

**EVALUATION OF PARTIAL REPLACEMENT OF FISHMEAL WITH SELECTED FEED INGREDIENTS ON GROWTH and SURVIVAL OF GREY MULLET, *Mugil cephalus* (Linnaeus, 1758)**

**ABSTRACT**

**Aims:** The present study was aimed to evaluate the effect of partial replacement of fishmeal with selected feed ingredients on growth and survival in *Mugil cephalus*. The experiment was conducted for 90 days. The experiment designed in completely randomised design (CRD) with five treatments and each treatment with four replications. Treatment T<sub>0</sub> represents control diet contain 100% fishmeal protein, treatment T<sub>1</sub> represent 50% fishmeal protein and 50% acetes meal protein, treatment T<sub>2</sub> represents 50% fishmeal protein and 50% BSF (Black Soldier Fly) meal protein, treatment T<sub>3</sub> represent 50% fishmeal protein and 50% clam meal protein and treatment T<sub>4</sub> represent 50% fishmeal protein and 50% poultry byproduct meal protein. Fish with a mean weight of 2.68 to 2.71 g were stocked at a density of 10 nos. /aquarium in all 20 aquaria and were fed three times per day. The findings distinctly highlight the significant ( $p < 0.05$ ) enhancements observed in growth and survival incorporating BSF as a feed ingredient in treatment T<sub>2</sub>. Moreover, both acetes (treatment T<sub>1</sub>) and the control diet (treatment T<sub>0</sub>) demonstrated improved performance in comparison to diets formulated with clam (treatment T<sub>3</sub>) and poultry byproduct (treatment T<sub>4</sub>). From the results of present study, it can be concluded that the incorporation of BSF and acetes can be beneficial to improve growth performance and survival rate in *M. cephalus*.

**Keywords:** *Mugil cephalus*, Fishmeal replacement, BSF (Black Soldier Fly meal), Acetes meal, Poultry byproduct and clam meal

## 1. INTRODUCTION

The fisheries and aquaculture sector plays a pivotal role in ensuring global food security, nutrition, and livelihood. Global fish production reached 177.8 million tonnes in 2022, comprising 90.3 million tonnes from capture fisheries and 87.5 million tonnes from aquaculture, with a total estimated value of USD 406 billion, of which USD 265 billion originated from aquaculture (FAO, 2022). Asia dominates aquaculture production, contributing over 91% of global output, primarily from China, India, and Indonesia. Per capita fish consumption increased from 9.0 kg in 1961 to 20.2 kg in 2020, representing an annual growth rate of 1.5%. Between 2001 and 2020, aquaculture expanded at an average annual rate of 5.3% (FAO, 2022).

In India, the fisheries sector contributes 1.1% to national GDP and 6.72% to agricultural GDP (NFDB, 2020). With a long tradition of aquaculture, India ranks second globally after China, producing 7.06 million tonnes annually, representing about 8% of global aquaculture production (MPEDA, 2023). Coastal aquaculture is primarily focused on shrimp and select marine finfish species. Among these, the grey mullet (*Mugil cephalus*) is recognized as a promising species due to its wide distribution, adaptability, and commercial value. *M. cephalus* is distributed across tropical, subtropical, and temperate coastal waters, from the Eastern Pacific (California to Chile) to the Western Pacific (Japan to Australia), and throughout the Western Indian Ocean (India to South Africa) (Smith, 1986; Baldwin et al., 2003). It is an omnivorous, hardy species suitable for mono- and polyculture systems, feeding on detritus and microflora (Moriarty, 1976). In India, mullet production reached 0.36 lakh tonnes on the east coast and 0.06 lakh tonnes on the west coast in 2019–2020 (FAO, 2020).

In Gujarat, *M. cephalus* is abundant in the Gulf of Kutch, Dwarka, and Diu, where it inhabits estuaries, lagoons, and salt pans (Gopalkrishnan & Thaker, 1990). Its high adaptability to salinity and temperature variations, fast growth, and market demand make it an ideal

candidate for mariculture. The species is also valued globally for its roe, leading to its nickname “grey gold” (Hung & Shaw, 2006).

Despite its potential, limited research exists on the nutritional requirements and feed formulation for *M. cephalus*. Feed cost represents 40–70% of total aquaculture expenditure (Sharawy et al., 2020). The decreasing availability and rising price of fishmeal, the primary protein source in aquafeeds, necessitate the exploration of sustainable alternatives (Craig, 2004; Tacon & Metian, 2015).

