

Effects of Fermented Tomato Meal Inclusion in Diets on the Growth and Feed Utilization of Nile Tilapia (*Oreochromis niloticus*)

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ABSTRACT

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The need for cost-effective feed ingredients for Nile tilapia has driven the exploration of agro-industrial by-products, including fermented plant materials, as alternative feed ingredients. This study evaluated the effects of dietary inclusion levels of fermented tomato meal on growth performance, feed utilization efficiency, and protein retention of Nile tilapia (*Oreochromis niloticus*). A 40-day feeding trial was conducted using a completely randomized design with four dietary treatments and three replicates. The treatments were A (5% fermented tomato meal + 15% soybean meal), B (10% fermented tomato meal + 10% soybean meal), C (15% fermented tomato meal + 5% soybean meal), and D (commercial feed). Fish with an initial body weight of 10.40 ± 1.06 g were stocked at ten fish per aquarium and fed at 5% biomass day⁻¹. The observed parameters included weight gain, specific growth rate, feed conversion ratio, feed efficiency, survival rate, and protein retention. Dietary treatment significantly affected weight gain and protein retention ($P < 0.05$) but had no significant effect on specific growth rate, feed conversion ratio, feed efficiency and survival rate ($P > 0.05$). Among the formulated diets, treatment B produced the most balanced feed utilization performance, with a weight gain of 3.88 g, a feed conversion ratio of 5.04, feed efficiency of 20.62%, and protein retention of 79.58%. These findings indicate that fermented tomato meal can partially replace soybean meal at a 10% inclusion level, making it a promising ingredient for Nile tilapia diets.

INTRODUCTION

Nile tilapia (*Oreochromis niloticus*) is one of the major aquaculture commodities due to its relatively high growth rate, broad adaptability to various environmental conditions, and efficient utilization of plant-based feed sources. Nevertheless, feed remains the largest cost component and a major source of sustainability-related pressure in fish production. Dependence on fishmeal and conventional feed ingredients is constrained by price, availability, and ecological impacts, making the development of locally available ingredients and agro-industrial by-products a strategic priority (Hussain *et al.*, 2024). However, plant-based ingredients cannot be regarded as direct substitutes for fishmeal because their

relatively high fiber content, suboptimal amino acid composition, relatively low digestibility, and the presence of antinutritional factors may limit feed intake and nutrient utilization (Li *et al.*, 2025; Sun *et al.*, 2026).

The utilization of fruits and vegetables that are no longer suitable or attractive for human consumption because they are overripe or rejected offers a circular-economy approach to reducing waste while expanding the range of available feed ingredients. Tomato is a potentially valuable ingredient because, although present in relatively small amounts, it contains protein and unsaturated lipids, as well as bioactive compounds such as lycopene and β -carotene (Lu *et al.*, 2019; Lourenço *et al.*, 2025). These components indicate that tomato meal may serve not only as a nutrient source but also as a functional ingredient capable of supporting antioxidant status. In common carp, the inclusion of tomato pomace has been shown to sustain growth up to a certain inclusion level; however, further increases in inclusion may reduce protein digestibility (Lourenço *et al.*, 2025). In Nile tilapia, tomato by-products and tomato extracts have been reported to support growth or improve physiological parameters, although responses have not been consistent among products or inclusion levels (Kesbiç *et al.*, 2022; Kamel *et al.*, 2026). In whiteleg shrimp, the inclusion of tomato meal has reportedly improved growth performance and feed-utilization efficiency (Firdaus *et al.*, 2026).

Fermentation is regarded as a processing technology capable of alleviating several limitations associated with plant-based ingredients. During fermentation, microorganisms may produce proteases, amylases, cellulases, organic acids, vitamins, and bioactive metabolites. Consequently, fermentation has the potential to break down complex molecules, reduce antinutritional factors, enhance nutrient solubility, and modulate the intestinal microbiota (Dawood & Koshio, 2019; Siddik *et al.*, 2024; Sun *et al.*, 2026). Evidence from aquafeed research indicates that fermented plant-based ingredients can improve nutrient digestibility and utilization efficiency; however, their effects are highly dependent on species, substrate, microbial strain, fermentation duration, and substitution level (Mugwanya *et al.*, 2023; Li *et al.*, 2025). In Nile tilapia, the fermentation of mixed plant-based ingredients and enzyme supplementation has been shown, under specific conditions, to improve growth, intestinal morphology, digestive enzyme activity, and physiological status (Hassaan *et al.*, 2021; Awad *et al.*, 2024; Hafez *et al.*, 2024). These findings support the hypothesis that fermentation may enhance the utilization of tomato meal, although improved performance cannot be assumed if the process increases the fiber fraction or reduces the availability of dietary energy.

