTRIENTS (%)						
	Crude Protein	Moisture Content	Crude Fat	Crude Fiber	Dry Matter	Ash	Phosphorous
T1 - Commercial Feed	27 a	12 c	5 d	8 a	88 a	12 a	-*
T2 - 75% Rice Bran + 25 % *Sarotherodon* Fish Meal	24.5 b	14.1 b	11.5 c	3.8 a	85. 9 b	8.1 b	1.8 a
T3 - 75% Rice Bran + 12.5% Spirulina + 12.5% *Sarotherodon* Fish Meal	22.5 b	16.7 a	12.4 b	3.7 a	83.3 c	8.4 b	1.5 a
T4 - 75% Rice Bran + 25% Spirulina	23.0 b	12.5 c	14.2 a	4.0 a	87.5 a	10.0 a	1.3 a

Note: Means having the same letter are not significantly different at 5% level of significance using LSD
** Phosphorus value for the commercial feed was not available from the manufacturer's guaranteed analysis.*

Physico-Chemical Parameters

The mean physico-chemical parameters of the culture area are shown in Table 3. Water temperature, pH, and dissolved oxygen did not differ significantly among treatments at the 5% level. Temperature remained stable at 23.80–23.83°C, while pH ranged from 7.9 to 8.0. Dissolved oxygen varied from 3.10 to 3.40 mg/L, with all treatments statistically comparable.

Overall, the culture conditions were uniform across treatments, indicating that differences in fish performance were likely attributable to dietary treatments rather than variation in water quality.

Table 3. Mean Level of Physico-chemical Parameters in the Culture Area

TREATMENTS	Level of Physico-Chemical		
	Water Temp. (ºC)	Water pH	Dissolved Oxygen (mg/L)
T1 – Commercial Feed	23.83 a	7.9 a	3.38 a
T2 - 75% Rice Bran (RB) + 25 % *Sarotherodon* Fish Meal (SRF)	23.8 a	7.9 a	3.40 a
T3 - T3 - 75% Rice Bran + 12.5% Spirulina + 12.5% *Sarotherodon*	23.8 a	8.0 a	3.37 a
T4- 75% Rice Bran + 25% Spirulina	23.8 a	7.9 a	3.10 a

Note: Any two means having a common letter are not significantly different at the 5% level of significance

4. Discussion

Growth performance, feed utilization, and survival

The combined growth and feed utilization results indicate that the response of Nile tilapia to the experimental diets became more evident with longer culture duration and advancing developmental stage. During the fry stage and the first 60 days of culture, DGR, SGR, mean length gain, FCR, and survival did not differ significantly among treatments, suggesting that all diets initially supported comparable growth, feed use, and viability. This may reflect the limited early expression of dietary effects, as growth responses in young fish can be influenced by acclimation to experimental diets, feed intake, ration size, feeding frequency, and physiological condition (Alava, 2002; Assan et al., 2021; Li et al., 2022).

By the fingerling stage and after 120 days, the diet containing 75% rice bran and 25% Spirulina produced growth rate, length gain, and FCR values comparable to the commercial diet and superior to the Sarotherodon fish meal-based formulations. This indicates that the Spirulina–rice bran diet was more effective in sustaining both weight and length development while improving feed conversion over the extended culture period. The comparable survival among treatments further suggests that none of the experimental diets compromised fish viability, although the Spirulina-based diet showed the most favorable overall performance pattern.

The improved performance of the Spirulina-based diet may be associated with the nutritional quality of the Spirulina used in this study, which contained 62.48% crude protein. Spirulina is also known to contain essential amino acids, essential fatty acids, vitamins, minerals, phycocyanin, carotenoids, polysaccharides, and other bioactive compounds that may support nutrient utilization and physiological condition in fish (Spínola et al., 2024; Youssef et al., 2023). In Nile tilapia, Spirulina supplementation has been associated with improved growth, feed utilization, immune response, oxidative status, and intestinal condition (Youssef et al., 2023; Alawagany et al., 2021). Bioactive compounds from Spirulina, particularly β-carotene and phycocyanin, have also been reported to improve digestive enzyme activity and immune-antioxidant responses in Nile tilapia (Hassaan et al., 2021).

The weaker performance of the Sarotherodon fish meal-based diets may reflect differences in ingredient quality, digestibility, palatability, amino acid balance, or nutrient availability. These factors are important because feed conversion and growth responses are influenced not only by the amount of protein supplied, but also by how efficiently nutrients are digested and utilized. Studies on alternative aquafeed ingredients have emphasized that digestibility, nutrient bioavailability, and ingredient quality strongly influence feed utilization and growth performance in fish, including Nile tilapia (Rahman et al., 2022; Kirimi et al., 2023). However, because feed intake, digestibility, and amino acid profiles were not directly measured in the present study, these should be considered plausible explanations rather than confirmed mechanisms.

