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EVALUATING THE POTENTIAL OF TUBIFEX MEAL AS A FISH MEAL SUBSTITUTE IN THE DIETS OF NILE TILAPIA (*Oreochromis niloticus*) FRY

Evaluasi Potensi Tepung *Tubifex* sebagai Pengganti Tepung Ikan dalam Pakan Benih Ikan Nila (*Oreochromis niloticus*)

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ABSTRACT

The high cost and limited availability of fishmeal in aquaculture feed formulations have prompted the search for sustainable and affordable alternative protein sources. This study aimed to evaluate the effects of substituting fishmeal with silk worm (*Tubifex* sp.) meal on the growth performance, feed utilization, and survival rate of Nile tilapia (*Oreochromis niloticus*) fry. A completely randomized design (CRD) was used with four dietary treatments: P1 (control, 0% *Tubifex*), P2 (15%), P3 (25%), and P4 (35%), each with three replications. Fish were fed twice daily for 30 days, and growth parameters were measured weekly. Results showed that the inclusion of *Tubifex* meal significantly improved the final weight, specific growth rate (SGR), average daily gain (ADG), and feed efficiency (FE), particularly in P3 and P4. The highest SGR (2.28%/day), ADG (0.016 g/day), and FE (61.93%) were recorded in the P4 group. Survival rate also improved, reaching 82.22% in P4 compared to 51.11% in the control. Water quality parameters remained within optimal ranges, indicating no adverse environmental impact from *Tubifex* inclusion. The findings suggest that *Tubifex* meal is a viable protein source that can replace fishmeal by up to 35% in tilapia fry diets. Its application offers nutritional, economic, and ecological benefits, making it a promising component in sustainable aquafeed development.

Keywords: Nile tilapia, *Tubifex*, growth, survival rate, sustainable aquaculture

ABSTRAK

Tingginya biaya dan keterbatasan ketersediaan tepung ikan dalam formulasi pakan budidaya mendorong pencarian sumber protein alternatif yang berkelanjutan dan terjangkau. Penelitian ini bertujuan untuk mengevaluasi pengaruh substitusi tepung ikan dengan tepung cacing sutra (*Tubifex* sp.) terhadap pertumbuhan, efisiensi pakan, dan tingkat kelangsungan hidup benih ikan nila (*Oreochromis niloticus*). Penelitian menggunakan Rancangan Acak Lengkap (RAL) dengan empat perlakuan pakan: P1 (kontrol, 0% *Tubifex*), P2 (15%), P3 (25%), dan P4 (35%), masing-masing dengan tiga ulangan. Ikan diberi pakan dua kali sehari selama 30 hari, dan parameter pertumbuhan diukur setiap minggu. Hasil penelitian menunjukkan bahwa

penambahan tepung *Tubifex* secara signifikan meningkatkan bobot akhir, laju pertumbuhan spesifik (SGR), pertambahan bobot harian rata-rata (ADG), dan efisiensi pakan (FE), terutama pada perlakuan P3 dan P4. Nilai tertinggi SGR (2,28%/hari), ADG (0,016 g/hari), dan FE (61,93%) ditemukan pada P4. Tingkat kelangsungan hidup juga meningkat, dengan nilai tertinggi pada P4 (82,22%) dibandingkan kontrol (51,11%). Selama pemeliharaan, parameter kualitas air tetap berada dalam kisaran optimal, yang menunjukkan bahwa penggunaan tepung *Tubifex* tidak berdampak negatif terhadap lingkungan budidaya. Temuan ini menunjukkan bahwa tepung *Tubifex* merupakan sumber protein yang layak digunakan sebagai pengganti sebagian tepung ikan hingga 35% dalam pakan benih ikan nila. Penggunaannya memberikan manfaat dari sisi nutrisi, ekonomi, dan ekologi, sehingga berpotensi menjadi komponen penting dalam pengembangan pakan budidaya yang berkelanjutan.

