Preliminary Assessment of Replacing Fishmeal and Fish Oil with Black Soldier Fly Larval Meal and Oil on Growth Performance and Economic Profitability of Juvenile Common Carp *Cyprinus Carpio* Culture

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Abstract
This study assessed the growth performance and economic profitability of juvenile common carp (*Cyprinus carpio*) cultured on Black Soldier Fly (BSF) *Hermetia illucens* larval-based diets. The experiment was conducted in a recirculating system. Four isonitrogenous (350 g kg^{-1} crude protein) and isolipidic (80 g kg^{-1} crude fat) diets were formulated in which fishmeal (400 g kg^{-1}) and fish oil (30 g kg^{-1}) were simultaneously replaced with a defatted BSF larval meal and BSF larval oil at 0, 25, 50, and 75%. Fish (initial body weight of 96.30±8.35g) were hand-fed at 3% body weight for 7 weeks. The result indicated a significant linear increase ($p < 0.05$) in mean final weight, weight gain, and specific growth rate (SGR) with higher dietary levels of BSF larval meal and oil. The feed conversion ratio (FCR) decreased linearly with increasing inclusion levels of BSF larval meal and oil. The economic analysis showed a linear decline in profitability with higher dietary levels of BSF larval meal and oil. The findings suggest that BSF larval meal and oil could potentially replace up to 75% of dietary fishmeal and fish oil (300 g kg^{-1} and 25 g kg^{-1}, respectively) without adversely impacting growth performance and nutrient utilization of juvenile common carp.

Keywords: alternative ingredients, growth rate, nutrient utilization, sustainability.

1. Introduction

Fish play a crucial role in providing food and nutritional security for humanity, supplying at least 15% of animal protein globally. Over 3.2 billion people rely on seafood for livelihood and sustenance [1]. Global per capita fish consumption has been rising, primarily due to population growth and a shift in consumers' preferences for fish over other animal proteins, driven by its health benefits, as a rich source of amino acids and omega-3 fatty acids [1]. Capture fisheries, once the primary source of fish supply, have stagnated in recent decades due to the overexploitation of marine fish stocks. In contrast, aquaculture has been steadily growing and is currently the fastest-growing animal production sector worldwide. With the world population projected to reach 9.7 billion by 2050,

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aquaculture will play a crucial role in meeting the increasing demand of consumers [1-2].

Fishmeal and fish oil are the optimal protein and lipid ingredients in aquafeed. Fishmeal is a high-quality and highly digestible source of protein with a well-balanced amino acid profile. Fish oil, on the other hand, is rich in omega-3 highly unsaturated fatty acids (n-3 HUFA), including eicosatetraenoic acid (EPA) and docosahexaenoic acid (DHA), both of which are essential for growth and fish well-being [3-4]. However, these marine ingredients are derived from the reduction of small pelagic fish, raising ecological concerns about the rapid expansion of feed aquaculture and its negative impact on marine fish stocks [2-5].

Additionally, the rising cost of fishmeal and fish oil poses a threat to the sustainability of the aquaculture industry [2-6]. As a result, there has been an increasing focus on evaluating a wide variety of alternative, cost-effective, and sustainable ingredients that could partially or completely replace fishmeal and fish oil in fish feed formulation and utilization.

Insects, particularly the larvae of Black Soldier Fly (BSF), appeared to have potential due to their high protein and fat content. They are fast-growing, have a short life cycle, are easy to produce as they can be reared on organic waste streams, and they do not contribute to environmental carbon footprint [7-8].

The BSF larvae (the larval meal and its fractional oil - BSF larval oil) have been tested as ingredients for various fish species, including the Jian carp *Cyprinus carpio* var. Jian [9], African catfish *Clarias gariepinus* [10], Nile tilapia *Oreochromis niloticus* [11], European sea bass, *Dicentrarchus labrax* [12], rainbow trout *Oncorhynchus mykiss* [4] and Pacific white shrimp Litopenaeus vannamei [13].

