

## SUSTAINABLE FISH FEED ALTERNATIVES: PERFORMANCE OF FISH WASTE AND TEMPE-BASED FEED ON THE QUALITY AND FEED ACCEPTANCE OF EARLY FISH FRY

**Alternatif Pakan Ikan Berkelanjutan: Kinerja Pakan Berbasis Limbah Ikan dan Tempe Terhadap Kualitas dan Penerimaan Pakan pada Benih Ikan Tahap Awal**

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### ABSTRACT

*The availability of organic waste offers a promising opportunity for developing sustainable alternative feed sources. This study aimed to evaluate the performance of an independent feed formulated from fish waste and tempe waste on feed acceptance and early-stage fry performance. A non-factorial Completely Randomized Design (CRD) was employed, consisting of five feed formulation treatments with four replications: P0 (100% control), P1 (100% alternative), P2 (50% alternative + 50% control), P3 (75% alternative + 25% control), and P4 (25% alternative + 75% control). ANOVA results showed no significant differences ( $p > 0.05$ ) in growth performance, but revealed significant differences in survival rate ( $p < 0.05$ ). The best performance was observed in treatment P1, which resulted in length gain (4.63 cm), weight gain (17.01 g), SGR (3.22%), FCR (1.84), and SR (54%). The buoyancy test indicated that the alternative feed could float for 2 minutes with 100% palatability. Water quality parameters remained within optimal ranges across all treatments, with temperature (26°C), DO (5 mg/L), pH (8.5),  $\text{NH}_3/\text{NH}_4$  (0.3 mg/L), and TDS (197.8 mg/L). These findings indicate that feed formulated from fish and tempe waste can serve as a sustainable, cost-effective, and environmentally friendly alternative feed for tilapia fry during the early stages of culture.*

*Keywords: Alternative Feed, Fish–Tempe Waste, Tilapia Fry*

### ABSTRAK

Ketersediaan limbah organik merupakan peluang untuk menciptakan pakan alternatif yang berkelanjutan. Penelitian ini bertujuan untuk mengevaluasi kinerja pakan mandiri berbasis limbah ikan-tempe terhadap penerimaan dan performa benih pada tahap awal. Rancangan yang digunakan berupa Rancangan Acak Lengkap (*non factorial*) yang terdiri dari lima perlakuan formulasi pakan dengan empat ulangan. P<sub>0</sub> (kontrol 100%), P<sub>1</sub> (alternatif 100%), P<sub>2</sub> (alternatif 50%+ kontrol 50%), P<sub>3</sub> (alternatif 75% + kontrol 25%), P<sub>4</sub> (alternatif 25% + kontrol 75%). Hasil anova tidak berbeda nyata ( $p > 0,05$ ) pada performa pertumbuhan, namun berbeda nyata pada tingkat kelangsungan hidup ( $p < 0,05$ ). Perlakuan terbaik pada P<sub>1</sub> dengan pertumbuhan

panjang (4,63 cm), penambahan bobot (17,01 g), SGR (3,22%), FCR (1,84), dan SR (54%). Daya apung pakan alternatif mencapai 2 menit dengan palatabilitas 100 %. Kualitas air berada pada kisaran ideal pada seluruh perlakuan dengan suhu (26°C), DO (5 mg/L), pH (8,5), NH<sub>3</sub>/NH<sub>4</sub> (0,3 mg/L), serta TDS (197,8 mg/L). Hasil penelitian menunjukkan bahwa pakan berbasis limbah ikan dan tempe dapat digunakan sebagai pakan alternatif berkelanjutan yang murah dan ramah lingkungan untuk benih ikan pada tahap awal pemeliharaan.