Kata Kunci: Nile tilapia, *Tubifex*, pertumbuhan, sintasan, akuakultur berkelanjutan

INTRODUCTION

Nile tilapia (*Oreochromis niloticus*) is one of the most prominent freshwater aquaculture commodities in Indonesia and globally, due to its high economic value and favorable biological traits. This species is well recognized for its wide environmental adaptability, tolerance to varying water conditions, and relatively fast growth rate (Arumugam et al., 2023; Robisalmi et al., 2025). Despite its advantages, the larval and juvenile stages of Nile tilapia are highly sensitive to fluctuations in water quality and nutritional imbalances (Siddique et al., 2023). Therefore, the success of tilapia aquaculture, particularly during early life stages, strongly depends on the provision of high-quality and nutritionally balanced feed (Gule & Geremew, 2022; Ng & Romano, 2013; Simangunsong et. al., 2023).

Feed plays a central role in supporting growth performance and survival in cultured fish. One of the major challenges faced by aquaculture producers is the heavy reliance on fishmeal as the primary protein source in aquafeeds (Ayele, 2015). Fishmeal is well regarded for its high digestibility and excellent amino acid profile (Jasour et al., 2018; Li et al., 2009). However, its global supply is becoming increasingly limited due to overfishing and competition with other industries, which has led to escalating prices and reduced accessibility for small-scale farmers (Jasour et al., 2018; Olsen & Hasan, 2012). Consequently, there is a growing demand for sustainable, cost-effective, and locally available alternative protein sources that can partially or fully replace fishmeal in aquafeed formulations.

Silk worms (*Tubifex* sp.) have been widely recognized as a natural live feed with high nutritional value, containing approximately 50-60% crude protein on a dry matter basis (Mugwanya et al., 2025; Simangunsong et al., 2024; Sutarjo, 2018). In addition, *Tubifex* worms contain essential amino acids such as lysine, methionine, and threonine, which are crucial for muscle development and protein synthesis in fish. Their small size, soft texture, and high palatability make them particularly suitable for early-stage fish, including fry and fingerlings (Firdausi et al., 2025; Herawati et al., 2016; Jin et al., 2023; Velasco-Santamaría & Corredor-Santamaría, 2011; Windarto et al., 2023). Previous studies have consistently shown that the inclusion of *Tubifex* in aquafeeds can significantly enhance growth performance, improve survival rates, and increase feed utilization efficiency in cultured aquatic species. However, empirical evidence regarding the use of *Tubifex* meal as a functional additive in formulated diets remains limited and warrants further investigation (Akebai et al., 2024; Alam et al., 2021; Firdausi et al., 2025; Herawati et al., 2020; Kautsar et al., 2022; Nuswantoro & Rahardjo, 2018; Sunarno et al., 2023; Syamsunarno & Sunarno, 2022).

This study aims to evaluate the effects of partially replacing fishmeal with *Tubifex* meal in the diet of Nile tilapia fry on growth performance, feed utilization, and survival rate. The findings are expected to contribute to the development of sustainable aquafeeds by promoting

the use of locally sourced protein alternatives, thereby reducing dependence on imported fishmeal and improving aquaculture productivity.

RESEARCH METHODS

Time and Location

This research was conducted from August 2024 to January 2025 at the Laboratory of Fisheries Productivity and Entrepreneurship Development, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman, Indonesia.

Tools and Materials

The equipment used included a recirculating aquaculture system (RAS), drying oven, feed grinder, rearing containers, aeration tools, water quality measuring instruments, sieves, digital scales, and office supplies. Materials used in this study consisted of *Tubifex* worms, tofu waste, rice field mud, Nile tilapia (*Oreochromis niloticus*) fry, shrimp head meal, rice bran, tapioca flour, fish oil, premix, and water.

Experimental Design

This study used a Completely Randomized Design (CRD) consisting of four feed treatments with three replications each referring to the study conducted by Kautsar et al. (2022) with modifications to the treatment differences, as follows:
P1: Control feed without silk worm (*Tubifex* sp.) meal (0%)
P2: Feed with 15% substitution of *Tubifex* meal
P3: Feed with 25% substitution of *Tubifex* meal
P4: Feed with 35% substitution of *Tubifex* meal
Each experimental unit consisted of 15 Nile tilapia (*Oreochromis niloticus*) fry with an average initial weight of 0.45 ± 0.03 g and an average length of 3.0 ± 0.04 cm. The fish were reared for 30 days in 15-liter aquaria equipped with continuous aeration systems.