A knowledge gap remains regarding the use of fermented tomato meal as an ingredient in Nile tilapia feed formulations. Previous studies have primarily evaluated unfermented tomato pomace, tomato extracts, or fermented silage mixtures in which tomato was processed together with other ingredients. Therefore, the specific effects of fermenting tomato meal have not yet been clearly separated from those of the other components or processing conditions. Meanwhile, studies on fermented vegetable wastes have shown that growth and feed efficiency may remain stable at relatively high inclusion levels; nevertheless, changes in amino acid profiles, digestive enzyme activity, and health indicators do not always follow the same pattern (Saleh *et al.*, 2026; Moniruzzaman *et al.*, 2019). Accordingly, biological evidence does not fully support the theoretical assumption that fermentation automatically produces a more efficient feed ingredient. Evaluating growth performance, feed conversion ratio, feed efficiency, and protein retention is therefore necessary to determine a rational inclusion level.

Based on this background, the present study aimed to evaluate the effects of incorporating fermented tomato meal at different inclusion levels in the diets of Nile tilapia, using a commercial diet as a reference. The analyzed parameters included weight gain, specific growth rate, feed conversion ratio, feed efficiency, survival rate, and protein retention. This study is expected to provide an empirical basis for identifying the most promising inclusion level of fermented tomato meal and to clarify whether the increase in protein content following fermentation is genuinely reflected in protein utilization and fish growth.

METHODS

Study Duration and Location

The study was conducted over a 40-day period from November to December 2021 at the Laboratory of Aquatic Productivity and Environmental Units and the Laboratory of Seed Production and Hatchery Technology Units, Faculty of Fisheries and Marine Sciences, Halu Oleo University. Proximate analyses of the feed ingredients and experimental diets were performed in a laboratory equipped with the appropriate facilities for the nutritional parameters evaluated.

Experimental Fish and Rearing Units

The experimental fish consisted of 120 Nile tilapia fingerlings with an initial mean body weight of 10.40 ± 1.06 g. The fish were obtained from the Abeli Sawah Freshwater Fish Hatchery, Kendari City. They were reared in 12 aerated aquaria measuring $90 \times 40 \times 40$ cm. Each experimental unit contained 10 fish.

Feed Ingredients and Preparation of Fermented Tomato Meal

The primary raw material used to prepare fermented tomato meal was overripe or rejected tomato fruit that was unsuitable for marketing but remained suitable for use as a feed ingredient. The feed formulation consisted of fermented tomato meal, fishmeal, shrimp-head meal, soybean meal, cornmeal, fine rice bran, wheat flour, tapioca flour, sago flour, fish oil, squid oil, and a commercial premix.

Fermented tomato meal was prepared with modifications based on the solid-state fermentation procedures described by Shakouri *et al.* (2023) and Roja *et al.* (2017). Tomatoes were sorted to remove rotten materials and thoroughly washed. The washed tomatoes were sun-dried until the surfaces became wrinkled to reduce moisture content, cut into small pieces, and blended into a pulp. The tomato pulp was heated over low heat for several minutes and then cooled to room temperature. After cooling, “NKL” commercial Indonesian tape starter was added as the fermentation inoculum and mixed thoroughly until homogeneous. The inoculated pulp was placed in a clean container, covered with wrapping paper, and aerobically fermented for 48 h at room temperature. The fermented material was then sun-dried until completely dry, ground, and sieved to obtain a uniform meal. The resulting fermented tomato meal was subjected to proximate analysis before being incorporated into the experimental diets. The “NKL” commercial Indonesian tape starter containing *Amylomyces rouxii*, *Rhizopus oryzae*, *Candida tropicalis*, *Mucor indicus*, and *Saccharomycopsis fibuligera* (Abe *et al.*, 2004).