Potential substitutes include plant-based proteins (e.g., soybean meal, corn gluten, and distillers’ dried grains) and animal-based proteins such as poultry by-product meal, clam meal, crustacean meal, and insect meals (Van et al., 2018; Abdel-Tawwab & Abbass, 2016; Rapatsa & Moyo, 2017). These alternatives have shown promise in various species, though tolerance levels differ depending on species and rearing conditions.

## **2. MATERIALS AND METHODS**

### **2.1 Experimental Animal**

Fry of *Mugil cephalus* were collected from Rupen Bandar, Dwarka. The specimens were initially maintained in oxygenated seawater and transported to the Fisheries Research Station, Okha. The fry were stocked in 500 L tanks and acclimatized under continuous aeration and controlled feeding to minimize mortality from environmental fluctuations.

### **2.2 Experimental Design**

The experiment was conducted from July to October 2023 at the College of Fisheries Science, Veraval, and the Fisheries Research Station, Okha. A Completely Randomized Design (CRD) with five treatments and four replicates was employed.

**Table 1:** Details of treatments for *Mugil cephalus*

<b>Treatment</b>	<b>Details</b>
<b>T<sub>0</sub></b>	Diet prepared with 100% Fishmeal protein
<b>T<sub>1</sub></b>	Diet prepared with 50% Fishmeal protein and 50% Acetes meal protein
<b>T<sub>2</sub></b>	Diet prepared with 50% Fishmeal protein and 50% Black Soldier Fly (BSF) meal protein
<b>T<sub>3</sub></b>	Diet prepared with 50% Fishmeal protein and 50% Clam meal protein
<b>T<sub>4</sub></b>	Diet prepared with 50% Fishmeal protein and 50% Polutry by-product meal protein

### 2.3 Experimental Diet Preparation

Five iso-nitrogenous diets (35% protein) were formulated using locally available ingredients. Fishmeal was procured from Porbandar, Acetes from Veraval, clam meal from Kerala, BSF meal from Navsari, and poultry by-product meal from online sources. Other ingredients, including soybean flour, wheat flour, tapioca powder, fish oil, sunflower oil, vitamins, and minerals, were locally sourced.

**Table 2:** The composition of experimental diet

<b>Ingredients (%)</b>	<b>Diet (35 % Protein)</b>				
	<b>T<sub>0</sub></b>	<b>T<sub>1</sub></b>	<b>T<sub>2</sub></b>	<b>T<sub>3</sub></b>	<b>T<sub>4</sub></b>
<b>Sterilized fish meal</b>	39.00	20.00	20.00	20.00	20.00
<b>Acetes</b>	0.0	21.0	0.0	0.0	0.0
<b>Black soldier fly</b>	0.0	0.0	26.0	0.0	0.0
<b>Clam</b>	0.0	0.0	0.0	21.0	0.0
<b>Poultry by product</b>	0.0	0.0	0.0	0.0	25.00
<b>Soyabean</b>	31.00	31.00	31.00	31.00	31.00
<b>Wheat flour</b>	15.00	15.00	15.00	11.00	12.00

<b>Tapioca flour</b>	9.00	7.00	7.00	6.00	6.00
<b>Fish oil</b>	2.00	2.00	2.00	2.00	2.00
<b>Sunflower oil</b>	2.00	2.00	2.00	2.00	2.00
<b>Vit. &amp; Min.</b>	2.00	2.00	2.00	2.00	2.00
<b>Total</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>

### 2.3.1 Ingredient Processing

Acetes and clam samples were dried at 40–50°C and ground into fine powder. Proximate composition of all ingredients was analyzed following AOAC (2018) methods for moisture, crude protein (Micro-Kjeldahl), crude fat (Soxhlet), and total ash (muffle furnace at 600°C).

### 2.3.2 Feed Formulation

All diets were formulated using Pearson's square method to achieve an equal protein level of 35%. Ingredient proportions for each treatment are presented in Table 3. After mixing dry ingredients, oils were added to achieve uniform consistency. The dough was steam-cooked at 121°C under 15 psi pressure for 10–15 minutes. After cooling, vitamins, minerals, and specific protein sources were incorporated. The mixture was pelleted using a mechanical pelletizer, oven-dried at 40-50°C for 5-6 hours, and stored in airtight, labelled plastic containers.