Research Procedure

Preparation of Tubifex Culture Media

Silk worms (*Tubifex* sp.) were cultured at the Laboratory of Fisheries Productivity and Entrepreneurship Development, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman. The culture media was prepared by collecting rice field mud from local paddy fields. The mud was sun-dried, then ground using a milling machine, sieved through a 50-mesh screen, and stored in a dry place until ready for use.

Maintenance of Tubifex Worms

The *Tubifex* worms used in this study were reared in a recirculating aquaculture system (RAS). An initial culture stock of 300 g of *Tubifex* was introduced into the culture media. During the culture period, the worms were fed with tofu residue obtained from a local tofu production plant. After 30 days of maintenance, the worms were harvested and used as the protein source for feed formulation.

Feed Formulation and Preparation

The feed was formulated using a mixture of shrimp head meal, fine rice bran, tapioca flour, fish oil, a vitamin-mineral premix, and *Tubifex* meal according to the treatment levels. The *Tubifex* meal was prepared by drying fresh worms in an oven at 58°C for 72 hours, followed by grinding and sieving through an 80-100 mesh screen. Feed formulation was carried out using Pearson's Square method to achieve a balanced nutritional profile. The feed ingredients were thoroughly mixed, then processed using a pelleting machine to form and size the pellets. The pellets were then dried at 60°C in an oven for two days and stored in airtight

plastic bags until used during the feeding trials. The complete feed composition is presented in Table 1.

Table 1. Feed Formulation/Ingredient Composition for Each Treatment

Inggredients	Experimental Diet (%)			
	P1	P2	P3	P4
Shrimp head meal	27.75	21.35	17.08	12.81
Rice bran flour	37.25	28.65	22.92	17.19
Tapioca flour	20	20	20	20
Tubifex meal	0	15	25	35
Fish oil	10	10	10	10
Premix	5	5	5	5
Total	**100**	**100**	**100**	**100**

Rearing of Nile Tilapia Fry

The experimental fish used in this study were Nile tilapia (*Oreochromis niloticus*) fry with an average initial body weight of 0.45 ± 0.03 g and an average length of 3.0 ± 0.04 cm. A total of 15 fry were randomly stocked into each of 12 rearing tanks (15 L) equipped with continuous aeration. Prior to stocking, the fish were acclimated to the new water conditions and system for 24 hours. The fry were obtained from the Kutasari Freshwater Fish Hatchery, Purbalingga, Indonesia.

During the 30-day experimental period, the fish were fed twice daily at 8:00 AM and 4:00 PM at a feeding rate of 5% of the total biomass. Uneaten feed and feces were removed by siphoning to maintain water quality. Fish growth parameters including weight gain, length increment, feed conversion ratio (FCR), feed efficiency (FE), average daily gain (ADG), specific growth rate (SGR), and survival rate (SR) were measured weekly to monitor growth performance. Water quality parameters were monitored daily throughout the rearing period to ensure optimal conditions.

Research Parameter

Proximate Analysis

The proximate composition of *Tubifex* meal was analyzed to determine moisture, ash, crude protein, crude lipid, and carbohydrate contents. Moisture content was measured using a standard thermogravimetric method by drying the samples at 105 °C for 1-6 hours until a constant weight was achieved. Ash content was determined by incinerating the samples in a muffle furnace at a temperature of 500-600 °C until complete combustion was achieved. Crude protein content was analyzed using the Kjeldahl method after the samples were oven-dried, while crude lipid was extracted using the Soxhlet method with an organic solvent. Carbohydrate content was calculated by subtracting the sum of moisture, ash, protein, and fat contents from the total weight of the sample. The proximate analysis procedures followed the standard methods as described by Junianto et al. (2020).

Growth Performance of Fish Fry

Growth performance parameters observed in this study included weight gain (WG), length increment (LI), feed conversion ratio (FCR), feed efficiency (FE), average daily growth (ADG), specific growth rate (SGR), and survival rate (SR), following the methodology described by (Madusari et al., 2025; Rahman & Arifuzzaman, 2021).