Formulation and Preparation of the Experimental Diets

The experimental diets were prepared in pellet form with a target crude protein content of approximately 30%. All ingredients were weighed according to the formulation, thoroughly mixed, and combined with an adequate amount of water before being processed using a pelletizer. The pellets were oven-dried to achieve a moisture content suitable for storage and

were subsequently stored in a dry area before being provided to the fish. Proximate analysis was conducted to determine the nutrient composition of the experimental diets.

Table 1. Ingredient Composition of the Experimental Diets for Each Treatment (%)

Ingredient	A	B	C	D
Fish meal	20	20	20	-
Shrimp-head meal	15	15	16	-
Soybean meal	15	10	5	-
Fermented tomato meal (FTM)	5	10	15	-
Cornmeal	10	10	10	-
Rice bran meal	8	8	10	-
Wheat flour	10	10	12	-
Tapioca flour	8	8	5	-
Sago flour	5	5	3	-
Fish oil	1	1	1	-
Squid oil	1	1	1	-
TOP Mix premix	2	2	2	-
Commercial feed	-	-	-	100
Total	100	100	100	100

The dietary treatments were formulated based on the dosage levels adopted from Rani *et al.* (2023). Treatments specifications were as follows: A, 5% fermented tomato meal and 15% soybean meal; B, 10% fermented tomato meal and 10% soybean meal; C, 15% fermented tomato meal and 5% soybean meal; and D, Hi-Pro-Vite 782 commercial feed containing 28–30% crude protein. TOP Mix was used as a source of vitamins, minerals, amino acids, and antioxidants according to the product formulation.

Fish Rearing Procedures

Before the feeding trial began, the fish were acclimated to the rearing environment and experimental diets for five days. During acclimation, the fish were fed commercial feed alternately with the prepared experimental diets. After acclimation, the fish were fasted for 24 h to empty the digestive tract and then weighed to determine their initial body weight.

The diets were provided three times daily at 08:00, 12:00, and 17:00, with an initial feeding rate of 5% of the fish biomass per day. The amount of feed was adjusted periodically according to changes in fish biomass. Uneaten feed and feces were removed daily by siphoning. Water temperature and pH were measured daily, whereas dissolved oxygen and ammonia were measured at the beginning and end of the rearing period.

Experimental Design

The study employed an experimental method using a completely randomized design consisting of four treatments and three replicates, resulting in 12 experimental units. The dietary treatment levels were adopted from Rani *et al.* (2023), with modifications to accommodate the nutritional composition and experimental requirements of the present study. The treatments were as follows:

Treatment A: Diet containing 5% fermented tomato meal and 15% soybean meal.

Treatment B: Diet containing 10% fermented tomato meal and 10% soybean meal.

Treatment C: Diet containing 15% fermented tomato meal and 5% soybean meal.

Treatment D: Hi-Pro-Vite 782 commercial feed as the reference diet.

Observed Parameters

Proximate Analysis

Proximate analysis was conducted on the tomato meal before and after fermentation and on the experimental diets. The analyses covered moisture, ash, crude protein, crude fat, and crude fiber contents, all determined in accordance with the Official Methods of Analysis of AOAC International (2019). Moisture content was determined by oven drying (Method 934.01), ash by incineration (Method 942.05), crude protein by the Kjeldahl method involving block digestion and steam distillation (Method 2001.11), crude fat by Soxhlet extraction (Method 920.39), and crude fiber by acid–alkali digestion (Method 962.09). All results were expressed as percentages on a dry-weight basis.

Growth Performance, Feed Utilization, and Survival

Growth performance, survival, and feed utilization were evaluated using weight gain (WG), specific growth rate (SGR), survival rate (SR), feed conversion ratio (FCR), and feed efficiency (FE) was determined according to Kurnia *et al.* (2025a) and Kurnia *et al.* (2025b).