**Kata Kunci:** Limbah Ikan-Tempe, Pakan Alternatif, Benih Nila

## INTRODUCTION

Feed is a key component in aquaculture activities, playing a role in improving growth and health, and determining production efficiency. In intensive farming systems, feed distribution costs can reach 50–70% of production costs. Therefore, the sustainability of aquaculture businesses depends on the availability of quality feed. Dependence on commercial feed, coupled with fluctuating feed prices, presents a significant challenge for small- to medium-scale farmers in securing capital. This is driven by the export of raw materials for commercial feed, such as fishmeal and soybean meal. Fishmeal and soybean meal are the ingredients with the largest composition in formulations, serving as sources of animal and vegetable protein. Therefore, this situation encourages efforts to develop more economical, independent feeds utilizing local raw materials. A potential approach could be utilizing industrial waste from organic materials as an alternative raw material (Estévez *et al.*, 2022; Karimi *et al.*, 2018).

On the other hand, handling organic waste from the processing industry presents a serious challenge. Organic waste management is not limited to controlling environmental impacts (Saribanon *et al.*, 2023). However, it also presents an opportunity to innovate alternative feed sources for fish farming. Waste from the fish canning industry can include heads, bones, and even meat still attached to the bones (Orbawati *et al.*, 2024). The nutritional content of this waste consists of 21.5% protein, 5.08% fat, and 4.46% ash (Ovissipour *et al.*, 2012). With proper handling and processing, this waste has the potential to be used as a substitute for commercial fishmeal. At the medium-scale industrial level, tempe waste, in the form of skins and unsold tempe scraps or tempe that has failed production, is rich in vegetable protein, soluble fiber, and micronutrients that can improve the nutritional balance in feed (Romulo & Surya, 2021; Karimi *et al.*, 2018). Fermented soybeans, which are used to make tempe, contain 17.4% protein, 8.23% fat, 1.33% ash, 7.3% carbohydrate, and 65.74% water (Rizal *et al.*, 2022). Therefore, the combination of fish waste and tempe in feed formulations can be an opportunity to support circular economy policies by reducing sources of environmental pollution and directly reducing feed costs in aquaculture production.

Although fish waste and tempe waste have potential as raw materials for fish feed, the simultaneous use of these two materials has not been reported. Varied nutritional characteristics pose a challenge in developing feed formulations to obtain fish feed with nutritional standards. Appropriate feed nutrition will positively impact feed effectiveness and efficiency (Gatlin *et al.*, 2007; Sagada *et al.*, 2017). In the fry phase, these aspects are very necessary so that the nutritional suitability and level of fish preferences can be met to increase the metabolism of the fry (Hamre *et al.*, 2013; Papatryphon & Soares, 2000; Rønnestad *et al.*, 2013). Therefore, this study was conducted to assess the quality of feed nutrition, palatability and buoyancy of the feed to evaluate the growth performance of fish in the early phase of tilapia fry, so that it can be used as a basis for the development of sustainable local industrial waste.

## METHODS

### Research Time and Location

This research was conducted in August – October 2025. Fish maintenance was carried out in the freshwater fish cultivation pond of Banyuwangi State Polytechnic and chemical testing was carried out at the Integrated Laboratory, Department of Agriculture, Banyuwangi State Polytechnic.

### Tools and Materials

The tools used in this study included a grinding machine, a press, a heater, scales, a millimeter block, and a water quality tester. The materials used included test fry, fish waste, tempe waste, bran, tapioca, natural attractants, vitamins, minerals, and commercial feed as controls.

### Research Design

This study used a Completely Randomized Design (CRD) consisting of 5 treatments and 4 replications, resulting in 20 experimental units.

- P<sub>0</sub> : Commercial feed (100%)
- P<sub>1</sub> : Alternative feed (100%)
- P<sub>2</sub> : Alternative feed (50%) + commercial feed (50%)
- P<sub>3</sub> : Alternative feed (75%) + commercial feed (25%)
- P<sub>4</sub> : Alternative feed (25%) + commercial feed (75%)

Twenty fish were stocked in each experimental unit. The average length of the fish was  $4.38 \pm 0.03$  cm and the average weight was  $0.99 \pm 0.02$  g.