Absolute weight gain (WG) was calculated as:

$$WG = Wt - W_0,$$

where Wt is the final weight (g) and W_0 is the initial weight (g).

Absolute length increment (LI) was determined using the formula:

$$LI = Lt - L_0,$$

where Lt is the final length (cm) and L_0 is the initial length (cm).

Feed conversion ratio (FCR) was computed as:

$$FCR = \text{Total feed given (g)} / \text{Total weight gain (g)}.$$

Feed efficiency (FE) was expressed as:

$$FE = (\text{Weight gain} / \text{Feed intake}) \times 100.$$

Average daily growth (ADG) was calculated using:

$$ADG = (Wt - W_0) / t,$$

where t is the duration of the study in days.

Specific growth rate (SGR) was determined by the equation:

$$SGR = [(\ln Wt - \ln W_0) / t] \times 100,$$

where ln represents the natural logarithm.

Survival rate (SR) was measured using the following formula:

$$SR = (\text{Number of fish harvested} / \text{Number of fish stocked}) \times 100.$$

Water quality

Water quality parameters, including temperature, pH, and dissolved oxygen (DO), were routinely measured using a digital thermometer, a pH meter, and a DO meter to ensure optimal rearing conditions, with measurements conducted daily at 8:00 AM and 4:00 PM.

Data Analysis

Experimental data on growth performance, feed efficiency, and survival rate were collected every seven days, whereas water quality parameters were measured daily (morning and afternoon). The growth, feed utilization, and survival data were analyzed using one-way analysis of variance (ANOVA) at a 5% significance level. If significant differences were found, post hoc comparisons were performed using Tukey's Honest Significant Difference (HSD) test. For non-parametric data, the Kruskal–Wallis test was applied, followed by Mann–Whitney U tests for pairwise comparisons. All statistical analyses were conducted using SPSS software version 22. Water quality data were analyzed descriptively to assess the environmental stability throughout the experimental period.

RESULTS

Proximate Composition of Feed

The results of the proximate analysis (Table 2) indicate that increasing the substitution level of fishmeal with silk worm (*Tubifex* sp.) meal significantly influenced the nutrient composition of the experimental diets, particularly in terms of crude protein (CP) content. The CP content increased markedly from 17.68% in the control diet (P1) to 26.77% in the P4 treatment, where 35% of fishmeal was replaced with *Tubifex* meal. This notable increase suggests that *Tubifex* meal serves as a highly promising source of animal protein, particularly suitable as an alternative to fishmeal in supporting the high protein requirements of Nile tilapia (*Oreochromis niloticus*) fry.

Previous studies have demonstrated that *Tubifex* sp. contains high levels of crude protein, typically ranging from 50% to 60% on a dry matter (Herawati et al., 2016). In addition, *Tubifex* is known to possess a relatively complete profile of essential amino acids, including lysine, methionine, and threonine, which are crucial for protein synthesis, tissue development, and overall growth in fish (Herawati et al., 2020; Stern et al., 1990; Yanar et al., 2003).

Table 2. Proximate Composition of Experimental Diets

Experimental Diet	Chemical composition/proximate					
	Moisture (%)	CP (%)	CL (%)	CF (%)	NFE (%)	Ash (%)
P1	12,05	17,68	12,20	11,46	51,06	7,60
P2	10,85	20,53	12,25	9,39	46,05	11,78
P3	11,11	20,36	10,77	8,11	45,62	15,15
P4	11,62	26,77	13,32	6,27	41,53	12,11

Abbreviations: (CP) Crude Protein, (CL) Crude Lipid, (CF) Crude Fiber, (NFE) Nitrogen-free Extract

In addition to protein, crude lipid (CL) content also increased, from 12.20% in the control (P1) to 13.32% in P4. Lipids serve as a critical energy source for fish, contributing to the absorption of fat-soluble vitamins and the structural integrity of cell membranes. The observed increase in fat content suggests that *Tubifex* meal also contributes beneficial lipid fractions, which can enhance the energy density and nutritional value of aquafeed formulations (Tocher, 2003).

