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EVALUATION OF GROWTH, PROXIMATE COMPOSITION AND FATTY ACID PROFILE OF STRIPED MURREL (CHANNA STRIATA) FED ON BLACK SOLDIER FLY LARVAE

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Abstract

Sustainable feed alternatives are essential for reducing reliance on conventional aquaculture diets. This study evaluated the effects of substituting conventional feed with live Black Soldier Fly Larvae (BSFL, *Hermetia illucens*) on growth performance, feed utilization, and fatty acid composition of Striped Murrel (*Channa striata*). A 130-day feeding trial compared three diets: Control (100% conventional feed), T1 (50% BSFL partial replacement), and T2 (100% BSFL complete replacement). The Control group achieved the highest weight gain (204.81 g), while T1 (163.26 g) and T2 (144.53 g) showed reduced growth. Moisture-adjusted Dry-FCR values for BSFL-fed fish (2.90–3.00) were comparable to Control (2.54), demonstrating efficient feed utilization. Survival (78–84%) and whole-body proximate composition did not differ significantly among treatments ($p > 0.05$), indicating tolerance to BSFL inclusion.Fatty acid profiles were significantly modulated: T2 exhibited elevated methyl laurate (9.45%), reflecting BSFL lipids, whereas T1 enhanced polyunsaturated fatty acid deposition, including linoleic (18.49%), linolenic (1.06%), and docosahexaenoic acid (7.34%). Overall, partial BSFL replacement provided an optimal balance between growth performance and essential fatty acid retention, supporting its potential as a sustainable feed strategy in *C. striata*aquaculture.

1. INTRODUCTION

Aquaculture is undergoing a paradigm shift from conventional survival diets toward precision nutrition and functional feeds [1]. The Food and Agriculture Organisation's "Blue Transformation" (FAO, 2024) emphasises reducing reliance on fishmeal and fish oil by incorporating novel protein sources such as insect meals, microalgae, and single-cell proteins. These innovations aim to sustain growth performance while mitigating ecological pressures on marine ecosystems [2].

Among alternative proteins, Black Soldier Fly Larvae (BSFL, *Hermetia illucens*) have emerged as a particularly promising candidate [3]. BSFL provide 30–50% crude protein in dry matter, a favorable amino acid profile rich in lysine, and bioactive lipids such as lauric acid with antimicrobial properties [4]. Chitin further contributes prebiotic benefits, supporting gut health and immunity [5]. Recent advances include defatted BSFL meal for improved protein density and substrate enrichment strategies to enhance omega-3 deposition [6]. In India, BSFL integration into circular bioeconomy models is gaining traction, offering cost-effective feed solutions derived from organic waste [7].

Striped Murrel (*Channa striata*), a carnivorous species of high therapeutic and economic value, requires protein-rich diets but faces nutritional bottlenecks when fishmeal is replaced [8]. BSFL are abundant in medium-chain fatty acids yet deficient in long-chain polyunsaturated fatty acids, particularly DHA [9]. The capacity of Striped Murrel to metabolize highly saturated fat loads and synthesize essential LC-PUFAs from BSFL-based diets has yet to be fully elucidated. The present study therefore investigates the effects of partial (50%) and complete (100%) replacement of conventional feed with live BSFL on growth performance, feed utilization, survival, and fatty acid deposition in *C. striata*, with emphasis on moisture adjustment dry-weight FCR and lipid metabolism outcomes.

2. MATERIALS AND METHODS

2.1 Study Site and Experimental Design

The experiment was conducted at the Shanthisagara Fish Seed Center in Davangere, Karnataka, India. A triplicated experimental design was employed using nine cement lined earthen ponds. Each pond measured 3.05m in width, 9.14 m in length, and 2.13 m in depth, with an average water column maintained constantly to ensure reproducibility of the volume data at1.5 m.A natural photoperiod was maintained for all the ponds. Three dietary treatments were tested, and each treatment was directly assigned to three ponds, thereby providing replication. This arrangement ensured a randomized triplicate design with three ponds per dietary treatment, allowing for reliable statistical comparison among treatments [10].

Juvenile Striped Murrel were sourced from the Shanthisagara Fish Seed Center. The fish had an average initial weight (W_i) of 55 ± 0.5 g and initial length (Li) 12.55 ± 0.45 cm (mean ± SD), were acclimatized to the experimental environment for 14 days fed with the conventional feed. Each pond was stocked under uniform conditions at a fish density of 50 fishes per pond. Conventional feed reference (Magna-M EWOS, Cargill India Pvt. Ltd., Andhra Pradesh) was acquired from the Shanthisagara Fish Seed Center.