### Research Procedure

#### Waste Raw Material Preparation

The first step in this study was the collection of industrial waste raw materials from a fish canning industry in Muncar District, Banyuwangi Regency. Meanwhile, soybean tempe waste comes from a home industry in Rogojampi District, Banyuwangi Regency. Next, the waste is washed thoroughly under running water, removing gills and blood residue. The collected tempe waste is first cleaned of any physical dirt. The next process is drying under direct sunlight for 2-3 days until it reaches a moisture content of approximately 12%. The drying process facilitates the flouring process, which is the process of converting coarse raw materials into finer particles to facilitate the mixing and feed manufacturing process. The fermentation process of raw materials is a biological process involving microorganisms (such as bacteria, yeast, or mold) to break down complex compounds in raw feed materials into simpler forms, thereby increasing the nutritional value, digestibility, and palatability of the feed (Elsaidy et al., 2015). This process can be carried out on raw feed materials and feed pellets. Fermentation is carried out by heating the refined raw materials and adding a combination of microorganisms such as *Lactobacillus* sp., *Saccharomyces cerevisiae*, and *Aspergillus niger* for 3-7 days. The success of the fermentation process is indicated by a distinctive aroma and the presence of mold on the surface of the material.

#### Feed Formulation

Feed formulation calculations were carried out using a trial-and-error method using a Microsoft Excel worksheet. A Microsoft Excel worksheet is a simple method that is quite relevant for aquaculture needs (Suresh, 2016; Risyahadi et al., 2022). This formulation calculation aims to obtain the correct composition for feed production (Table 1).

Table 1. Feed Formulation

Name of Raw Material	Amount of Raw Materials (%)
Fish Waste	40
Tempe Waste	25
Fine Bran	10
Natural Attractant	10
Starch Flour	10
Vitamin and Mineral	5
Total	100

### Feed Manufacturing

Feed manufacturing begins with mixing the raw feed ingredients according to the composition. Mixing is done by mixing the smallest amount of ingredients first to ensure a thorough blend. The bonding process is carried out using heat for 10-15 minutes at 100°C. Next, the material is molded to a diameter of approximately 1-2 mm, matching the fish's mouth opening. The molded feed is dried again to obtain feed with a moisture content of <12%.

### Research Parameters

#### Independent Feed Nutrition Analysis

Proximate analysis was conducted to determine the levels of protein, fat, carbohydrate, crude fiber, and water. Moisture content was tested by heating the sample at 105°C for 3 hours until a constant weight was achieved. Ash content was tested by burning the sample at 550°C until a constant weight was achieved. Protein content was analyzed using the Kjeldahl method, while fat content was analyzed using the extraction method. Meanwhile, carbohydrates are determined based on the difference of 100% with the total moisture, ash, protein, and fat content (National Standardization Agency, 2006).

#### Floating Time

Floating time testing is conducted to assess the ability of pellets to float in water. The test is conducted by placing a number of pellets in the water and measuring the time between when the pellets are released and when they sink (Hutagalung *et al.*, 2021).

#### Feed Palatability

Feed palatability is evaluated by measuring the level of feed consumption in fish after feeding. Palatability is calculated based on (Alves *et al.*, 2019).

$$\text{Palatability (\%)} = (\text{weight of feed consumed} / \text{weight of feed given}) \times 100$$

#### Fish Fry Growth Performance

Fish fry growth performance was observed through length gain (L), weight gain (Wg), specific growth rate (SGR), feed conversion ratio (FCR), survival rate (SGR), and survival rate (SR) calculated based on (Hassan *et al.*, 2021; Méndez-Martínez *et al.*, 2023), where:

Length Growth (cm): Final length – Initial length

Weight Gain (Wg): Final weight – Initial weight

Specific Growth Rate (%/day):  $[(\ln(\text{final weight}) - \ln(\text{initial weight})) / \text{time}] \times 100$

Feed Conversion Ratio:  $[\text{Total feed given (g)} / \text{Final biomass - dead fish weight (g)}] - \text{Initial fish biomass (g)}$

Survival Rate (%):  $[(\text{Initial number of fish} / \text{Final number of fish}) \times 100]$

## Water Quality

Water quality is a supporting factor in the success of aquaculture activities. Water quality parameters measured in this study included temperature, dissolved oxygen, pH, NH<sub>3</sub>/NH<sub>4</sub>, and TDS. Water quality measurements were conducted daily at 7:00 AM and 4:00 PM.