- Weight gain (WG) was calculated as the difference between the mean final and initial body weights:

$$WG = W_t - W_0$$

- Specific growth rate (SGR) was calculated using the following equation:

$$SGR = [\ln(W_t) - \ln(W_0)]/t \times 100\%$$

- Feed conversion ratio (FCR) was calculated as the ratio of feed intake to the increase in fish biomass:

$$FCR = F/(W_t - W_0)$$

- Feed efficiency (FE) was calculated from the relationship between the increase in biomass and feed intake:

$$FE = [(W_t - W_0)/F] \times 100\%$$

- Survival rate (SR) was calculated using the following equation:

$$SR = N_t/N_0 \times 100\%$$

Where W_t is the mean final body weight (g), and W_0 is the mean initial body weight (g), t is the rearing period (days), F is feed intake (g), N_t is the number of fish alive at the end of the rearing period, and N_0 is the initial number of fish.

Protein Retention

Protein retention was calculated to determine the proportion of dietary protein deposited in the fish body, following Huang *et al.* (2024):

$$PR = [(P_t \times W_t) - (P_0 \times W_0)]/(F \times P_f) \times 100\%$$

Where PR is protein retention (%), P_t is crude protein content of the final fish (%), P_0 is crude protein content of the initial fish (%), W_t is the final body weight (g), W_0 is the initial body weight (g), F is feed intake (g), and P_f is the protein content of the diet (%).

Data Analysis

Data on weight gain, specific growth rate, FCR, feed efficiency, survival rate, and protein retention were analyzed using analysis of variance (ANOVA) at a 95% confidence level or $\alpha = 0.05$. When significant differences were detected, the analysis was followed by an appropriate multiple-comparison test based on the statistical design. Statistical analyses were performed using SPSS software.

RESULTS

Proximate Composition of Tomato Meal Before and After Fermentation

Proximate analysis indicated changes in the nutrient composition of tomato fruit meal following fermentation. The protein content increased from 22.77% before fermentation to 24.86% after fermentation. In contrast, lipid content decreased from 8.31% to 6.05%. Crude fiber increased from 18.12% to 25.79%, whereas ash content increased from 9.92% to 11.47%. Moisture content decreased from 11.25% to 8.23%. Thus, fermentation produced tomato meal with a higher protein content and lower moisture content, but was accompanied by increases in crude fiber and ash contents.

Table 2. Nutrient Composition of Tomato Fruit Meal Before and After Fermentation

Parameter	Before fermentation (%)	After fermentation (%)
Protein	22.7668	24.8578
Lipid	8.3079	6.0451
Crude fiber	18.1197	25.7906
Ash	9.9218	11.4747
Moisture	11.246	8.2267

Weight Gain

During the 40-day rearing period, the highest weight gain of Nile tilapia was recorded in treatment D, which received the commercial Hi-Pro-Vite 782 diet, with a value of 4.17 g. This was followed by treatment B, consisting of a diet containing 10% fermented tomato meal and 10% soybean meal, with a value of 3.88 g; treatment C, containing 15% fermented tomato meal and 5% soybean meal, with a value of 3.27 g; and treatment A, containing 5% fermented tomato meal and 15% soybean meal, with a value of 2.60 g (Figure 1).

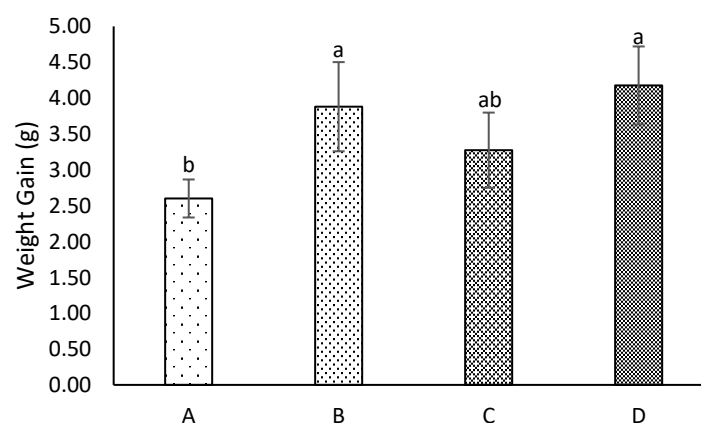


Figure 1. Weight Gain (g) of Nile Tilapia Fed Experimental Diets with Different Inclusion Levels of Fermented Tomato Meal During the 40-Day Rearing Period

Analysis of variance showed that dietary treatment significantly affected the weight gain of Nile tilapia ($P < 0.05$). Based on the subsequent LSD test, treatment D did not differ significantly from treatments B and C but differed significantly from treatment A. These results indicate that the inclusion of fermented tomato meal at levels of 10% and 15% produced weight gain statistically comparable to that obtained with the commercial diet, whereas the 5% inclusion level used in treatment A resulted in the lowest growth.