Conversely, a notable decline was observed in crude fiber (CF) content, which decreased from 11.46% in P1 to 6.27% in P4. A similar trend was observed for nitrogen-free extract (NFE), which also decreased with increasing *Tubifex* inclusion. Lower levels of CF and NFE in the feed indicate a shift towards a more digestible and energy-efficient formulation (Saeid et. al., 2013). This could improve nutrient utilization and enhance feed digestibility, which are particularly important during early growth stages (Wang & Wang, 2018).

Overall, the improvement in key nutrient components such as crude protein and lipid, alongside the reduction in indigestible fractions like crude fiber and NFE, suggests that the inclusion of *Tubifex* meal enhances feed quality. This makes *Tubifex*-based feed a nutritionally advantageous option for supporting optimal growth and health in Nile tilapia fry.

Growth Performance of Nile Tilapia Fry

The results of this study demonstrated that replacing fishmeal with silk worm (*Tubifex* sp.) meal had a significantly positive impact on the growth performance of Nile tilapia (*Oreochromis niloticus*) fry. As shown in Table 3, the highest final body weight was achieved in the P4 treatment group (35% *Tubifex* substitution) at 0.95 g, followed by P3 (25%) at 0.91 g. In contrast, the control group (P1) recorded a final weight of only 0.75 g. These findings

clearly indicate that increasing levels of *Tubifex* meal in the diet promoted superior weight gain compared to diets based solely on fishmeal. This trend was further confirmed by the absolute weight gain data, where P3 and P4 exhibited significantly higher values (0.45 g and 0.46 g, respectively) compared to P1 (0.32 g) and P2 (0.34 g).

Absolute length gain also showed a consistent upward trend with increasing levels of *Tubifex* inclusion. The P4 treatment resulted in the highest length gain (0.97 cm), followed by P3 (0.66 cm), while the control group recorded the lowest length increment (0.42 cm). These differences were statistically significant ($P < 0.05$), suggesting that the partial substitution of fishmeal with *Tubifex* meal significantly enhanced linear growth. This improvement may be attributed to the presence of essential amino acids in *Tubifex sp.*, such as lysine, methionine, and threonine, which are vital for muscle development and protein synthesis in fish (Herawati et al., 2020; Herawati et al., 2016; Santamaría & Santamaría, 2011; Sholikah et al., 2020; Yanar et al., 2003).

In addition, both Average Daily Gain (ADG) and Specific Growth Rate (SGR) reflected the same growth-enhancing trend. The highest ADG was recorded in P4 (0.016 g/day), followed by P3 (0.015 g/day), while P1 and P2 exhibited lower values (0.011 g/day). Similarly, SGR values were highest in P4 (2.28%/day) and P3 (2.27%/day), whereas P1 recorded the lowest SGR (1.85%/day). These results confirm that the substitution of fishmeal with *Tubifex* meal not only supports safe growth but also enhances growth rate efficiency in tilapia fry.

Table 3. Growth Performance Measurement

Parameter	Treatment			
	P1	P2	P3	P4
W_o (g)	0,43	0,44	0,46	0,48
Wt (cm)	2,91	2,95	3,02	3,01
L_o (g)	0,75	0,77	0,91	0,95
Lt (cm)	3,34	3,47	3,69	3,94
WG (g)	$0,32\pm0,05^{ab}$	$0,34\pm0,03^{a}$	$0.45\pm0,03^{b}$	$0.46\pm0,05^{b}$
LI (cm)	$0,42\pm0,03^{a}$	$0.52\pm0,04^{a}$	$0.66\pm0,03^{b}$	$0.97\pm0,05^{c}$
ADG (g)	$0,011^{a}$	$0,011^{a}$	$0,015^{a}$	$0,016^{a}$
SGR (%)	$1,85^{a}$	$1,87^{a}$	$2,27^{b}$	$2,28^{b}$
FCR (%)	$0,97\pm0,05^{a}$	$1.08\pm0,004^{b}$	$1.03\pm0,02^{a}$	$1.08\pm0,04^{b}$
FE (%)	$37,75\pm5,62^{a}$	$40.78\pm2,71^{a}$	$57.07\pm2,35^{b}$	$61.93\pm0,61^{b}$
SR (%)	$51,11\pm3,85^{a}$	$66.67\pm6,67^{b}$	$75.56\pm3,85^{bc}$	$82.22\pm3,85^{c}$