## RESULTS

### Nutritional Content of Feed

Feed nutrient content testing showed that the feed based on fish waste and tempe raw materials contained 10.47% moisture, 9.58% ash, 10.19% fat, 42.16% protein, 25.11% carbohydrate, and 3.2% crude fiber (Table 2). These components are within the recommended range for fish fry feed (NRC, 2011). The tested protein content can be classified as very good for fish fry and meets the standard requirements for freshwater fish fry, which is 25-45%. Similarly, the maximum moisture content of 12% indicates that the quality of the pellet feed meets the standards for artificial feed (National Standardization Agency, 2024).

Table 2. Nutritional Composition of Fish Waste and Tempe-Based Feed

Parameter	Result (%)
Protein	42.16
Fat	10.19
Carbohydrate	25.11
Crude Fiber	3.2
Ash	9.58
Water	10.47

Proximate analysis results indicate that the self-contained feed, composed of fish waste from trimmings and discarded tempe waste, meets the nutritional requirements of fry in the early stages of nursery or early growth.

### Feed Palatability

Palatability testing demonstrated that the self-contained feed, containing protein sources derived from fish waste and tempe, had 100% palatability, characterized by a rapid, aggressive, and zero-waste response in the experimental units. This value indicates that the fry consumed all of the feed provided.

### Buoyancy

The physical quality of the feed in this study was demonstrated by its buoyancy, which lasted approximately 2 minutes before sinking. Although this is a relatively short time, this lag allows the fry to recognize aromas and respond to the feed on the surface.

### Early-Phase Tilapia Performance

The results of the fry performance study indicate that the use of feed based on fish waste, tempe, and a combination of other raw materials resulted in different growth responses in early-stage fry reared for 60 days (Table 3). The initial length of the fish was relatively uniform, ranging from 4.38 to 4.63 cm. However, the highest length increase was recorded in P3 (11.23 cm) and P2 (11.18 cm). A similar pattern was observed for final weight, with P1 (18.0 g) and P3 (17.75 g) showing the highest values compared to the control (15.0 g). Meanwhile, absolute weight increased across all treatments, with the highest value in P1 (17.01 g), followed by P3 (16.76 g), and P2 (15.28 g).

In this study, the specific growth rate (SGR) ranged from 3.01 to 3.22%/day. The highest

values were achieved in P1 (3.22%) and P3 (3.20%), while the control had the lowest SGR (3.01%). Feed efficiency also increased across all treatments, as indicated by higher FCR values in P1 (1.84) and P3 (1.86) compared to the control (2.32). Despite differences in the average treatment, the ANOVA results showed no significant differences between treatments ( $P > 0.05$ ). Meanwhile, the survival rate (SR) showed a significant difference ( $p < 0.05$ ), with the highest values in P4 (55%) and P1 (54%). This value indicates that the feed formulation was able to support physiological conditions and improve fish survival. Overall, the independent feed formulation based on fish waste and tempe resulted in better growth performance and feed efficiency in P1–P3 compared to the control.

Table 3. Performance of Early-Phase Tilapia Fry

Parameter	P0	P1	P2	P3	P4
Initial Length (cm)	4.63	4.63	4.50	4.63	4.38
Final length (cm)	9.33	10.88	11.18	11.23	10.15
Length Increase (cm)	4.63	4.63	4.50	4.63	4.38
Initial Weight (g)	0.98	0.99	0.98	1.00	1.00
Final Weight (g)	15.0	18.0	16.25	17.75	16.0
Weight Gain (g)	14.03	17.01	15.28	16.76	14.99
SGR (%)	3.01	3.22	3.10	3.20	3.06
FCR	2.32	1.84	2.13	1.86	2.06
SR (%)	51 <sup>b</sup>	54 <sup>a</sup>	53 <sup>ab</sup>	43 <sup>c</sup>	55 <sup>a</sup>

### Water Quality Measurements

Water quality parameters throughout the study showed relatively uniform values across all treatments (P0–P4) and were within the optimal range for rearing freshwater fish fry. The rearing temperature was stable at 26°C across all treatments. Dissolved oxygen (DO) levels were recorded at 5 mg/L across all experimental units. The water pH was around 8.5, while the ammonia ( $\text{NH}_3/\text{NH}_4^+$ ) concentration ranged from 0.30–0.33 mg/L. Total dissolved solids (TDS) ranged from 195–200 mg/L (Table 4).