The 130 days feeding trial was conducted from May 13, 2025 to September 20, 2025.Live BSFL was locally cultured on a substrate of broken rice [11]. Larvae were harvested at the final instars stage, washed, and immediately administered as live feed [12]. The conventional feed had a nutrient-dense, dry matrix (11% moisture) with 42% crude protein and 6% crude fat.

Three dietary treatments were employed.

- Control = 100% conventional feed.
- Treatment 1 (T1) = 50% live BSFL + 50% conventional feed.
- Treatment 2 (T2) = 100% live BSFL

Fish were fed twice daily at fixed times (07:00 and 18:00 hours), with the feeding rate set at 4% of the calculated biomass and adjusted at 10-day intervals. Uneaten conventional feed was collected, dried, and weighed to accurately determine the actual feed consumed and live larvae were weighed directly (Actual Feed Intake) [13]. The average cumulative feed offered for each treatment was Control 30,741 g, T1- 60,214 g, and T2-92,636 g.

2.2 Water Quality Monitoring

Water quality was monitored every five days using calibrated instruments (HANNA portable meter HI98129/HI9147 for DO and TDS); API Freshwater Master Test Kit for (NH_3/ NH^+_4, NO_2^-, NO_3^-, and pH). The water temperature was monitored daily using a calibrated thermometer. Conditions were maintained within target ranges: DO > 6.0 mg/L, ammonia and nitrite = 0.0 mg/L, nitrate < 25 mg/L, and pH between 7.5 and 8.5. A 20–35%water exchange was performed every 10 days to Control nitrogenous waste [14].

2.3 Growth Performance Assessment

Biometric measurements were recorded every ten days using nine representative fish (n=9 fish per Treatment) randomly sampled from each treatment. Body weight (W) and total length (L) were measured using calibrated digital scales (0.01 g precision) and a measuring scale (0.1 cm precision), respectively [15].

Average Growth and feed utilization indices were calculated based on the initial (i) and final (f) values, Number of fish (N) and the trial duration (T, days) as follows [16-18];

- Weight Gain (WG)= $W_f - W_i$
- Length Increase(LI)=$L_f - L_i$

Specific growth rate is the daily percentage increase in the body weight over 130 days.

- Specific GrowthRate(SGR, % day^{-1}) $= \frac{(\ln Wf - \ln Wi)}{T} \times 100$
- Relative Growth Rate (RGR, %) $= \frac{Wf - Wi}{Wi} X\ 100$
- Feed Conversion Ratio (wet FCR) $= \frac{Feed\ consumed\ \ (F)}{Wf - Wi} x100$

FCR moisture adjustment standardizes the Feed Conversion Ratio by calculating it based on Total Dry Matter Feed Intake for high-moisture live feeds with dry conventional feed pellets. This composition contrasts significantly with the moisture content (70%) of live BSFL biomass. This substantial moisture disparity necessitated the moisture adjustment of the Feed Conversion Ratio (FCR) to a dry matter basis for all comparative analyses [19,20].

- Dry Matter = (wet weight – Moisture %)

Therefore (weight of BSFL – 70% Moisture) = 30% of the live weight contributes as dry matter, and (weight of conventional feed – 11% Moisture) = 89% of the pellet weight contributes as dry matter.

- Dry FCR $= \frac{Total\ Dry\ Matter\ \ Feed\ Intake\ \ (g)}{Total\ \ Weig\,t\ Gain\ \ (g)}$.
- Viscerosomatic Index (VSI, %) $= \frac{\text{Viscera Weight (Wv)}}{\text{Total body Weight (Wt)}} X\ 100$
- Survival Rate (SR, %) $= \frac{Nf}{Ni} X\ 100$[21]

2.4 Biochemical Analysis of Striped murrel fish

2.4.1 Sample Collection and Preparation

At the end of rearing, nine representative fish (n=9) per treatment were collected and euthanized [22]. Immediately following euthanasia, the viscera were excised and weighed for the calculation of the Viscerosomatic Index (VSI). The remaining eviscerated whole-body tissue was processed into homogenates using a sterile stainless-steel grinder. Subsamples for proximate and fatty acid analyses were immediately frozen and stored at –20 °C until further analysis was performed.

2.4.2 Proximate Analysis

Proximate analysis of whole-body homogenates was performed in triplicate following the AOAC (2019) protocols, with the results expressed on a dry-matter basis [23]. Moisture content was determined by drying a 5 g sample at 105 °C to a constant weight [24]. Crude protein content was measured using the Kjeldahl method (N X 6.25) [25]. Crude lipid was extracted via Soxhlet extraction

using petroleum ether (40 -60 °C) [26]. The ash content was determined by incineration at 550 °C for 6 h [27].