Regarding feed utilization, Feed Conversion Ratio (FCR) and Feed Efficiency (FE) provided complementary insights. The best FCR was obtained in the control group (0.97), closely followed by P3 (1.03), while P2 and P4 had slightly higher values (1.08). Nevertheless, FE was highest in P4 (61.93%), followed by P3 (57.07%), with the control showing the lowest value (37.75%). This suggests that despite a slightly higher FCR, the feed in the P4 group was more efficiently converted into biomass. This enhanced bioconversion is likely due to the digestibility of *Tubifex* meal and its favorable lipid profile (Saravanan, Samyappan, Gnanavel, & Purushothaman, 2015). As reported, the presence of natural digestive enzymes and essential fatty acids in *Tubifex* worms may facilitate faster metabolism and better nutrient absorption (Ghorbani Vaghei, Yousefi Jourdehi, Pajand, Monsef Shokri, & Mohseni, 2023; X. Li et al., 2024).

The Survival Rate (SR) data also revealed a consistent increase with higher levels of *Tubifex* inclusion. The highest SR was recorded in P4 (82.22%), followed by P3 (75.56%) and P2 (66.67%), while the control group had the lowest survival at 51.11%. This improvement in

survival may be attributed to the presence of functional nutrients in *Tubifex*, such as unsaturated fatty acids, bioactive peptides, zinc, and B-complex vitamins, which contribute to enhanced immunity and physiological resilience in fish (Simangunsong, et. al., 2023; Sravani et al., 2025). Overall, these findings are consistent with previous studies. (Listya & Himmatul, 2022; Sebayang, Sabrina, Rahmawati, & Lubis, 2021) reported that locally available animal proteins, such as earthworms and insect larvae, can improve growth performance and feed efficiency in freshwater fish. (Aktaş, Genç, Bozkurt, Genç, & Naz, 2019; Mugwanya, Dawood, & Sewilam, 2025) reported that the inclusion of *Tubifex* meal in aquafeed can enhance growth performance, immune response, flesh quality, and pigmentation without compromising overall fish productivity. Despite these promising findings, studies investigating the incorporation of Tubifex meal into formulated diets remain limited. The present study demonstrates that dietary inclusion levels of *Tubifex* meal up to 35% exerted beneficial effects across all assessed growth parameters.

Considering the significant improvements in weight gain, length increment, ADG, SGR, FE, and SR, the use of *Tubifex* meal as a partial replacement for fishmeal, particularly at 25-35% inclusion levels can be considered highly effective in enhancing the growth performance of Nile tilapia fry. In addition to improving farming efficiency, this strategy may also reduce reliance on imported fishmeal, which continues to rise in cost and faces sustainability concerns (Mugwanya et al., 2025; Oplinger, Bartley, & Wagner, 2011). Thus, the development of *Tubifex*-based feeds holds great promise from both biological and economic perspectives in sustainable freshwater aquaculture.

Water Quality

Throughout the rearing period, the water quality parameters remained within the optimal range to support the growth and survival of Nile tilapia fry (Table 4). Water temperature was consistently stable, ranging from 28.08 to 28.32 °C. This range falls within the optimal temperature window for tilapia aquaculture, which is generally between 26 and 30 °C. Within this range, metabolic activity, feed intake, and growth performance are typically maximized (Lou, Cao, Sun, & Zheng, 2013; Smutná, Hilscherová, Pašková, & Maršálek, 2008). The negligible variation in water temperature among treatments indicates that the feed formulations, particularly the replacement of fishmeal with *Tubifex* meal, did not induce thermal stress or disrupt thermal homeostasis in the fish.