Specific Growth Rate

The specific growth rate of Nile tilapia during the 40-day rearing period ranged from 0.56 to 0.85% day⁻¹. The highest value was recorded in treatment D, at 0.85% day⁻¹, followed by treatment B at 0.82% day⁻¹, treatment C at 0.69% day⁻¹, and treatment A at 0.56% day⁻¹. Although numerical differences were observed among treatments, analysis of variance showed that diets containing fermented tomato meal had no significant effect on the specific growth rate of Nile tilapia ($P > 0.05$) (Figure 2).

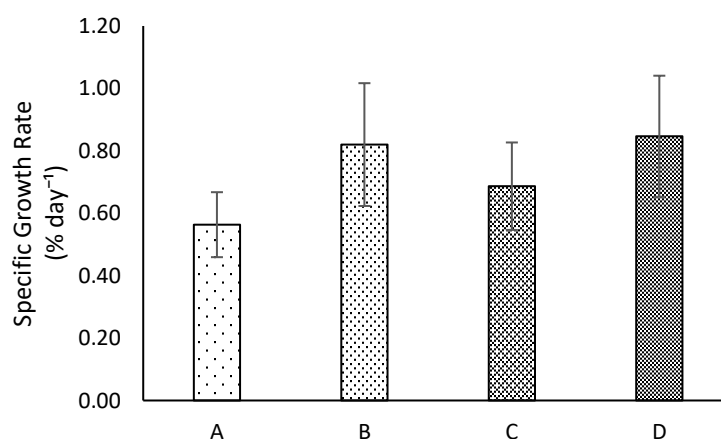


Figure 2. Specific Growth Rate (% day⁻¹) of Nile Tilapia Fed Experimental Diets with Different Inclusion Levels of Fermented Tomato Meal During the 40-Day Rearing Period

Feed Conversion Ratio

The feed conversion ratio in treatments A, B, C, and D were 5.76, 5.04, 7.54, and 5.13, respectively. The lowest FCR was observed in treatment B, whereas the highest value was recorded in treatment C. Numerically, increasing the proportion of fermented tomato meal from 10% to 15% did not improve feed utilization efficiency, as indicated by the increased FCR in treatment C. However, analysis of variance showed that dietary variation had no significant effect on the FCR of Nile tilapia ($P > 0.05$) (Figure 3).

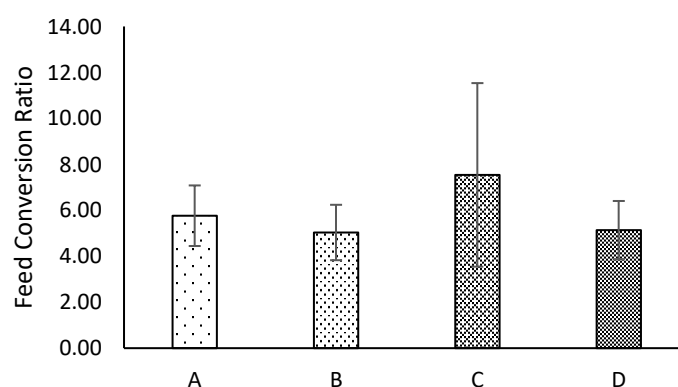


Figure 3. Feed Conversion Ratio of Nile Tilapia Fed Experimental Diets with Different Inclusion Levels of Fermented Tomato Meal During the 40-Day Rearing Period

Feed Efficiency

The highest feed efficiency was recorded in treatment B, at 20.62%, followed by treatment D at 20.20%, treatment A at 18.05%, and treatment C at 17.01%. Analysis of variance showed that the substitution of fermented tomato meal had no significant effect on feed efficiency in Nile tilapia ($P > 0.05$). The numerically higher feed efficiency observed in

treatment B indicates that the combination of 10% fermented tomato meal and 10% soybean meal was the most efficient dietary composition under the conditions of this study, although this advantage was not statistically significant (Figure 4).