2.4.3 Fatty Acid Profiling

The fatty acid composition was analyzed using Gas Chromatography (GC) [28]. Total lipids were first extracted using the Bligh and Dyer method (chloroform-methanol-water, 2:2:1.8 v/v/v) and subsequently trans-esterified into Fatty Acid Methyl Esters (FAMEs) using 2% sulfuric acid in methanol incubated at 70 °C for 2 h. FAMEs were analyzed using an Agilent 7890B GC (FID, DB-23 column: 60 m × 0.25 mm × 0.25 µm). The oven temperature was ramped from 150 - 230 °C at 4 °C /min using helium (1.0mL/min) as the carrier [29]. FAMEs were identified against a Supelco 37 Component FAME Mix standard, quantified as a percentage of total fatty acids (% of Total FA), and categorized into SFA, MUFA and PUFA

2.5 Statistical Analysis

The pond was considered the experimental unit (n = 3 per treatment). Individual fish measurements (n = 9 per treatment) were averaged to obtain pond-level values. Treatment effects were evaluated using one-way analysis of variance (ANOVA) on pond-level means. When significant differences were detected, Data were analyzed using GraphPad prism 9. Tukey's HSD test was applied for mean comparisons, and effects were considered significant at $p < 0.05$.

3. RESULTS AND DISCUSSIONS

A130-dayfeedingtrialwas conducted to assess the effects of partial and complete replacement of conventional feed with live BSFL on Striped Murrel (*Channa striata*). The results were presented in four key areas: specific growth trajectory, final performance metrics, whole-body composition, and fatty acid biomodification.

3.1 Specific Growth Trajectory

At the end of the 130-day feeding trial, growth performance metrics indicated that the Control group achieved significantly higher maximum weight and length compared to the T1 and T2 groups ($p < 0.05$) (Figure 1).

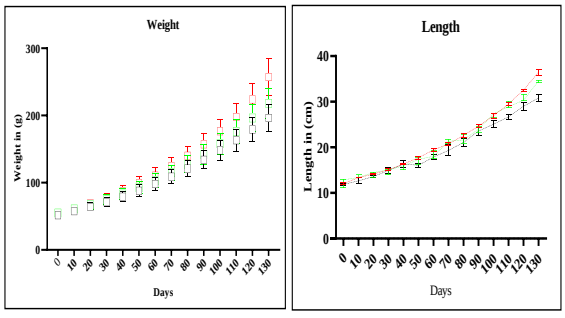

Figure 1: Left: Mean weight (g) and Right: length (cm) of *C. striata* over a 130-day period. Data points represent the mean ± SD, n=9 for three treatments.

Dietary influences were more pronounced in total biomass accumulation than in skeletal growth. Fish in the T2 group exhibited limited weight gain despite measurable increases in length, with variability in their responses to black soldier fly larvae (BSFL) diets becoming increasingly evident during the later stages of the trial. This dose-dependent growth penalty aligns with the findings [30], who reported similar growth constraints in Snakehead fish (Channa sp.) when diets incorporated high proportions of fresh BSFL. The restricted weight gain observed in T2, despite the active motility of live BSFL stimulating natural predatory behaviour in C. striata, suggests limitations in nutrient bioavailability. Given that live BSFL contains approximately 70% moisture, complete dietary substitution likely reduces the volumetric intake of dry matter required to sustain optimal somatic growth. Comparable growth in yellow catfish (*Pelteobagrus fulvidraco*) at high BSFL replacement levels, reinforcing the premise that although BSFL is highly palatable, a 100% replacement strategy cannot support growth velocities equivalent to those achieved with conventional nutrient-dense pellets containing only 11% moisture.

3.2 Final Performance Metrics

3.2.1 Weight gain and Length increase

The final harvest results obtained at the end of the 130-day trial are presented in Table 1. Weight gain was highest in the Control, followed by T1and T2, with differences among treatments being statistically significant ($p < 0.05$). Similarly, final length was greatest in the Control, compared to T1 and T2, with highly significant differences observed ($p < 0.05$).

Table 1: Growth Performance, Feed Utilization Efficiency, and Survival Metrics of Striped Murrel Fed Experimental Diets for 130 days.