Table 4. Water quality parameters observed throughout the experimental period for each dietary treatment

Parameter	Treatment			
	P1	P2	P3	P4
Temperature (ºC)	28,08	28,26	28,29	28,32
pH	7,20	7,38	7,36	7,60
DO (mg/L)	7,91	7,94	7,99	7,96

The pH values of the water were also within an acceptable range, ranging from 7.20 to 7.60 during the study. This range is considered neutral to slightly alkaline and falls well within the ideal tolerance range for Nile tilapia, which is typically between 6.5 and 8.5 (El-Sherif & El-Feky, 2009). The stability in pH across treatments suggests that metabolic activities and organic matter decomposition in the rearing environment were proceeding normally, without generating excessive acidic byproducts that could compromise water quality.

Dissolved oxygen (DO) concentrations were recorded between 7.91 and 7.99 mg/L, which is considered highly favorable for freshwater fish. DO levels above 5 mg/L are generally

sufficient to support aerobic respiration and physiological processes in fish (Marian & Pandian, 1984). The consistently high DO values observed in all treatment groups suggest that the rearing system was well-oxygenated and that the inclusion of *Tubifex* meal did not contribute fto increased organic waste accumulation or oxygen depletion (Yang et al., 2020).

Overall, the data indicate that substituting fishmeal with *Tubifex* meal in feed formulations did not have any adverse effects on water quality. This finding implies that *Tubifex*-based diets are environmentally compatible with intensive aquaculture systems and can be used without compromising water quality parameters essential for fish health and productivity. Thus, the integration of *Tubifex* meal into tilapia diets supports not only biological performance but also environmental sustainability in aquaculture operations.

DISCUSSION

The findings of this study demonstrate that silk worm (*Tubifex* sp.) meal possesses substantial potential as a substitute for fishmeal in the diet of Nile tilapia (*Oreochromis niloticus*) fry. Inclusion of *Tubifex* meal at substitution levels of 25% (P3) and 35% (P4) significantly improved growth performance, feed utilization efficiency, and survival rate compared to the control group without *Tubifex* meal (P1). These results confirm that *Tubifex* meal is not only functionally capable of replacing fishmeal, but also enhances the overall aquaculture performance of Nile tilapia fry.

Fishmeal remains the dominant protein source in aquafeeds due to its excellent amino acid profile and high digestibility. However, the global fishmeal industry faces challenges including limited supply, escalating prices, and environmental concerns related to overfishing of small pelagic fish (Jannathulla et al., 2019). Consequently, identifying high-quality, cost-effective, and environmentally friendly local protein sources is critical for advancing sustainable aquaculture practices (Iheanacho, Hornburg, Schulz, & Kaiser, 2025).

Tubifex sp. emerges as one of the most promising local protein alternatives. It contains 50-60% crude protein on a dry matter basis and is rich in essential amino acids such as lysine, methionine, threonine, and arginine, which are essential for growth and tissue repair in fish (Herawati et al., 2020; Stern et al., 1990; Yanar et al., 2003). Additionally, *Tubifex* is known to contain beneficial lipids, including polyunsaturated fatty acids (e.g., EPA and DHA), which support physiological functions and immune response in fish (Sravani et al., 2025). Its high palatability and digestibility make it especially suitable for fry and early juvenile stages (Oplinger et al., 2011).

This study found that the highest Specific Growth Rate (SGR) was recorded in the P4 group (2.28%/day), followed closely by P3 (2.27%/day), while the control group showed the lowest SGR (1.85%/day). A similar trend was observed for Average Daily Gain (ADG), with the highest values in P4 (0.016 g/day) and P3 (0.015 g/day), compared to 0.011 g/day in both P1 and P2. These results confirm that *Tubifex* meal enhances daily growth rates and protein utilization efficiency in Nile tilapia fry.

Feed Efficiency (FE) also improved significantly in the P3 and P4 treatments, reaching 57.07% and 61.93%, respectively, compared to only 37.75% in the control. Although the lowest Feed Conversion Ratio (FCR) was recorded in the control group (0.97), values in P3 (1.03) and P4 (1.08) were still within an acceptable and efficient range for intensive aquaculture systems. The high FE values in *Tubifex*-based diets suggest better digestibility and nutrient conversion, likely due to the presence of proteolytic enzymes and balanced lipid composition (de Valk, 2021; Mugwanya et al., 2025; Oplinger et al., 2011).