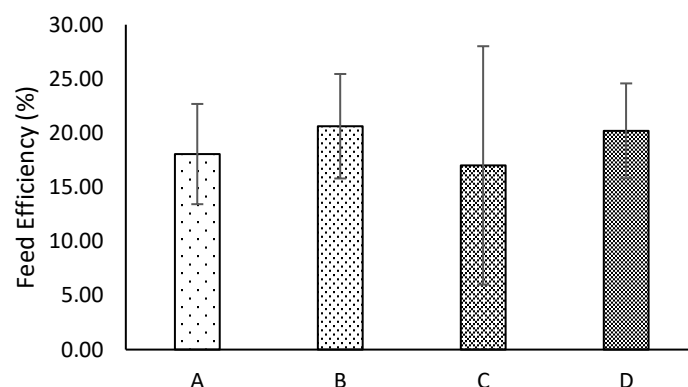


Figure 4. Feed Efficiency (%) of Nile Tilapia Fed Experimental Diets with Different Inclusion Levels of Fermented Tomato Meal During the 40-Day Rearing Period

Survival Rate

The highest survival rate during the rearing period was observed in treatment A, at 100%, followed by treatment B at 97% and treatment C at 93%. Analysis of variance indicated that dietary variation did not significantly affect the survival rate of Nile tilapia ($P > 0.05$). The high survival rates observed in all treatments containing fermented tomato meal indicate that this ingredient can be incorporated into experimental diets without causing significant adverse effects on fish survival during the rearing period (Figure 5).

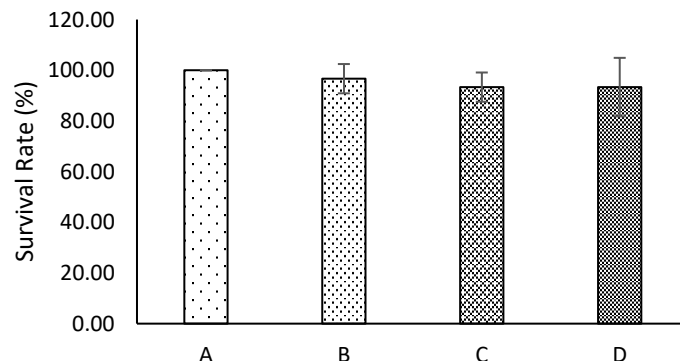


Figure 5. Survival Rate (%) of Nile Tilapia Fed Experimental Diets with Different Inclusion Levels of Fermented Tomato Meal During the 40-Day Rearing Period

Protein Retention

Protein retention in Nile tilapia was highest in treatment B, at 79.58%, followed by treatment A at 70.10%, treatment C at 44.98%, and treatment D at 33.59%. Analysis of variance showed that dietary treatment significantly affected protein retention ($P < 0.05$). Based on the subsequent test, treatments A and B belonged to the same statistical group, whereas treatments C and D belonged to a different group. These findings indicate that diets containing 5% to 10% fermented tomato meal resulted in higher protein retention than the diet containing 15% fermented tomato meal and the commercial diet (Figure 6).

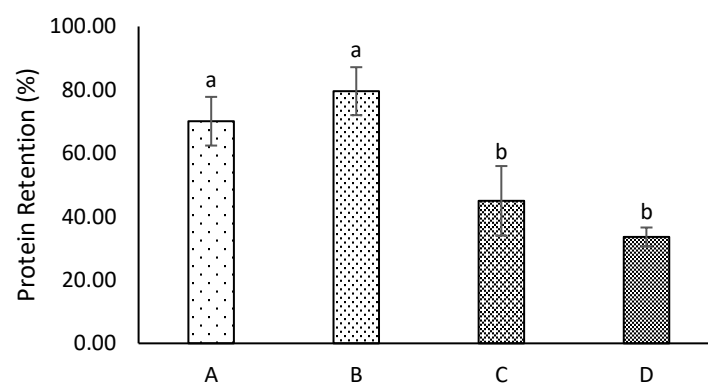


Figure 6. Protein Retention (%) of Nile Tilapia Fed Experimental Diets with Different Inclusion Levels of Fermented Tomato Meal During the 40-Day Rearing Period