**Table 3:** The composition of experimental diet

<b>Ingredients (%)</b>	<b>Diet (35 % Protein)</b>				
	<b>T<sub>0</sub></b>	<b>T<sub>1</sub></b>	<b>T<sub>2</sub></b>	<b>T<sub>3</sub></b>	<b>T<sub>4</sub></b>
<b>Sterilized fish meal</b>	39.00	20.00	20.00	20.00	20.00
<b>Acetes</b>	0.0	21.0	0.0	0.0	0.0
<b>Black soldier fly</b>	0.0	0.0	26.0	0.0	0.0
<b>Clam</b>	0.0	0.0	0.0	21.0	0.0

<b>Poultry by product</b>	0.0	0.0	0.0	0.0	25.00
<b>Soyabean</b>	31.00	31.00	31.00	31.00	31.00
<b>Wheat flour</b>	15.00	15.00	15.00	11.00	12.00
<b>Tapioca flour</b>	9.00	7.00	7.00	6.00	6.00
<b>Fish oil</b>	2.00	2.00	2.00	2.00	2.00
<b>Sunflower oil</b>	2.00	2.00	2.00	2.00	2.00
<b>Vit &amp; Min</b>	2.00	2.00	2.00	2.00	2.00
<b>Total</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>

## 2.4 Experimental Procedure

### 2.4.1 Growth and Survival

The experiment was conducted in glass aquaria (2 \* 1 \* 1 ft) disinfected with potassium permanganate (4 ppm) and rinsed thoroughly. Each aquarium was stocked with *M. cephalus* fry and maintained under continuous aeration for 90 days. Fish were fed at 10% of body weight per day, divided into two feedings. Fish were weighed at 15-day intervals using an electronic balance to assess growth. Survival rates were recorded daily by counting live fish. Health, activity, and feeding behaviour were monitored throughout the study.

### 2.4.2 Tank Management

Fish were acclimated before stocking to match temperature, salinity, and pH. Tanks were continuously aerated, and uneaten feed and waste were siphoned twice daily. Water exchange was performed regularly to maintain optimal quality.

### 2.4.3 Growth Performance Parameters

Mean Weight Gain (MWG) = Final – Initial body weight

Specific Growth Rate (SGR, %/day) =  $[(\ln W_2 - \ln W_1)/T] \times 100$

Survival Rate (%) = (Number survived / Number stocked)  $\times$  100

#### **2.4.4 Feed Utilization and Body Composition**

Feed utilization efficiency was determined through Feed Conversion Ratio (FCR) and Protein Efficiency Ratio (PER), calculated as:

$$\text{FCR} = \text{Feed intake (g)} / \text{Weight gain (g)}$$

$$\text{PER} = \text{Weight gain (g)} / \text{Protein intake (g)}$$

#### **2.5 Water Quality Monitoring**

Temperature (digital thermometer), pH (digital pH meter), alkalinity (Himedia kit), and dissolved oxygen (Winkler method) were recorded regularly.

#### **2.6 Statistical Analysis**

Data were analyzed using one-way ANOVA under CRD in SPSS (v26). Differences among means were determined using Duncan's Multiple Range Test at  $p < 0.05$  (Snedecor and Cochran, 2014).

### **3. RESULTS AND DISCUSSION**

#### **3.1 Proximate Composition of Feed Ingredients**

Fishmeal exhibited the highest crude protein (62.6%) and low moisture (5.7%), confirming its superior role as a protein source. Acetes and clam meals also contained high protein levels (60%), though accompanied by higher moisture and ash. BSF meal demonstrated elevated lipid content (20.3%), while poultry by-product meal and soybean meal showed moderate protein and high ash levels. These differences highlight the potential for nutritional complementarity in *Mugil cephalus* diets.

**Table 4:** Proximate composition of feed ingredients

<b>Ingredients (%)</b>	<b>Moisture</b>	<b>Crude Protein</b>	<b>Crude Lipid</b>	<b>Ash</b>
<b>Fish meal</b>	5.70	62.60	7.80	12.43
<b>Acetes</b>	17.80	60.00	3.90	16.10
<b>BSF</b>	7.10	50.00	20.30	8.72
<b>Clam</b>	9.45	60.00	7.50	10.40
<b>Poultry by-product</b>	5.55	50.00	12.50	16.10
<b>Soybean meal</b>	6.00	32.00	7.60	20.5

### 3.2 Proximate Composition of Experimental Diets

All formulated diets were designed to maintain ~35% crude protein. BSF-based diet (T<sub>2</sub>) recorded the highest protein (35.77%) and lipid (8.56%) levels, while poultry by-product meal (T<sub>4</sub>) showed the lowest protein (34.85%) and highest ash (10.62%). These minimal variations reflect balanced formulation and nutritional adequacy across treatments.