Table 4. Water Quality Measurements

Parameter	Treatment				
	P0	P1	P2	P3	P4
Temperature (°C)	26	26	26	26	26
DO (mg/L)	5	5	5	5	5
pH	8.5	8.5	8.5	8.5	8.5
$\text{NH}_3/\text{NH}_4$	0.3	0.3	0.3	0.3	0.3
TDS	196	195	200	199	199

Variation between treatments in this study was minimal and did not indicate ecological fluctuations that could cause environmental stress. Overall, all parameters were within the recommended range for early-stage fish fry rearing, suggesting that differences in fish performance in this study were primarily due to the influence of feed formulation rather than differences in environmental conditions.

## DISCUSSION

### **Feed Nutritional Quality**

The protein content of 42.16% in the alternative feed indicates that the combination of fish waste from fish trimmings and discarded tempe can provide a highly recommended source of animal and vegetable protein. This level is within the optimal range to support the growth of tilapia fry in the early stages. Fry require a protein content of 35-45% in feed for tissue growth and to meet the body's metabolic needs (Fernandes *et al.*, 2016; Sankian *et al.*, 2017; Teles *et al.*, 2020). The fat content of 10.19% meets the standard energy requirements for fry. According to the National Research Council (2011), the ideal fat range for larval and fry feed is 8-12% as a backup energy source in addition to protein (Mir *et al.*, 2020; Morais *et al.*, 2007). The availability of adequate fat can optimize protein performance in the fish's body, resulting in optimal growth. This is because the amino acids in the protein are not used as the primary energy source but rather for tissue synthesis (Paul *et al.*, 2022).

A moisture content of 10.47% indicates excellent physical stability of the feed. A moisture content of <12% in artificial feed can reduce the risk of microbial contamination and extend the feed's shelf life (Maghfiroh & Ikerismawati, 2024; Senarathna *et al.*, 2021). Meanwhile, the use of waste in the form of fillet pieces attached to the head, bones, and fins of fish contributes to an ash content of 9.58%. The ash content range of 5-12% indicates that the homemade feed contains sufficient mineral content without burdening the fish's metabolism (Shearer *et al.*, 1992).

The carbohydrate content of 25.11% and crude fiber of 3.20% are levels that meet the standard requirements of fish fry. Carbohydrates serve as an additional energy source in addition to protein and fat. The digestible carbohydrate level in the diet is 40% for tilapia (Maas *et al.*, 2020). Crude fiber content significantly influences growth rate and feed efficiency, with a crude fiber content of  $\leq 5\%$  being the recommended limit to ensure proper digestive function of the fry (Sun *et al.*, 2019). Crude fiber levels above 8–12% can reduce nutrient digestibility (Obeng *et al.*, 2015). The proximate results of the independent feed indicate that the feed produced in this study can be categorized as a potential sustainable alternative feed for the nursery stage. The use of this feed, in addition to meeting nutritional needs, utilizing organic waste can support approaches to sustainable economic policies for aquaculture (Afreen & Ucak, 2020; Rout *et al.*, 2025; Voss *et al.*, 2021).

### **Palatability**

A palatability value of 100% indicates that the fish are responding perfectly to the feed. Preventing feed loss is crucial, both economically and environmentally (Hancz, 2020). Similar palatability values have been reported with the addition of squid meal, which can increase feed response (Arditya *et al.*, 2019). This high level of palatability is influenced by the combination of raw materials rich in compounds that stimulate fish appetite. Although the fish meal used is derived from trimmings, a byproduct of fish filleting, this waste contains free amino acids, particularly alanine, histidine, and glutamate, which significantly increase fish feeding responses (Putra *et al.*, 2018; Takagi *et al.*, 2020; Wenno *et al.*, 2022). These compounds serve as attractants in feed ingredients that can stimulate the sense of smell and taste in young fish, resulting in a rapid response by the fish being raised (Baek & Cho, 2024; X. Li *et al.*, 2022).