DISCUSSION

Changes in Nutrient Composition Following Fermentation

The changes in the proximate composition of tomato meal following 48 h of fermentation with tape starter in the present study were consistent with trends reported in recent literature. The increase in protein content from 22.77% to 24.86%, representing an approximately 9.2% relative increase, may be attributed to two primary mechanisms: (1) the accumulation of protein-rich yeast biomass during the logarithmic growth phase, and (2) a concentration effect resulting from the enzymatic degradation of soluble carbohydrate fractions by microbial activity (Siddik *et al.*, 2024). This finding is consistent with Shakouri *et al.* (2023), who reported an increase in the protein content of tomato pomace from 14.21% to 25.82% following solid-state fermentation with *S. cerevisiae* under optimal conditions. Furthermore, Demirgöl & Öztürk (2021) recorded a 55.99% increase in the crude protein content of tomato pomace after fermentation with *Aspergillus niger*, although the substrate and fermentation conditions differed from those used in the present study.

The increase in crude fiber from 18.12% to 25.79% warrants critical consideration. This increase likely does not indicate an absolute accumulation of fiber, but rather a relative concentration effect resulting from the preferential degradation of readily soluble carbohydrates, particularly the nitrogen-free extract (NFE), by *S. cerevisiae*, which utilizes simple sugars as sources of carbon and energy. Demirgöl & Öztürk (2021) reported a similar pattern, in which fermentation reduced the NFE content of tomato pomace by 31.74%, thereby proportionally increasing the fiber fraction. Overall, the changes in proximate composition observed in the present study suggest that fermentation with tape yeast modified the nutrient matrix of tomato meal in a potentially more favorable direction from a biological perspective.

Weight Gain and Specific Growth Rate

The growth response of Nile tilapia to varying inclusion levels of fermented tomato meal (FTM) in the present study revealed a distinct non-linear relationship. Treatment B, containing 10% FTM and 10% soybean meal, resulted in a weight gain of 3.88 g, which was statistically comparable to that of the commercial diet, at 4.17 g. In contrast, treatment A, containing 5% FTM and 15% soybean meal, produced significantly lower growth, at 2.60 g. This pattern suggests the existence of a minimum inclusion threshold at which the nutritional benefits of FTM begin to be expressed measurably. At the 5% inclusion level, the contribution of FTM-derived protein and bioactive metabolites may not have been sufficient to elicit a positive

growth response. Although the higher soybean meal proportion in this treatment, at 15%, would theoretically provide an adequate supply of amino acids, the lower growth observed in treatment A may instead be associated with the overall dietary formulation, particularly the energy-to-protein ratio, rather than with an adverse effect of tomato meal itself.

The advantage of treatment B is supported by the findings of Amirkolaie *et al.* (2015), who reported that the inclusion of 10% tomato pomace in common carp diets significantly increased final body weight and specific growth rate, with the response attributed to improved lipid and dry matter digestibility. At the higher inclusion level represented by treatment C, which contained 15% FTM, growth tended to decline to 3.27 g, although it remained statistically comparable to that of the commercial diet. This reduction was likely associated with the high crude fiber content of treatment C, which may increase digesta viscosity and restrict the accessibility of digestive enzymes to nutrient substrates (Amirkolaie *et al.*, 2015).

The specific growth rate followed the same numerical ranking: 0.85% day⁻¹ in treatment D, 0.82% day⁻¹ in treatment B, 0.69% day⁻¹ in treatment C, and 0.56% day⁻¹ in treatment A; however, the differences were not statistically significant. The discrepancy between weight gain and specific growth rate may result from the relative nature of the specific growth rate calculation, which is based on initial body weight and logarithmic transformation. Therefore, the most defensible conclusion is that a 10% FTM inclusion level was able to maintain growth comparable to that achieved with the commercial diet, rather than statistically increasing the growth rate. This finding is consistent with reports on the use of tomato pomace in Nile tilapia and common carp, indicating that this ingredient can be tolerated at certain inclusion levels (Lourenço *et al.*, 2025).