**Table 5:** Proximate composition of experimental diets

<b>Treatment</b>	<b>Crude Protein</b>	<b>Moisture</b>	<b>Crude Lipid</b>	<b>Ash</b>
<b>T<sub>0</sub></b>	35.46	7.65	8.53	10.20
<b>T<sub>1</sub></b>	35.40	7.52	8.25	10.45
<b>T<sub>2</sub></b>	35.77	7.45	8.56	10.25
<b>T<sub>3</sub></b>	35.20	7.82	8.46	10.35
<b>T<sub>4</sub></b>	34.85	7.45	8.35	10.62

### 3.3 Growth Performance and Survival

After 90 days, significant differences ( $p < 0.05$ ) were observed among treatments. The highest final mean weight ( $10.81 \pm 0.015$  g) was recorded in T<sub>2</sub> (BSF meal), followed by T<sub>1</sub> (Acetes meal) and control (T<sub>0</sub>). The lowest growth was observed in T<sub>4</sub> (Poultry by-product meal). These findings corroborate improved growth potential of BSF-based diets.

**Table 6:** Mean weight gain (g) of *M.cephalus* recorded in different treatments after 15 Days

T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	
0.640±0.007 <sup>b</sup>	0.680±0.011 <sup>a</sup>	0.697±0.002 <sup>a</sup>	0.605±0.009 <sup>c</sup>	0.600±0.007 <sup>c</sup>	
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.031	4	0.008	32.014	S
Within Groups	0.004	15	0.000		
Total	0.034	19			

Note: Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).

**Table 7:** Mean weight gain (g) of *M.cephalus* recorded in different treatments after 30 days

T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	
1.629±0.003 <sup>b</sup>	1.750±0.022 <sup>a</sup>	1.772±0.011 <sup>a</sup>	1.542±0.006 <sup>c</sup>	1.510±0.007 <sup>c</sup>	
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.225	4	0.056	99.103	S
Within Groups	0.009	15	0.001		
Total	0.233	19			

Note: Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).

**Table 8:** Mean weight gain (g) of *M.cephalus* recorded in different treatments after 45 days

T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	
2.655±0.003 <sup>c</sup>	2.822±0.020 <sup>b</sup>	2.950±0.027 <sup>a</sup>	2.469±0.006 <sup>d</sup>	2.470±0.006 <sup>d</sup>	
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.729	4	0.182	186.36 5	S
Within Groups	0.015	15	0.001		
Total	0.744	19			

Note: Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).

**Table 9:** Mean weight gain (g) of *M. cephalus* recorded in different treatments after 60 days

T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	
3.895±0.006 <sup>c</sup>	4.102±0.014 <sup>b</sup>	4.305±0.035 <sup>a</sup>	3.685±0.050 <sup>d</sup>	3.550±0.063 <sup>e</sup>	
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.494	4	.373	58.742	S
Within Groups	0.095	15	0.006		
Total	1.589	19			

Note: Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).

**Table 10:** Mean weight gain (g) of *M. cephalus* recorded in different treatments after 75 days

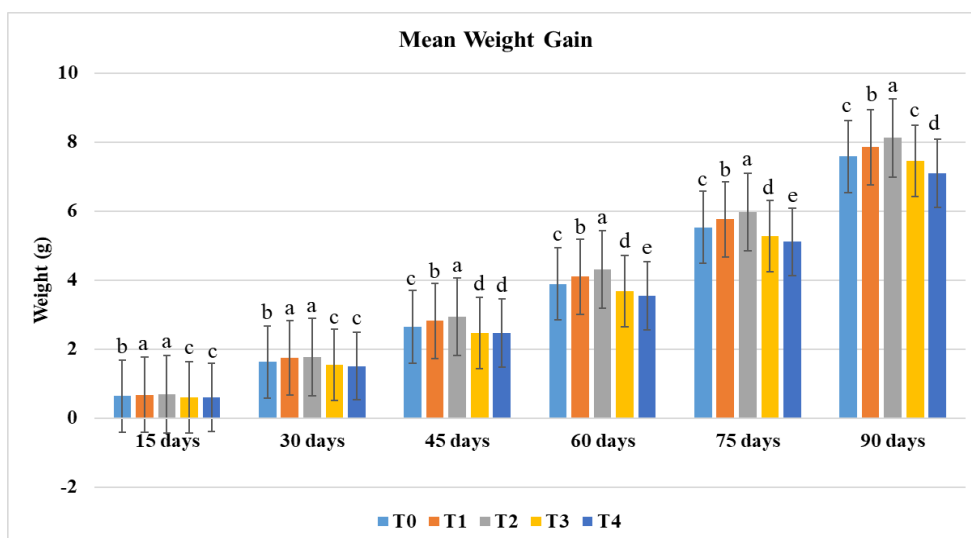
T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	
5.532±0.012 <sup>c</sup>	5.765±0.017 <sup>b</sup>	5.980±0.023 <sup>a</sup>	5.285±0.061 <sup>d</sup>	5.115±0.068 <sup>e</sup>	
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.959	4	0.490	65.383	S
Within Groups	0.112	15	0.007		
Total	2.072	19			