Furthermore, the use of fermented soybean tempe waste can improve palatability through the addition of *Rhizopus* spp. *Rhizopus* spp. produces free amino acids, such as peptides, and volatile compounds that impart a distinctive aroma favored by various types of farmed fish. Previous research has shown that fermented raw materials have a positive effect on appetite, reducing anti-nutritional properties, and improving fish digestibility (Onomu & Okuthe, 2024). The findings of this study support the full acceptance of fish feed produced using fermented fish waste and tempe by fry.

Another contribution comes from the addition of natural attractants containing trimethylamine (TMA), nucleotides, and other marine volatile compounds that can enhance the response of both carnivorous and omnivorous fish (Fang *et al.*, 2019a; Murwani *et al.*, 2016). Attractants produced from fermented shrimp/crustaceans can increase the feeding response in various farmed fish species due to their strong aroma and resemblance to natural prey (He *et al.*, 2022). Therefore, these ingredients enhance feed appeal and maximize palatability. Crustacean-based attractants or marine fermentation enhance consumption, growth performance, and survival in sensitive early stages of fish (Roda *et al.*, 2024).

Fish feed palatability can also be influenced by pellet texture and size, especially for early-stage fish fry, which are sensitive to the physical quality of the feed (Gao *et al.*, 2019a). Early-stage fish fry prefers pellets that are not too hard and are sized to accommodate the fish's mouth opening, making them easy to consume (Lee *et al.*, 2016). A palatability score of 100% indicates that the feed formulation and manufacturing technology have achieved the desired physical characteristics.

### **Buoyancy**

Observations based on physical quality aspects revealed that the feed's buoyancy only reached approximately 2 minutes. This value is lower than the standard for buoyant feed, which is around 10 minutes (Felix & Oscar, 2018). This low value is influenced by the conventional feed production process without high-pressure extrusion, resulting in low porosity in the pellets (Epifânio *et al.*, 2024; Gao *et al.*, 2019b).

Although the fat content (10.19%) in the feed can increase buoyancy, the hydrophobic nature and uneven distribution of fat during the mixing process can cause the pellets to sink more quickly (Pennells *et al.*, 2025). During the fry stage, feed buoyancy can influence successful ingestion. However, the high palatability score, reaching 100%, indicates that the sinking speed (2 minutes) does not inhibit the fish's feeding response. However, buoyancy still needs to be optimized by increasing starch gelatinization using other binders and adopting pressure extrusion technology to achieve commercial floating pellet standards.

### **Fry Growth Response**

The increased growth in treatments P1–P3 indicates that the combination of fish waste and tempe provides a source of animal and vegetable protein with good quantity and quality. Animal protein from fish waste is composed of complex essential amino acids that stimulate muscle tissue growth (Macusi *et al.*, 2023). Fermenting soybeans in tempe supports the availability of free amino acids and reduces antinutrients such as trypsin inhibitors, thereby improving feed digestibility (Nout & Kiers, 2005).

These two components contribute to the increase in fish length and weight, resulting in higher SGR values in P1 and P3. This mechanism suggests that a fermented animal-vegetable protein mixture can increase growth rates in both omnivorous and herbivorous fish (Pratiwy & Triyani, 2022; Zhang *et al.*, 2016). This study confirms that substituting local ingredients with appropriate formulations can produce performance equivalent to, and even superior to, commercial feed. High performance in P1 (1.84) and P3 (1.86) was accompanied by low FCR values. Low FCR levels indicate that fish utilize feed efficiently. This efficiency is related to the fry's ability to digest protein and fat from processed animal-plant-based ingredients (Duan *et al.*, 2022). Furthermore, the addition of attractants enhances the feeding response because they contain free amino acids, peptides, and volatile compounds that effectively stimulate the fish's chemoreceptor system (Fang *et al.*, 2019b).