Indicators	Control	T1	T2	SEM	*P-value*
Weight Gain (g)	204.81^{a}	163.26^{ab}	144.53^{b}	10.59	0.025
Length Increase (cm)	24.26^{a}	21.57^{b}	19.58^{c}	0.68	<0.0001
Specific Growth Rate (SGR)	1.22^{a}	1.06^{b}	1.02^{b}	0.03	0.001
Relative Growth Rate (RGR)	390.04^{a}	297.89^{b}	278.57^{b}	17.96	0.001
Feed Conversion Ratio (Wet-FCR)	2.83^{a}	6.51^{b}	9.65^{b}	1.00	0.001
Dry-FCR	2.54^{a}	2.90^{b}	3.00^{b}	0.08	0.014
Viscerosomatic Index (VSI)	6.91^{a}	7.84^{a}	7.54^{a}	0.17	0.055
Survival Rate (SR)	78.00^{a}	80.00^{a}	84.00^{a}	1.28	0.147

Cumulative fish weight of each treatment Values (mean, n=9), SEM= Standard Error of the Mean in the row and the values with different superscripts indicate significant differences as Tukey's HSD test ($p < 0.05$).

The predatory feeding behavior of *C. striata* ensures high palatability of liveBSFL, aided by their visual and vibratory

stimulation. However, the high-water content of live prey likely induces satiety before fish can ingest the equivalent dry-matter energy provided by conventional pellets with 11% moisture. similarly noted that while BSFL is a high-quality protein source, its chitin fraction may restrict nutrient bioavailability at full replacement levels in yellow catfish (*Pelteobagrus fulvidraco*). Importantly, Dry-FCR values in this study (2.90–3.00) show that once moisture is excluded, BSFL nutrient assimilation efficiency is nearly comparable to conventional feed. These findings indicate that the growth bottleneck in T2 arises from volumetric ingestion limits rather than deficiencies in BSFL protein quality.

3.2.2 SGR and RGR

At the end of the feeding trial, Specific growth Rate(SGR) differed significantly among treatments ($p < 0.05$). Tukey's multiple comparison test showed that Control differed significantly from T1 and T2, whereas no significant difference was observed between T1 and T2.Relative growth rate (RGR) differed significantly among treatments ($p < 0.05$). Tukey's multiple comparison test revealed that the control showed significantly higher RGR compared to both T1 and T2 ($p < 0.01$), while no significant difference was observed between T1 and T2 ($p > 0.05$).The data suggest that while BSFL inclusion supports growth, it does so at a reduced rate compared to the Control.These results indicate potential constraints regarding nutrient bioavailability or metabolic compatibility as the inclusion of BSFL increases.[31].As an ambush predator, *Channa striata* exhibits a strong instinctual preference for live prey. The motility of BSFL provides visual and vibratory cues that stimulate natural hunting responses, ensuring rapid feed acceptance and minimizing uneaten pellet-associated waste [32].

3.2.3 Feed Conversion, Moisture Adjustment

Upon completion of the feeding trial, the highest wet-FCR was observed in T2 (9.65), followed by T1 (6.51) and the Control (2.83). When FCR was adjusted to a dry-weight basis, values decreased markedly, with T2 recording 3.00, T1 at 2.90, and the Control at 2.54. Moisture adjusted FCR values across treatments remained within a close range, with BSFL-fed groups (T1 and T2) showing comparable efficiencies to the Control. Statistical analysis confirmed significant differences among treatments ($p< 0.05$). The difference in Dry-FCR demonstrates that, after accounting for water content, BSFL protein exhibits biological value comparable to fishmeal. This suggests high amino acid availability, with growth variation attributable to intake constraints rather than nutritional deficiency.

3.2.4 Viscerosomatic Index (VSI)

In contrast to growth parameters, VSI did not differ significantly among treatments. This indicates that neither partial nor complete BSFL inclusion caused abnormal visceral enlargement or excessive fat deposition. The absence of significant differences ($p > 0.05$) suggests that BSFL diets did not induce metabolic stress or pathological organ development in *C. striata.* Similar findings have been reported in feeding trials using insect-based protein sources, where somatic indices remained stable despite variations in growth rate. This suggests physiological tolerance of murrel fish to BSFL inclusion. Contrasting many plant-based proteins that induce visceral fat deposition in carnivorous fish, the stable VSI in *C. striata* indicates efficient BSFL lipid metabolism, supporting physiological functions without pathological fat accumulation in the body cavity [31].

3.2.5Survival Rates (SR)

Remained consistently high across treatments, ranging from 78% in the Control to 84% in T2. The (SEM = 1.28) indicates minimal variability within groups. Statistical analysis ($P>0.05$) confirmed that differences among treatments were not significant. Therefore, partial or complete inclusion of BSFL in the diet did not produce a measurable effect on fish survival under the tested conditions, with values remaining comparable to the Control. Likely due to lauric acid and antimicrobial peptides enhancing innate immunity and gut health in *Channa striata*, conferring bio security benefits and reducing reliance on medicinal interventions in intensive aquaculture.