Note: Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).

**Table 11:** Mean weight gain (g) of *M. cephalus* recorded in different treatments after 90 days

T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	
7.582±0.008 <sup>c</sup>	7.855±0.020 <sup>b</sup>	8.122±0.017 <sup>a</sup>	7.450±0.142 <sup>c</sup>	7.102±0.044 <sup>d</sup>	
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.423	4	0.606	33.198	S
Within Groups	0.274	15	0.018		
Total	2.697	19			

Note: Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).



**Figure 1:** Mean weight gain (g) of *M. cephalus* recorded in different treatments at the end of the experiment

### 3.4 Specific Growth Rate (SGR)

BSF meal (T<sub>2</sub>) and Acetes meal (T<sub>1</sub>) diets significantly improved SGR compared to control (T<sub>0</sub>), while Clam (T<sub>3</sub>) and Poultry by-product (T<sub>4</sub>) diets reduced SGR. ANOVA confirmed significant differences ( $p < 0.05$ ) among treatments

**Table 12:** Specific Growth Rate (SGR) of *M. cephalus* recorded in different treatments at the end of experiment

T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>	
1.4896±0.001 <sup>c</sup>	1.5164±0.008 <sup>b</sup>	1.5442±0.031 <sup>a</sup>	1.4741±0.016 <sup>c</sup>	1.4326±0.004 <sup>d</sup>	
ANOVA					
	Sum of Squares	df	Mean Square	F	Sig.
<b>Between Groups</b>	0.029	4	0.007	29.018	S
<b>Within Groups</b>	0.004	15	0.000		
<b>Total</b>	0.032	19			

**Note:** Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different ( $p < 0.05$ ).

The specific growth rate (SGR) of *Mugil cephalus* varied significantly among treatments. The highest SGR was observed in T<sub>2</sub> (50% fishmeal + 50% black soldier fly meal), followed by T<sub>1</sub> (50% fishmeal + 50% Acetes meal), the control (T<sub>0</sub>), T<sub>3</sub> (50% fishmeal + 50% clam meal), and the lowest in T<sub>4</sub> (50% fishmeal + 50% poultry by-product meal). These findings align

with previous research indicating that partial replacement of fishmeal with black soldier fly (BSF) meal can enhance growth performance in various fish species. For instance, Mapanao et al. (2023) reported improved SGR in *Anabas testudineus* fed diets containing 50% BSF meal, while similar enhancements were recorded in *Oreochromis niloticus* and *Cyprinus carpio* by Munguti et al. (2023) and Gebremichael et al. (2021), respectively. Likewise, the inclusion of *Acetes* meal improved SGR in *M. cephalus*, corroborating Mahida et al. (2017), who found significantly higher growth in shrimp diets containing 50% *Acetes* meal. In contrast, clam meal inclusion yielded no significant difference in SGR compared to the control, consistent with Habte-Tsion et al. (2022), who observed reduced growth performance in *Trachinotus carolinus* fed clam-based diets.

Conversely, substitution with poultry by-product meal resulted in the lowest SGR, similar to findings in *Scophthalmus maeoticus* (Turker et al., 2005) and *Cyprinus carpio* (Emre et al., 2003), where increased poultry meal levels led to diminished growth rates. Variability in the nutrient composition and digestibility of poultry by-product meals, owing to differences in bone, meat, and blood content, may account for these effects (Nengas et al., 1999; Webster et al., 2000). Furthermore, the presence of anti-nutritional factors (ANFs), such as trypsin inhibitors and phytates, can impair protein digestion and mineral absorption, thereby reducing feed efficiency and growth (Prabu et al., 2017; Gopan et al., 2020).