The common carp, *Cyprinus carpio* (Cyprinidae), is the fourth most widely cultured inland finfish species in the world, following grass carp, silver carp, and Nile tilapia, with production totalling about 4.23 million tonnes in 2020, accounting for 8.6% of global finfish production [14]. This study is a preliminary assessment of the growth performance, nutrient utilization, and economic viability of replacing fishmeal and fish oil with BSF larval meal and oil in diets for juvenile common carp *Cyprinus carpio* culture.

2. Materials and methods

2.1 Fish culture

The procedures were approved by the Workplace Animal Welfare Committee of the University of Debrecen (7/2025/DEMÁB) and complied with the European Union Directive (2010/63/EU) regarding animal experiments. The experiment was conducted at the Fish Biology Laboratory, University of Debrecen, Hungary, in a recirculating system, circular plastic tanks (350 L), in a completely randomized design. Four isonitrogenous (350 g kg^{-1} crude protein) and isolipidic (80 g kg^{-1} crude fat) diets were formulated in which fishmeal (400 g kg^{-1}) and fish oil (30 g kg^{-1}) were simultaneously replaced with a defatted BSF larval meal and BSF larval oil at 0, 25, 50, and 75%, coded as Control (containing 0% BSF larval meal and oil), BSF 25, BSF 50 and BSF 75 diets, respectively. The mixed feed ingredient was pelleted at 4.5 mm, dried in an oven at 50 °C for 48 h. Fish (initial body weight of 96.30±8.35g, 10 fish per tank, 4 treatments, 3 replicates) were hand-fed at 3% body weight for 7 weeks. Sampling was carried out weekly. Chemical analysis was performed to determine the proximate composition, according to standard methods as described in [15].

The following indices were calculated as follows;

a. Weight Gain (g) = (Initial mean weight - final mean weight).
b. Specific Growth Rate (SGR) = In [(mean final weight) – In (mean initial weight)] / (Time /days) x 100.
c. Feed Conversion Ratio (FCR) = (Weight of feed fed) / (Weight gain of fish).
d. Protein efficiency ratio (PER) = [Weight gain (g) / protein intake (g)].
e. Conditioning factor (cm) = [$(W/L^3) \times 100$], where W is the wet weight (g), L is the standard length (cm).
f. Feed intake = Total feed intake(g) per fish.

2.2 Economic assessment of diets

The cost-effectiveness of replacing fishmeal and fish oil with BSF larval meal and oil was determined. The cost of the diets was calculated using retail market prices of the ingredients, which were provided by a distributor in the Hajdu-Bihar Region of Hungary in Hungarian Forint (Ft), then converted to Euro (€) at a prevailing exchange rate of 400 Forint to €1 as of October 2025. The prices per kilogram of the ingredients are as follows:

Blood meal = €1.70; HP300 soy conc. = €1.38; fishmeal = €1.85; BSF larval meal = €3.75; vitamin/mineral premix = €4.75; zeolite = €0.35; glucose = €1.38; immunotox = €1.00; vitamin C = €3.75; fish oil = €3.75; BSF oil = €6.00; novilpel = €1.88; lysine = €1.75; methionine = €2.50; threonine = €1.75; tryptophan = €8.25; Wheat meal = € 0.20. The sale price of fish (fillet per kg = €7.50) was provided by the fish farmers in Hajdu-Bihar (personal communication). Cost of labour, taxes and other components of the cost of production were discounted.

The cost-effectiveness of the diets was determined using the following formulae, according to Rawski et al. [16]:

a) Economic conversion ratio, (ECR) (€/kg of fish gain) = [FCR × DP (€ /1 kg)].
b) Economic profitability index (EPI), (€/kg of fish gain) = (WG×SP) – (WG×DP×FCR) Where WG = Weight gain of fish (kg); SP = Selling price of fish (fillet) (€/kg); DP = Diet price (€/kg).
c) Profitability (€/kg weight gain of fish) = (SP – ECR).

2.3 Data analysis

Data was checked for normality of distribution with the Kruskal-Wallis test. Homogeneity of variances between experimental groups was checked using Levene's test. The data were subjected to a one-way analysis of variance (ANOVA). Tukey's multiple comparison test was used to determine significant differences between treatments ($p < 0.05$ was considered significant). Polynomial contrast was applied to check the trend response. All analyses were carried out using IBM SPSS version 29.