Survival rate (SR) was another critical parameter that improved consistently with increasing levels of *Tubifex* meal. The highest SR was observed in P4 (82.22%), followed by P3 (75.56%) and P2 (66.67%), while the control showed the lowest survival (51.11%).

Enhanced survival may be attributed to functional nutrients in *Tubifex*, such as bioactive peptides, unsaturated fatty acids, zinc, and B-complex vitamins, which are known to improve immune response and disease resistance (Firdausi et al., 2025).

Importantly, the use of *Tubifex* meal did not negatively affect water quality during the study. Parameters such as temperature (28.08-28.32 °C), pH (7.20-7.60), and dissolved oxygen (7.91-7.99 mg/L) remained within optimal ranges for tilapia growth. This indicates that *Tubifex*-based feeds did not lead to increased organic waste or deterioration of the aquatic environment, supporting their use in sustainable and intensive culture systems (Yang et al., 2020).

From an economic and environmental perspective, *Tubifex* meal also offers distinct advantages. It can be produced locally at relatively low cost using organic waste as a substrate, aligning with the principles of circular economy and waste-to-feed bioconversion. Thus, replacing fishmeal with *Tubifex* supports production cost (Wanapat, Cherdthong, Phesatcha, & Kang, 2015).

Nonetheless, practical application of these findings requires attention to feed safety and consistency. The production of *Tubifex* meal must adhere to hygienic standards to avoid contamination with heavy metals or pathogens. Further studies are needed to assess the long-term effects of *Tubifex*-based diets on reproductive performance, flesh quality, and consumer acceptance, particularly for market-sized fish.

This study also contributes to the broader development of local protein-based feed innovations. In addition to *Tubifex* sp., other alternative protein sources such as *Hermetia illucens* larvae (black soldier fly), *Lumbricus rubellus* (earthworms), and aquatic snails have been investigated for feed diversification (Čengić-Džomba, Džomba, Muratović, & Hadžić, 2019; Wanapat et al., 2015; Wu et al., 2024). Compared to these alternatives, *Tubifex* offers distinct benefits in terms of palatability, availability in tropical aquatic ecosystems, and ecological compatibility with freshwater fish diets.

Strategically, the findings of this study align with national priorities to reduce dependency on imported feed ingredients, particularly fishmeal, and to strengthen food security through sustainable aquaculture. The Ministry of Marine Affairs and Fisheries of Indonesia emphasizes the importance of promoting local feed development to enhance productivity, efficiency, and sustainability in the aquaculture sector (KKP, 2021; Wardono & Prabakusuma, 2017).

In conclusion, considering growth performance, feed efficiency, survival, environmental impact, and economic viability, *Tubifex* meal is a promising and feasible ingredient for replacing fishmeal at up to 35% inclusion in the diet of Nile tilapia fry. The wide-scale adoption of this strategy has the potential to serve as a sustainable feed innovation for Indonesia's national aquaculture industry.

CONCLUSIONS

This study confirms the potential of silk worm (*Tubifex* sp.) meal as a partial substitute for fishmeal in the diet of Nile tilapia (*Oreochromis niloticus*) fry. Replacing fishmeal at levels of 25-35% significantly enhanced growth performance, feed efficiency, and survival rate without negatively affecting water quality. The P4 treatment (35% *Tubifex* meal) achieved the highest specific growth rate, feed efficiency, and survival, demonstrating that *Tubifex* meal supports optimal physiological development in early-stage tilapia. Moreover, the use of *Tubifex* meal provides environmental and economic advantages, including the potential for local production using organic waste substrates and contributing to reduced dependency on imported fishmeal. These benefits align with the principles of sustainable and resilient aquaculture. It is recommended that *Tubifex* meal be further explored in commercial feed formulations, while

ensuring safety standards for feed hygiene and nutrient consistency. Future research should also investigate its long-term effects on reproduction, product quality, and consumer acceptance in market-sized fish.

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