### **3.5 Survival Rate**

Survival rates ranged between 87.50% and 92.50%, with no significant differences among treatments ( $p > 0.05$ ). BSF and *Acetes* diets (T<sub>1</sub> and T<sub>2</sub>) yielded the highest survival, indicating good tolerance and feed acceptability.

**Table 13:** Survival rate (%) of *M. cephalus* recorded in different treatments at the end of experiment

<b>T<sub>0</sub></b>	<b>T<sub>1</sub></b>	<b>T<sub>2</sub></b>	<b>T<sub>3</sub></b>	<b>T<sub>4</sub></b>	
90.00±4.082 <sup>a</sup>	92.50±2.500 <sup>a</sup>	92.50±2.500 <sup>a</sup>	87.50±4.787 <sup>a</sup>	87.50±4.787 <sup>a</sup>	
<b>ANOVA</b>					
	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Square</b>	<b>F</b>	<b>Sig.</b>
<b>Between Groups</b>	100	4	25.000	0.417	NS
<b>Within Groups</b>	900	15	60.000		
<b>Total</b>	1000	19			

**Note:** Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).

The findings of the present study are consistent with previous research across various aquaculture species, demonstrating that dietary inclusion of alternative protein sources such as black soldier fly (BSF) meal, Acetes meal, and poultry by-products can influence fish survival rates. Enhanced survival was observed in *Mugil cephalus* fed diets containing BSF meal, aligning with reports in *Oreochromis niloticus* (Limbu et al., 2022), *Anabas testudineus* (Mapanao et al., 2023), and *Clarias gariepinus* (Adeoye et al., 2020), where partial replacement of fishmeal with BSF significantly improved fish performance and survival. Similarly, the inclusion of Acetes meal in aquafeeds has been associated with higher survival rates in multiple species, including *Epinephelus coioides* (Millamena, 2002), *Oreochromis nmossambicus* (Parmar et al., 2016), and *Litopenaeus vannamei* (Malli et al., 2017). This enhancement is attributed to the balanced amino acid profile and high digestibility of Acetes-based proteins. Conversely, diets incorporating clam meal resulted in reduced survival compared to the control, in agreement with findings in *Labeo rohita* (Begum et al., 1994) and *Trachinotus carolinus* (Habte-Tsion et al., 2022), suggesting possible palatability or digestibility limitations associated with molluscan proteins. Similarly, diets containing poultry by-product meal produced survival rates statistically comparable ( $p > 0.05$ ) to control diets in *Cromileptes altivelis* (Shapawi et al., 2007) and *Litopenaeus vannamei* (Cruz-Suarez

et al., 2007), indicating that poultry by-products can serve as a viable, though not superior, protein source in aquaculture nutrition.

### 3.6 Effect of Selected Feed Ingredients on Feed Conversion Ratio (FCR) of *Mugil cephalus*

At the end of the 90-day feeding trial, the feed conversion ratio (FCR) of *Mugil cephalus* was evaluated across the different dietary treatments. All fish from each tank were collected, individually weighed, and their feed requirements were calculated based on 10% of their body weight. The feed quantities were measured precisely using an electronic balance. The mean FCR values obtained for each treatment are presented in Table 14.

Among the experimental diets, treatment T<sub>2</sub> exhibited the lowest FCR ( $1.133 \pm 0.029^c$ ), followed by T<sub>1</sub> ( $1.172 \pm 0.030^{bc}$ ), T<sub>0</sub> ( $1.253 \pm 0.058^{bc}$ ), T<sub>3</sub> ( $1.314 \pm 0.059^{ab}$ ), and T<sub>4</sub> ( $1.380 \pm 0.075^a$ ). Treatments T<sub>3</sub> and T<sub>4</sub> demonstrated significantly higher FCR values compared to the control (T<sub>0</sub>). Statistical analysis revealed a significant difference among treatments ( $p < 0.05$ ), indicating that the partial replacement of fish meal with selected alternative protein sources had a measurable impact on feed efficiency.