3.3 Whole-Body Proximate Composition

Whole-body proximate analysis of *Channa striata*as presented in Table 2, reveals a highly consistent composition across dietary treatments, with protein content remained consistent in all groups (Control: 22.04%, T1: 22.04%, T2: 22.09%). This stability, despite differences in growth performance, reflects a conserved physiological homeostasis regulation that prioritizes the regulation of protein and lipid ratios irrespective of dietary source [32, 33]. Moisture content remained comparable, ranging from 70.80% to 71.44%, while crude lipid content ranged (0.76–0.91%) and ash content was similarly stable (4.52–4.63%). The low SEM values and non-significant difference ($p> 0.05$) across all proximate parameters indicate that dietary replacement with BSFL did not alter the fundamental nutritional composition of the fish.

Table 2: Whole-body proximate composition.

Matrix	Control	T1	T2	SEM	*P-value*
Moisture	70.81 ± 0.03	71.44 ± 0.34	70.80 ± 0.93	0.20	0.38
Protein	22.04 ± 0.69	22.04 ± 0.88	22.09 ± 0.54	0.21	0.99
Fat	0.91 ± 0.19	0.76 ± 0.19	0.85 ± 0.21	0.06	0.65
Ash	4.62 ± 0.27	4.52 ± 0.21	4.63 ± 0.10	0.06	0.78

Values (mean ± SD, n=9), SEM= Standard Error of the Mean in the row and significantly different ($p < 0.05$)

Sudha et al. reported that Snakehead fingerlings maintain stable muscle proximate composition despite variations in growth performance, indicating tissue homeostasis. These

findings confirm that complete replacement with BSFL produces fillets nutritionally comparable to controls, supporting BSFL as a bio equivalent protein source for consumer applications [34].

3.4 Fatty Acid Biomodulation

The whole-body fatty acid profile of striped murrel is presented in Table 3, and the corresponding heat map is shown in Figure 2.

Table 3: Striped Murrel fish whole body fatty acid profile (% of total fatty acids).

Fatty acid Name	Code	Control	T1	T2	SEM	*P-value*
SFA						
Methyl Laurate	C12:0	6.38	0.23	9.45	1.49	0.03
Methyl Tetradecanoate	C14:0	3.97	2.12	5.05	0.59	0.13
Methyl Pentadecanoate	C15:0	0.00	0.12	0.00	0.02	0.16
Methyl Palmitate	C16:0	23.38	22.54	24.09	0.85	0.77
Methyl Octadecanoate	C18:0	8.28	9.64	7.53	0.03	0.03
Methyl Heneicosanoate	C21:0	0.21	0.30	0.40	0.07	0.68
Methyl Tricosanoate	C23:0	1.23	1.78	0.84	0.11	0.001
MUFA						
Methyl Palmitoleate	C16:1	3.42	2.51	3.43	0.11	<0.001
Elaidic acid, Oleic acid ME	C18:1n9	31.05	30.81	26.93	1.10	0.24
Methyl cis-11-eicosenoate	C20:1n9	0.98	0.83	1.02	0.08	0.62
PUFA						
Linolelaidic acid, Methyl Linoleate	C18:2n6	13.74	18.49	15.20	0.76	0.03
Methyl linolenate	C18:3n3	0.79	1.06	0.55	0.07	0.02
cis-11,14-Eicosatrienoic acid ME	C20:2	0.35	0.83	0.25	0.07	<0.001
cis-8,11,14-Eicosatrienoic acid ME	C20:3n6	1.17	1.30	0.96	0.08	0.21
cis-13,16-Docosadienoic acid ME	C22:2	0.96	0.00	0.00	0.23	0.16
Methyl cis-5,8,11,14,17-Eicosapentaenoate	C20:5n3	0.00	0.10	0.00	0.02	0.16
cis-4,7,10,13,16,19-Docosahexaenoate	C22:6n3	4.10	7.34	4.30	0.619	0.06

Values (mean, n=9), SEM= Standard Error of the Mean in the row and significantly different ($p < 0.05$)

Saturated Fatty Acids (SFA)