Feed Utilization Efficiency

The analysis of feed conversion ratio and feed efficiency revealed practically relevant findings. Treatment B produced the lowest feed conversion ratio (5.04) and the highest feed efficiency (20.62%), even outperforming the commercial diet (FCR, 5.13; feed efficiency, 20.20%). Although these differences were not statistically significant, the numerical superiority of treatment B suggests that fermentation may have improved the biological quality of tomato meal through several mechanisms. First, the partial degradation of protein macromolecules into more readily absorbable peptides and amino acids may have produced a “predigestion” effect (Sun *et al.*, 2026). Second, extracellular enzymes, including proteases, amylases, and cellulases, produced by *S. cerevisiae* may have accumulated in the fermented substrate and contributed to nutrient digestion in the gastrointestinal tract of the fish (Wang *et al.*, 2024). Third, bioactive metabolites, including β -glucans, mannan-oligosaccharides, and nucleotides derived from yeast cell walls, may have stimulated endogenous digestive enzyme activity (Agboola *et al.*, 2020).

Fermentation may theoretically improve feed conversion ratio through predigestion, the production of proteases and hydrolytic enzymes, substrate acidification, and the formation of metabolites that support the intestinal microbiota. Evidence from studies on fermented plant proteins has demonstrated improved digestibility and feed utilization in several species; however, these effects are not universal and may be inferior to those obtained with fishmeal-based diets (Hamidoghli *et al.*, 2020; Jannathulla *et al.*, 2019; Mugwanya *et al.*, 2023). Therefore, the relatively high feed conversion ratio values observed across all treatments (5.04–7.54) likely reflect an interaction between the incomplete benefits of fermentation and the increased fiber burden.

Survival

The high and relatively consistent survival rates observed across all treatments, ranging from 93% to 100%, provide strong evidence of the biological safety of fermented tomato meal as a feed ingredient for Nile tilapia. The absence of treatment-related mortality suggests that fermentation with tape yeast produced a feed ingredient without toxic metabolites at biologically harmful concentrations. Similar findings were reported by Saleh *et al.* (2026) in Nile tilapia fed fermented vegetable waste processed with *Bacillus subtilis* and *S. cerevisiae* at inclusion levels of up to 30%; survival reached 100%, with no histopathological abnormalities in intestinal architecture. These results are also consistent with the meta-analysis by Mugwanya *et al.* (2023), which showed that replacing fishmeal with fermented plant proteins generally had no adverse effect on survival across various aquaculture species.

Protein Retention

Protein retention was the most informative parameter for explaining the superior performance of treatment B. The high retention observed in this treatment indicates that a greater proportion of the consumed protein was directed toward tissue deposition rather than being lost through excretion. The combination of 10% fermented tomato meal and 10% soybean meal appeared to provide the most appropriate balance among dietary protein, energy, and amino acids. Conversely, the marked decline observed in treatment C indicates that increasing the inclusion level of fermented tomato meal did not improve protein utilization. The higher crude fiber content may have reduced protein digestibility, whereas limiting amino acids or an imbalance in dietary energy may have promoted the utilization of protein as an energy source rather than for tissue growth (Hussain *et al.*, 2024; Maas *et al.*, 2020).

The lowest protein retention observed in treatment D should be interpreted cautiously because the commercial diet differed from the experimental diets in ingredient composition, energy content, and potentially feeding procedures. Nevertheless, the results for treatment B remain important: this treatment produced the highest protein retention, together with the lowest feed conversion ratio and the highest feed efficiency. Other studies have shown that fermented plant-based ingredients can improve nutrient digestibility, digestive enzyme activity, and intestinal integrity when the microbial strain and fermentation conditions are appropriate (Adeoye *et al.*, 2016; Hassaan *et al.*, 2021; Moniruzzaman *et al.*, 2019).

CONCLUSION

Treatment B, containing 10% fermented tomato meal and 10% soybean meal, demonstrated the most balanced performance, as indicated by weight gain of 3.88 g, feed conversion ratio of 5.04, feed efficiency of 20.62%, and protein retention of 79.58%. Dietary treatment significantly affected weight gain and protein retention, whereas specific growth rate, feed conversion ratio, feed efficiency and survival rate did not differ significantly among treatments. Increasing the inclusion level of fermented tomato meal to 15% provided no additional benefits and tended to reduce feed utilization efficiency.

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