**Table 14:** Feed Conversion Ratio (FCR) of *M. cephalus* recorded in different treatments at the end of experiment

	<b>R<sub>1</sub></b>	<b>R<sub>2</sub></b>	<b>R<sub>3</sub></b>	<b>R<sub>4</sub></b>	<b>Mean±SE</b>
<b>T<sub>0</sub></b>	1.401715	1.249265	1.118421	1.244327	<b>1.253±0.058<sup>abc</sup></b>
<b>T<sub>1</sub></b>	1.207729	1.206187	1.193988	1.081425	<b>1.172±0.030<sup>bc</sup></b>
<b>T<sub>2</sub></b>	1.167422	1.163109	1.155991	1.048089	<b>1.133±0.029<sup>c</sup></b>
<b>T<sub>3</sub></b>	1.326467	1.422356	1.148649	1.360435	<b>1.314±0.059<sup>ab</sup></b>
<b>T<sub>4</sub></b>	1.507092	1.180556	1.347282	1.486014	<b>1.380±0.075<sup>a</sup></b>
<b>ANOVA</b>					
	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Squares</b>	<b>F</b>	<b>Sig.</b>
<b>Between Groups</b>	0.163	4	0.041	3.572	0.031
<b>Within</b>	0.171	15	0.011		

Groups					
<b>Total</b>	0.334	19			

**Note:** Data expressed as Mean  $\pm$  SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05)

In particular, treatment T<sub>2</sub>, consisting of a 50% fish meal and 50% black soldier fly (*Hermetia illucens*) meal formulation, yielded the most efficient feed utilization, reflected by the lowest FCR value. This was followed by T<sub>1</sub> (50% fish meal + 50% *Acetes* meal), T<sub>0</sub> (100% fish meal), T<sub>3</sub> (50% fish meal + 50% clam meal), and T<sub>4</sub> (50% fish meal + 50% poultry by-product meal), in ascending order of FCR.

The superior performance of the BSF-based diet (T<sub>2</sub>) aligns with findings from earlier studies demonstrating improved FCR in other fish species, including *Pelteobagrus fulvidraco* (Xiao et al., 2018), *Cyprinus carpio* (Gebremichael et al., 2021), and *Anabas testudineus* (Mapanao et al., 2023). Arsiwalla and Waagbø (2016) also reported that partial replacement of fish meal with BSF larvae up to 75% improved feed utilization efficiency; however, higher inclusion levels increased thiobarbituric acid reactive substances, potentially reducing diet palatability. Similarly, inclusion of *Acetes* meal (T<sub>1</sub>) as a partial fish meal substitute resulted in reduced FCR compared to the control diet, suggesting enhanced nutrient utilization. Comparable results were reported for *Penaeus monodon* (Calpe et al., 2016) and *Litopenaeus vannamei* (Mahinda et al., 2017), indicating that *Acetes*-based meals may serve as a viable protein alternative in aquafeeds.

In contrast, treatment T<sub>3</sub> (50% fish meal + 50% clam meal) exhibited a higher FCR compared to the control (T<sub>0</sub>), indicating reduced feed efficiency. This observation is consistent with findings reported for *Salmo gairdneri* (Goodrich et al., 1984) and *Labeo rohita* (Begum, 1994), where diets containing clam meal resulted in increased FCR values.

Likewise, the diet containing poultry by-product meal (T<sub>4</sub>) produced the highest FCR, reflecting lower feed efficiency compared to the control. Similar trends have been documented by Galkanda-Arachchige et al. (2020), who observed elevated FCR values in

fish fed diets containing poultry by-product meal. The reduced performance may be attributed to the imbalance of essential amino acids and fatty acids present in poultry by-products, particularly affecting marine species relative to freshwater fish.

Overall, the findings of the present study demonstrate that partial replacement of fish meal with BSF or *Acetes* meal can significantly enhance feed utilization efficiency in *M. cephalus*, whereas substitution with clam or poultry by-product meals may impair feed conversion performance.

### 3.7 Effect of Selected Feed Ingredients on Protein Efficiency Ratio (PER) of *Mugil cephalus*

The protein efficiency ratio (PER) of *Mugil cephalus* was evaluated after 90 days to assess dietary protein utilization efficiency across different feed formulations. Mean weight gain and total protein intake were used to calculate PER for each treatment group.