Among the saturated fatty acids, methyl laurate (C12:0,lauric acid) was higher in T2 (9.45%) compared with the Control (6.38%) and T1 (0.23%) with differences confirmed (p< 0.05). This reflects the characteristic lauric acid dominance in BSFL lipids, which are associated with antimicrobial activity and rapid metabolic oxidation. Methyl tetradecanoate (C14:0) was greater in T2 (5.05%) than in the Control (3.97%) and T1 (2.12%) although the difference was not statistically significant (p> 0.05), suggesting limited modulation of myristic acid. Methyl pentadecanoate (C15:0) appeared only in T1 (0.12%) and was absent in the Control and T2 (p> 0.05), indicating a treatment-specific but inconsistent response. Methyl palmitate (C16:0) remained stable across treatments with values between (22.54%) and (24.09%) and no differences observed (p> 0.05), underscoring its metabolic robustness. Methyl octadecanoate (C18:0) was higher in T1 (9.64%) compared with the Control (8.28%) and T2 (7.53%) with variation confirmed (p< 0.05), suggesting partial BSFL inclusion may promote stearic acid deposition while full substitution favors medium-chain fatty acids. Methyl heneicosanoate (C21:0) was consistently low (0.21–0.40%) and did not differ (p>0.05). Methyl tricosanoate (C23:0) was greater in T1 (1.78%) compared with the Control (1.23%) and T2 (0.84%) with differences confirmed (p< 0.05). Collectively, BSFL inclusion mainly influenced medium-chain fatty acids while partial substitution enhanced stearic and very-long-chain fatty acids [35].

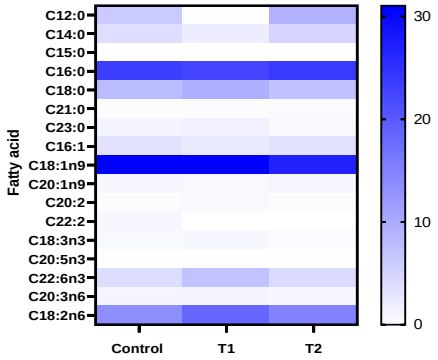

Figure 2: Heatmap for Fatty Acid profile of striped murrel fish in different treatment.

Monounsaturated Fatty Acids (MUFA)

Among the monounsaturated fatty acids, methyl palmitoleate (C16:1) was lower in T1 (2.51%) compared

with the Control (3.42%) and T2 (3.43%), with differences confirmed ($p < 0.001$). This indicates that partial BSFL inclusion reduced palmitoleic acid deposition, while full substitution-maintained values similar to the Control. Oleic acid (C18:1n9) represented the major MUFA fraction, with values of 31.05% in the Control, 30.81% in T1, and 26.93% in T2, though variation was not statistically supported ($p > 0.05$). Methyl cis 11 eicosenoate (C20:1n9) remained consistent across treatments (0.83–1.02%) with no differences ($p > 0.05$). Overall, MUFAs were stable, with palmitoleate showing treatment dependent variation.

Polyunsaturated Fatty Acids (PUFA)

Among the polyunsaturated fatty acids, methyl linoleate (C18:2n6) was higher in T1 (18.49%) compared with the Control (13.74%) and T2 (15.20%), with differences confirmed ($p < 0.05$). This suggests that partial BSFL inclusion enhanced linoleic acid deposition, which is important for membrane function and inflammatory regulation. Methyl linolenate (C18:3n3) was greater in T1 (1.06%) compared with the Control (0.79%) and T2 (0.55%), with statistical support ($p < 0.05$), indicating that intermediate substitution promoted n 3 fatty acid incorporation. Cis 11,14 eicosatrienoic acid (C20:2) was also higher in T1 (0.83%) compared with the Control (0.35%) and T2 (0.25%), with differences confirmed ($p < 0.05$), reflecting enhanced elongation activity under partial substitution. In contrast, cis 8,11,14 eicosatrienoic acid (C20:3n6) and cis 13,16 docosadienoic acid (C22:2) did not differ among treatments ($p > 0.05$), suggesting stability of these minor PUFAs. Eicosapentaenoic acid (C20:5n3) was detected only in T1 (0.10%) with no statistical relevance ($p > 0.05$). Docosahexaenoic acid (C22:6n3) was higher in T1 (7.34%) compared with the Control (4.10%) and T2 (4.30%), with approaching significance ($p = 0.06$), indicating that partial BSFL inclusion favored long chain n 3 PUFA deposition. Overall, PUFA profiles show that intermediate substitution enhanced both n 6 and n 3 fatty acids, while full BSFL inclusion shifted metabolism toward medium chain dominance [36, 37].

Integrative Interpretation

Taken together, the results reveal a non-linear effect of BSFL inclusion: partial substitution often enhanced PUFA deposition (C18:2n6, C18:3n3, C20:2, C22:6n3), while complete substitutionprimarily elevated medium-chain SFA (C12:0) and maintained MUFA levels. This pattern suggests that insect lipids interact metabolically with conventional feed oils, and that intermediate inclusion levels optimize fatty acid balance.

From a nutritional perspective, the increase in lauric acid at complete BSFL inclusion is consistent with the intrinsic lipid profile of BSFL, while the PUFA enhancements at partial inclusion highlight the potential of mixed diets to improve essential fatty acid status. These findings resonate with earlier reports in aquaculture and poultry nutrition, where BSFL inclusion altered lipid metabolism and tissue fatty acid composition.