### **Survival Rate (SR)**

Significant differences in survival rates (SR) between treatments indicate a significant effect of feed composition variations on the physiological performance of fry. Treatments P1 (54%) and P4 (55%) showed the highest SR and significantly differed from the other treatments, indicating that the fish waste-tempe feed composition provides stable and easily digestible nutritional conditions, thereby reducing the risk of metabolic stress. The availability of high-quality protein and sufficient essential amino acids plays a role in maintaining the immune system, which impacts survival during the fry stage (Habte-Tsion, 2020).

The SR values for P0 (51%) and P2 (53%) were in the intermediate group and were not significantly different, indicating that improving feed quality is not always directly proportional to survival. This can occur in the early stages of fish life, as environmental factors, density, and interactions occurring within the fry within a single container contribute more to the risk of mortality than variations in nutrient content (Nhan *et al.*, 2010). These results indicate that a high growth response does not correlate with survival (Gagliano *et al.*, 2007).

Conversely, treatment P3 showed the lowest SR (43%) and was significantly different from all treatments, despite P3's growth parameters being considered good. This pattern suggests that the fry competed more intensely for the feed provided, resulting in increased mortality. Rapid growth is often associated with individual dominance and increased contact between fish, ultimately leading to physiological stress and mechanical injury, which increases the risk of mortality (Ellison *et al.*, 2020). Furthermore, higher feed consumption in fast-growing groups can increase body size differences and exacerbate the risk of cannibalism and competition within a culture tank in various freshwater fish species (Baras & Jobling, 2002; Kestemont *et al.*, 2003). Overall, these results confirm that survival during the juvenile stage is determined not only by nutritional quality but also by behavioral dynamics and the stability of environmental conditions (Kozłowski & Piotrowska, 2024).

### **Water Quality**

Water quality parameters observed during the study included temperature, dissolved oxygen (DO), pH, ammonia (NH<sub>3</sub>/NH<sub>4</sub>), and total dissolved solids (TDS), which showed stable conditions across all treatments. The rearing temperature was 26°C, within the optimum range for most tropical freshwater fish and supports physiological processes such as metabolism, feed consumption, and energy conversion efficiency (Raval *et al.*, 2024). This temperature stability also reduces the potential for thermal stress that can inhibit fry growth.

A DO level of 5 mg/L in all treatments is appropriate to support aerobic respiration and maintain the fry's metabolic activity. A DO level of 5 mg/L or higher maintains feed utilization efficiency and prevents physiological disorders and liver damage in fry (Abdel-Tawwab *et al.*, 2014; J. Li *et al.*, 2020). A pH measurement of 8.5 indicates slightly alkaline water conditions, but still within the tolerance range for aquatic fish, which ranges from 6.5 to 9 (Mustapha & Atolagbe, 2018; Raval *et al.*, 2024). An unstable pH can disrupt gill function, osmoregulation, and metabolism due to extreme fluctuations in water levels.

Ammonia concentrations ranging from 0.30–0.33 mg/L are still tolerable by fish, as most of the ammonia is in the less toxic form of NH<sub>4</sub>. Ammonia toxicity depends on the free NH<sub>3</sub> fraction and pH levels (Emerson *et al.*, 1975). In this study, ammonia levels were relatively low and stable, thus not triggering chronic stress that could reduce growth responses or survival. TDS values ranging from 195–200 mg/L indicate stable dissolved mineral levels. Therefore, toxicity can be prevented by maintaining low TDS levels (Weber-Scan & Duffy, 2007).

## CONCLUSION

This study confirms that a feed formulation based on fish waste and tempe is capable of providing growth performance and feed acceptance levels that are competitive with commercial feeds for early-stage fish fry. Differences in each treatment indicate that the fry's response to growth, feed utilization efficiency, and survival rate are influenced by the composition of the raw materials, particularly related to nutrient content, palatability, and energy availability. A stable rearing environment with temperature, DO, pH, ammonia, and TDS parameters within the optimal range reinforces that differences in fish biological responses are primarily a result of differences in feed quality, rather than environmental factors. Therefore, fish waste and tempe-based feeds have the potential to be sustainable feed alternatives in the early stages of fish fry rearing.

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