**Table 15:** Protein efficiency ratio of *M. cephalus* recorded in different treatments at the end of experiment

	<b>R<sub>1</sub></b>	<b>R<sub>2</sub></b>	<b>R<sub>3</sub></b>	<b>R<sub>4</sub></b>	<b>Mean±SE</b>
<b>T<sub>0</sub></b>	2.038319	2.287059	2.554622	2.296134	<b>2.294±0.105<sup>bc</sup></b>
<b>T<sub>1</sub></b>	2.365714	2.368739	2.392941	2.642017	<b>2.442±0.067<sup>ab</sup></b>
<b>T<sub>2</sub></b>	2.447395	2.456471	2.471597	2.72605	<b>2.525±0.067<sup>a</sup></b>
<b>T<sub>3</sub></b>	2.15395	2.008739	2.487395	2.100168	<b>2.187±0.104<sup>bc</sup></b>
<b>T<sub>4</sub></b>	1.895798	2.420168	2.120672	1.922689	<b>2.089±0.121<sup>c</sup></b>
<b>ANOVA</b>					
	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Square</b>	<b>F</b>	<b>Sig.</b>
<b>Between Groups</b>	0.510	4	0.128	3.498	0.033
<b>Within Groups</b>	0.547	15	0.036		
<b>Total</b>	1.058	19			

**Note:** Data expressed as Mean ± SE (n=4); Mean value in the same column sharing different superscripts are significant different (p<0.05).

Among treatments, T<sub>2</sub> comprising a 50% fish meal and 50% black soldier fly (BSF) meal diet—exhibited the highest PER, indicating superior protein utilization efficiency compared

to the control ( $T_0$ , 100% fish meal). This finding aligns with previous studies reporting comparable outcomes with 50% BSF inclusion in *Channa striata* (Siddaiah et al., 2023), *Cyprinus carpio* (Gebremichael et al., 2021), *Carassius auratus* (Kamalii et al., 2022), and *Pelteobagrus fulvidraco* (Xiao et al., 2018). Similarly, Cengic Dzomba et al. (2020) found that substituting 50% fish meal with BSF larval meal did not adversely affect fish growth performance or PER.

Treatment  $T_1$  (50% fish meal and 50% *Acetes* meal) also showed improved PER relative to the control, likely due to *Acetes*' high digestibility (up to 90%) and balanced amino acid composition (Rahman et al., 2016; Balange et al., 2017; Vase et al., 2021). Comparable improvements were observed in *Litopenaeus vannamei* (Mahinda et al., 2017), *Penaeus monodon* (Calpe et al., 2016), and guppy (*Poecilia reticulata*) (Komilus & Mufit, 2021).

Conversely, diets incorporating clam meal ( $T_3$ ) and poultry by-product meal ( $T_4$ ) yielded lower PER values than the control. This reduction is consistent with earlier findings that protein source quality significantly affects PER (Steffen, 1989; Emre et al., 2003). Poultry by-products, containing poorly digestible components such as feathers and connective tissue, reduce protein availability and growth performance (Turker et al., 2005). The resulting decline in PER likely reflects increased protein catabolism and reduced efficiency in converting dietary protein to body mass.

### **3.8 Physico-Chemical Water Parameters**

All water quality parameters remained within the optimal range for aquaculture. The recorded temperature (29.4-30.4°C), pH (7.0-7.9), dissolved oxygen (5.41-6.55 ppm), and alkalinity (120-126 ppm) exhibited minimal variation among treatments, indicating stable and favourable rearing conditions throughout the experimental period.

#### 4. CONCLUSIONS

The present study systematically evaluated the effects of partial replacement of fishmeal with selected alternative feed ingredients namely Acetes, black soldier fly (BSF) larvae, clam, and poultry by-product on the growth performance, survival rate, and feed utilization efficiency of *Mugil cephalus*. Results demonstrated that the inclusion of BSF meal (treatment T<sub>2</sub>) in the diet significantly enhanced growth parameters, including weight gain and specific growth rate, as well as survival rate and feed utilization efficiency, compared to other treatments. Diets incorporating Acetes (T<sub>1</sub>) and the control diet (T<sub>0</sub>) also showed favourable outcomes, outperforming diets formulated with clam (T<sub>3</sub>) and poultry by-product (T<sub>4</sub>) in terms of growth and feed conversion. These findings indicate that BSF and Acetes meals serve as highly effective alternative protein sources in aqua feeds for *M. cephalus*, contributing to improved nutritional efficiency and overall fish health. The study underscores the potential of insect-based and small crustacean meals to partially replace conventional fishmeal without compromising growth performance or survival, highlighting their applicability in sustainable aquaculture practices.

Nevertheless, while the current results are promising, further research is warranted to investigate the long-term effects of these alternative feed ingredients on fish physiology, immune response, and nutrient digestibility. Additionally, optimization studies focusing on the inclusion levels, processing methods and economic feasibility of BSF and Acetes meals will be crucial to fully integrate these ingredients into commercial aqua feeds. Such investigations will provide comprehensive insights into their role in sustainable and cost-effective aquaculture production.



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