Mechanistically, the observed shifts reflect changes in desaturase and elongase activity, differential absorption of medium-chain versus long-chain fatty acids, and possible sparing effects when insect lipids replace plant oils. The balance between n-6 and n-3 PUFA is particularly important, and the elevation of DHA at partial inclusion suggests that BSFL-based diets support long-chain PUFA synthesis under certain conditions.

4. CONCLUSION

Black Soldier Fly Larvae (BSFL) proved to be a sustainable feed ingredient for Striped Murrel, maintaining survival and whole-body composition even under complete replacement. However, growth performance declined at 100% BSFL inclusion due to moisture. Moisture adjusted feed conversion ratios confirmed efficient nutrient assimilation, The incorporation of BSFL significantly modulated the fatty acid profile, with full inclusion (100%) enhancing lauric acid and maintaining MUFA, while partial inclusion (50%) promoted PUFA deposition, including linoleic acid, linolenic acid, and DHA. These results underscore the potential of BSFL as a sustainable feed ingredient, but also highlight that maximum sustainable replacement level inclusion levels lie in partial substitution rather than full replacement.Therefore, partial replacement at 50% offers the best balance between sustainability, feed efficiency, and nutritional quality in murrel aquaculture.

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7. AUTHOR CONTRIBUTION STATEMENT

Balu Amaresh D Joragi: Investigation, Methodology, Writing – Original draft, Formal Analysis.

Veeresh SJ:Conceptualisation, Supervision, Project administration, Writing – Review and Editing.

8. DISCLOSURE STATEMENT

The authors declare that they have no known competing financial or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process: During the

preparation of this work, the authors used a generative AI tool solely for language refinement. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

9. ETHICS AND ANIMAL USE

The protocols and procedures involving fish were conducted ethically reviewed and approved.

10. CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding the research, authorship, or publication of this article.

11. DATA AVAILABILITY STATEMENT

All data produced or analyzed in this study are included in the article.