Proximate composition and dietary nutrient profile

The proximate composition of the experimental diets provides context for interpreting the feeding performance of Nile tilapia. Although commercial feeds are formulated to meet stage-specific nutrient requirements, diet quality should not be evaluated based on crude protein level alone. Growth and feed utilization are also influenced by amino acid balance, digestibility, protein-to-energy ratio, lipid availability, mineral supply, and functional bioactive compounds (Bhatnagar and Devi, 2013; Hassaan et al., 2021; Youssef et al., 2023).

The comparable crude protein levels among the rice bran-based diets suggest that differences in nutritional value were more likely related to ingredient quality than total protein content. Rice bran is a locally available feed ingredient, but its use may be limited by variable nutrient composition, fiber, and phytate, which can reduce nutrient digestibility and mineral availability (Alava, 2002; Makori et al., 2017). Thus, supplementation with nutrient-dense ingredients such as Spirulina is important.

Spirulina may have improved the rice bran-based diet by contributing quality protein, lipids, minerals, pigments, vitamins, and bioactive compounds with reported antioxidant and immunostimulatory properties (Hassaan et al., 2021; Li et al., 2022; Spínola et al., 2024; Youssef et al., 2023). Its lipid contribution may also support energy supply and protein sparing, provided that the protein-to-energy ratio remains appropriate (Assan et al., 2021; Rahman et al., 2022). The higher dry matter and ash characteristics of the rice bran–Spirulina diet further indicate improved nutrient density, although mineral bioavailability requires further evaluation because plant-based diets may contain phytate-bound phosphorus (Alava, 2002; Kirimi et al., 2023).

The lack of significant variation in crude fiber and phosphorus among the formulated diets suggests that replacing Sarotherodon fish meal with Spirulina did not substantially increase fiber burden or alter total phosphorus concentration. This is important because excessive fiber and poorly available phosphorus can impair nutrient utilization in plant-based tilapia feeds (Bhatnagar and Devi, 2013; Makori et al., 2017).

Overall, the findings support the potential of Spirulina as a functional supplement for improving rice bran-based aquafeeds. Its contribution appears to extend beyond crude protein enrichment by enhancing the overall nutrient and functional quality of the diet, consistent with current efforts to develop sustainable and locally adaptable aquafeeds (FAO, 2024; Serra et al., 2024).

Water quality conditions

The physico-chemical conditions recorded during the culture period were generally adequate for maintaining survival, but some parameters may have constrained growth. Water temperature remained relatively low, likely because the culture period coincided with the cooler months from January to March. Since Nile tilapia is a warm-water species, lower temperature may reduce feed intake, metabolism, and growth rate. Temperature, dissolved oxygen, pH, and feeding conditions are recognized as important environmental factors influencing Nile tilapia growth and production performance (Abd El-Hack et al., 2022; Makori et al., 2017).

Water pH remained within a suitable range for tilapia culture and was therefore unlikely to have limited performance. In contrast, dissolved oxygen was below the commonly recommended optimum for fish culture, which may have reduced feed utilization and growth efficiency despite the high survival observed. Makori et al. (2017) reported that tilapia growth was positively associated with favorable temperature and dissolved oxygen levels, emphasizing the role of water quality in growth expression. Similarly, Bhatnagar and Devi (2013) emphasized that adequate dissolved oxygen is essential for maintaining fish health, feed utilization, and production efficiency.

Overall, the water quality conditions were sufficient to maintain Nile tilapia survival, but relatively low temperature and dissolved oxygen may have limited the full expression of growth potential. These environmental conditions should be considered when interpreting the dietary responses, particularly because the Spirulina-based diet still performed comparably to commercial feed under these conditions.

Conclusion

The findings of this study demonstrate that a diet containing 75% rice bran and 25% Spirulina can support growth, length gain, feed conversion efficiency, and survival of Nile tilapia at levels comparable to commercial feed, particularly during the fingerling stage and extended culture period. Among the rice bran-based formulations, the Spirulina-supplemented diet consistently performed better than the Sarotherodon fish meal-based diets, indicating that Spirulina was the more effective supplementary protein source under the conditions of the study.

The results further suggest that dietary performance was not determined by crude protein level alone, as the Spirulina–rice bran diet produced favorable growth and feed utilization despite having lower crude protein than the commercial feed. This highlights the importance of nutrient quality, ingredient suitability, and possible functional properties of feed ingredients in aquafeed formulation.

The use of rice bran as a basal ingredient supplemented with Spirulina offers a potentially accessible alternative feed strategy that may reduce dependence on commercial feed while maintaining acceptable growth and feed efficiency for Nile tilapia. Thus, this study provides additional knowledge on sustainable, locally adaptable, low-cost aquafeed formulation with practical potential for Nile tilapia fingerling production.

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