3. Results

3.1 Growth performance and nutrient utilization.

The results of growth and nutrient utilization parameters (Table 1) showed an increasing linear trend in the final mean weight, weight gain, and specific growth rate (SGR) indices with increasing dietary levels of BSF larval meal and oil. Fish fed the BSF 75% diet had the highest final mean weight, weight gain and SGR, which was similar to fish fed BSF 25 and BSF 50 diets, but significantly higher ($p < 0.05$) than fish fed the Control diet. No significant difference ($P > 0.05$) was found in the feed conversion ratio (FCR). However, a decreasing linear trend was observed with increasing BSF larval meal and oil inclusion. Feed intake was highest in fish fed BSF 75, which was similar to that fed BSF 50, but significantly higher ($p < 0.05$) than fish fed BSF 25 and the Control diets. Protein efficiency ratio (PER) increased with higher inclusion levels of BSF larval meal and oil. There were no significant differences ($p>0.05$) in survival rate (SR) and condition factor (CF) across the treatments.

3.2 Economic Assessment

The economic assessment of the diets (Table 2) indicated that the cost of diets increases with higher inclusion levels of BSF larval meal and oil, resulting in an increase in the ECR across the group. The EPI and profitability decreased with the inclusion of BSF larval meal and oil.

4. Discussion

4.1 Growth performance and Nutrient utilization

BSF larval meal and oil are a promising alternative to conversional fishmeal and fish oil in aquafeed. The present study indicates that the high inclusion levels of BSF larval meal and oil enhanced growth performance and feed utilization in juvenile common carp. This suggests that fishmeal and fish oil could be replaced with BSF larval meal and oil at levels up to 75% (300 $g.kg^{-1}$ BSF larval meal and 25 $g\ kg^{-1}$ BSF larval oil). The current study aligns with previous research involving African catfish *Clarias gariepinus* [10] and gold fish *Carassius aurata* [18]. Complete replacement of fishmeal with BSF larval meal has been reported in Jian carp Cyprinus carpio var. Jian [9], Atlantic salmon *Salmo salar* [19], and European sea bass, *Dicentrarchus labrax* [12]. However, the present study contrasts with previous findings in rainbow trout *Oncorhynchus mykiss* [4] and *African catfish* [20], in which the substitution of fishmeal with BSF larval meal above 50% impaired growth and feed conversion rates.

These discrepancies may be attributed to factors such as fish species, life stage, processing methods, and the dietary inclusion levels of the insect meal [6].

The significantly improved growth performance and efficient feed utilization observed with increasing levels of BSF larval meal and oil may be attributable to the richness in lauric acid (C12:0), which is known to have beneficial effects on gut bacteria. Similarly, BSF larval meal and oil contain bioactive compounds, such as chitin and antimicrobial peptides (AMPs), that enhance immune response in fish and help modulate the gut microbiome [16-21].

Table 1. Growth performance and nutrient utilization of juvenile common carp fed on graded levels of BSF larval meal and oil for 7 weeks.

	Control	BSF 25	BSF 50	BSF 75	SEM	P-values		
						ANOVA	L	Q
FW	178.56±13.78^{a}	182.67±12.27^{ab}	197.30±9.88^{ab}	213.20±13.86^{b}	5.139	0.035	0.006	0.439
WG	82.22±14.68^{a}	86.60±12.27^{ab}	100.97±9.06^{ab}	116.83±13.45^{b}	5.122	0.036	0.006	0.450
SGR	0.55±0.08^{a}	0.57±0.06ab	0.64±0.02^{ab}	0.70±0.06^{b}	0.233	0.038	0.007	0.519
FCR	1.98±0.18	1.86±0.22	1.66±0.21	1.62±0.17	0.066	0.156	0.034	0.733
FI	152.08±4.42^{ab}	148.82±6.22^{a}	167.45±4.18^{bc}	171.98±6.96^{c}	3.267	0.002	0.001	0.260
PER	2.21±0.19^{a}	2.26±0.12^{a}	3.02±0.10^{b}	3.40±0.15^{c}	0.156	0.001	0.001	0.087
CF	2.44±0.21	2.54±0.20	2.24±0.23	2.37±0.19	0.059	0.380	0.363	0.908
SR	96.67±5.77	96.67±5.77	100.00±0.00	100.00±0.00	1.124	0.596	0.242	1.000