12. REFERENCES

1. Jannathulla R, Rajaram V, Kalanjiam R, Ambasankar K, Muralidhar M, Dayal JS. Fishmeal availability in the scenarios of climate change: inevitability of fishmeal replacement in aquafeeds and approaches for the utilization of plant protein sources. Aquac Res. 2019;50(12):3493–506. doi:10.1111/are.14324.
2. Wang J, Zhang R, He T, Belgrano A. Editorial: Blue foods security and sustainability. Front Mar Sci. 2024;11. doi:10.3389/fmars.2024.1487645.
3. Zulkifli NFNM, Seok-Kian AY, Seng LL, Mustafa S, Kim Y, Shapawi R. Nutritional value of black soldier fly (Hermetia illucens) larvae processed by different methods. PLoS One. 2022;17(2):e0263924. doi:10.1371/journal.pone.0263924.
4. Ravi HK, Guidou C, Costil J, Trespeuch C, Chemat F, Vian MA. Novel insights on the sustainable wet mode fractionation of black soldier fly larvae (Hermetia illucens) into lipids, proteins and chitin. Processes. 2021;9(11):1888. doi:10.3390/pr9111888.
5. Phaengphairee P, Boontiam W, Wealleans A, Hong J, Kim YY. Dietary supplementation with full-fat Hermetia illucens larvae and multi-probiotics, as a substitute for antibiotics, improves the growth performance, gut health, and antioxidative capacity of weaned pigs. BMC Vet Res. 2023;19(1):7. doi:10.1186/s12917-022-03550-8.
6. Suwannayod S, Setthaya P, Limsopatham K, Harnpornchai N. The effect of growth and nutrition in black soldier fly larvae fed by hemp seed oil mixed diets. Insects. 2025;16(11):1081. doi:10.3390/insects16111081.
7. N R, Varghese T, Jana P, J ABR, A MS, S S, et al. Current status and global research trend patterns of insect meal in aquaculture from a scientometric perspective (2013–2022). Aquac Nutr. 2024;2024(1):5466604. doi:10.1155/2024/5466604.
8. Thomas A, Singh SK, Debbarma R, Angom J, Waikhom G, Patel A, Biswas P. Exploring the suitability of Hermetia illucens meal in Clarias magur catfish: effect on growth, physiology and flesh quality. J Insects Food Feed. 2024;11(1):187–200. doi:10.1163/23524588-00001089.
9. Hossain MS, Small BC, Hardy R. Insect lipid in fish nutrition: recent knowledge and future application in aquaculture. Rev Aquac. 2023;15(4):1664–85. doi:10.1111/raq.12810.
10. Xiao X, Jin P, Cai M, Yu Z, Yu J, Zhang J, Zheng L. Effects of black soldier fly (Hermetia illucens) larvae meal protein as a fishmeal replacement on the growth and immune index of yellow catfish (Pelteobagrus fulvidraco). Aquac Res. 2018;49(4):1569–77. doi:10.1111/are.13611.
11. Kinasih I, Nurhadi MY, Gusmara FF, Putra RE, Permana AD, Anitasari RA. Growth performance of black soldier fly larvae (Hermetia illucens) fed on some plant-based organic wastes. Hayati J Biosci. 2018;25(2):79. doi:10.4308/hjb.25.2.79.
12. Rossi G, Ojha S, Müller-Belecke A, Schlüter OK. Fresh aquaculture sludge management with black soldier fly (Hermetia illucens L.) larvae: investigation on bioconversion performances. Sci Rep. 2023;13(1). doi:10.1038/s41598-023-48061-0.
13. Moran D, Pether SJ, Lee PS. Growth, feed conversion and faecal discharge of yellowtail kingfish (Seriola lalandi) fed three commercial diets. N Z J Mar Freshw Res. 2009;43(4):917–27. doi:10.1080/00288330909510050.
14. Budiman F, Nugroho MA, Rivai M. Monitoring and control system for ammonia and pH levels for fish cultivation implemented on Raspberry Pi 3B. Proc Int Semin Intell Technol Appl (ISITIA). 2019;96:68–73. doi:10.1109/isitia.2019.8937217.
15. Wang T, Yang H, Wang R, Wang Y, Wang X, Zhang Z, Shehata AI, Wang J. Growth performance, physiological and antioxidant capacity responses to dietary fish meal replacement with insect meals for aquaculture: a case study in red claw crayfish (Cherax quadricarinatus). Aquac Res. 2022;53(10):3853–64. doi:10.1111/are.15892.
16. Kim J, Kurniawan H, Faqeerzada MA, Kim G, Lee H, Kim MS, Baek I, Cho B. Proximate content monitoring of black soldier fly larval (Hermetia illucens) dry matter for feed material using short-wave infrared hyperspectral imaging. Food Sci Anim Resour. 2023;43(6):1150–69. doi:10.5851/kosfa.2023.e33.
17. Jisr N, Younes G, Sukhn C, El-Dakdouki MH. Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon. Egypt J Aquat Res. 2018;44(4):299–305. doi:10.1016/j.ejar.2018.11.004.
18. Froese R. Estimating somatic growth of fishes from maximum age or maturity. Acta Ichthyol Piscat. 2022;52(2):125–33. doi:10.3897/aiep.52.80093.

19. Kim Y, Oh S, Lee W. Feeding ratio affects growth, body composition, and blood chemistry of mandarin fish (Siniperca scherzeri) in a recirculating aquaculture system. Fish Aquat Sci. 2021;24(6):219–27. doi:10.47853/fas.2021.e22.
20. Khan MA, Abidi SF, Ahmed I. Effect of ration size on growth, conversion efficiency and body composition of fingerling mrigal, Cirrhinus mrigala (Hamilton). Aquac Nutr. 2004;10(1):47–53. doi:10.1046/j.1365-2095.2003.00279.x.
21. Venkatachalam S, Kandasamy K, Krishnamoorthy I, Narayanasamy R. Survival and growth of fish (Lates calcarifer) under integrated mangrove-aquaculture and open-aquaculture systems. Aquac Rep. 2017;9:18–24. doi:10.1016/j.aqrep.2017.11.004.
22. Li Q, Huang Y, Zhang X, Qin Z, Zou C, Tan X, Xie X, Liang S, Lin L. Effects of faba beans (Vicia faba L.) on growth performance, textural quality and physiological indices of tilapia (Oreochromis niloticus). Aquaculture. 2023;574:739640. doi:10.1016/j.aquaculture.2023.739640.
23. Syandri H, Azrita A, Mardiah A, Aryani N, Diharmi A. The proximate composition, amino acid profile, fatty acid content, and mineral content of scale flour from three fish species as potential feeds for fish fry. F1000Res. 2023;12:1144. doi:10.12688/f1000research.141304.2.
24. Yeannes MI, Almandos ME. Estimation of fish proximate composition starting from water content. J Food Compos Anal. 2003;16(1):81–92. doi:10.1016/S0889-1575(02)00168-0.
25. Khodabux K, Lomelette M, Jhaumeerlaulloo S, Ramasami P, Rondeau P. Chemical and near-infrared determination of moisture, fat and protein in tuna fishes. Food Chem. 2006;102(3):669–75. doi:10.1016/j.foodchem.2006.05.057.