FW = Final weight (g); WG = Weight gain (g); SGR = Specific growth rate (% day^{-1}), FCR = feed conversion ratio, FI = Feed intake (gfish^{-1}); PER = protein efficiency ratio; CF = condition factor (g/cm^{3}); SR = survival rate (%); L, Q = Linear and quadratic polynomial contrasts, respectively. SEM = Standard error of the mean in triplicate. Values are means ±standard deviation, and pooled standard error of the mean in triplicate. Values of different superscripts in a row are significantly different ($p < 0.05$). The absence of a letter indicates no significant difference between treatments.

Table 2. Economic assessment of juvenile common carp fed on graded levels of BSF larval meal and oil for 7 weeks

	Control	BSF 25	BSF 50	BSF 75	SEM	P-value
FC (€/kg of feed)	1.11	1.34	1.56	1.8	-	-
ECR (€/kg of fish gain)	2.20±0.10^{a}	2.49±0.13^{ab}	2.59±0.12^{b}	2.9±0.13^{c}	0.082	<0.001
EPI (€/fish)	3.38±0.10^{b}	3.22±0.10^{a}	3.19±0.11^{a}	2.71±0.12^{a}	0.080	<0.001
PRO (€/1 kg fish gain)	5.30±0.10^{c}	5.01±0.12^{b}	4.91±0.09^{b}	4.59±0.10^{a}	0.080	<0.001

FC = Feed cost (€/kg), ECR = Economic conversion ratio (€/kg of fish weight gain); EPI = Economic profitability index (€/kg weight gain of fish); PRO = Profitability (€/kg weight gain of fish).
The values are mean ± standard deviation, pooled standard error of the mean (SEM), and p-value. Values with different superscripts in a row are significantly different ($p < 0.05$). The absence of a letter indicates no significant difference between treatments.

4.2 Cost-effectiveness of the diets

Few studies have examined the cost-effectiveness of using BSF larval meal and oil in aquafeed. The present study shows that replacing fishmeal levels (from 400 to 100 g kg^{-1}) and fish oil (from 30 to 5 g kg^{-1}) with BSF larval meal and oil increases diet costs, resulting in significantly higher ECR and reduced EPI and PRO. These findings contrast with those reported for Siberian sturgeon *Acipenser baerii* [16] and black sea bream *Acanthopagrus schlegelii* [22], where ECR decreased while EPI and PRO increased with higher inclusion levels of BSF larval meal. However, they are consistent with previous findings in European perch, *Perca fluviatilis* [17] and pikeperch *Sander lucioperca* [6].

The economic inefficiency of using BSF larval-based ingredients in aquaculture feed formulation primarily stems from the current lack of competitiveness in the insect production sector. This is due to several factors, including insufficient funding and stringent regulations. For instance, the European Union Regulation (EU 2017/893) prohibits the use of organic residual waste streams in rearing insects intended for aquaculture feed due to safety concerns [23-24]. These organic waste streams are often more cost-effective and promote circularity and sustainability within the feed value chain [23-24]. Research and innovations focused on the safe use of these organic waste streams for insect production could help maximise the benefits of the circular economy. It is expected that increased investment in the insect production industry will enhance production efficiency and make prices more competitive. Additionally, understanding consumers' attitudes and acceptance of fish that are fed on insect-based diets is crucial for ensuring the long-term economic sustainability of insect farming for aquaculture feed.

5. Conclusion and Recommendations

These preliminary findings indicate that BSF larval meal and oil significantly improved growth performance and feed utilization in common carp and could partially replace up to 75% of dietary fishmeal and fish oil (300 g kg^{-1} and 25 g kg^{-1}, respectively). However, the cost-effectiveness of these diets decreases with increasing inclusion levels of BSF larval meal and oil. Further studies are necessary to assess the long-term effects of substituting fishmeal and fish oil with BSF larval meal and oil on growth, nutrient utilization, fatty acid profile, immune response, and overall health status.

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