Effect of *Hermetia illucens* larvae rearing media on maggot oil inclusion to optimize growth and body composition of vannamei shrimp

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Abstract. The increasing demand and the high cost of raw materials for shrimp feed highlight the need for affordable alternatives that are both readily available and nutritionally adequate. Maggot oil, an insect-derived lipid, can be a potential solution to replace fish oil due to its rich fatty acids content, which supports shrimp growth. This study aimed to determine the effect of maggot oil inclusion, made by black soldier fly (BSF) (*Hermetia illucens*) larvae reared on different media compositions as an addition to fish oil in developing vannamei shrimp (*Litopenaeus vannamei*). An experimental design was conducted with six treatments and three replicates, including a control (commercial feed without maggot oil) and five experimental groups: A (150 g L^{-1} tofu waste), B (50 g L^{-1} fruit waste + 100 g L^{-1} tofu waste), C (50 g L^{-1} chicken manure + 100 g L^{-1} tofu waste), and D (50 g L^{-1} chicken manure + 100 g L^{-1} vegetable waste), where maggot oil was added as a supplement to fish oil in 100 g of feed. Vannamei shrimp with an initial weight of 1.95±0.005 g were reared in 30 L containers at a density of 10 shrimp per container for 45 days, starting from the PL-10 stage. The results showed that treatment C produced the best performance, in total feed consumption (TFC) (86.45±3.54 g), feed utilization efficiency (FUE) (35.79±3.36%), protein efficiency ratio (PER) (0.85± 0.08), length gain (5.90±0.26 cm), weight gain (3.17±0.45 g), specific growth rate (SGR) (2.15±0.20% day^{-1}), protein retention (69.90±1.81%), and survival rate (SR) (98.33±1.34%). The treatment C showed a significant ($p < 0.05$) effect compared to the other concentrations. These findings indicate that maggot oil derived from BSF larvae reared on a mix of chicken manure and tofu waste is an effective lipid source for enhancing the growth and feed efficiency of vannamei shrimp.

Key Words: feed, growth, insect lipid, vannamei.

Introduction. Vannamei shrimp (*Litopenaeus vannamei*) is a highly demanded aquaculture commodity due to its rapid growth, efficient space utilization, and strong tolerance to environmental fluctuations (Deswati et al 2020). Several factors influence shrimp growth, including larval quality, water quality, feed, and disease management. Among these, feed is the most critical factor affecting both shrimp production and operational costs, accounting for approximately 60-70% of total aquaculture expenses (Ulumiah et al 2020). Artificial feeds are formulated by combining various raw materials to meet the nutritional requirements of shrimp. Fish meal, a primary ingredient in commercial shrimp feed, contributes significantly to its high cost due to limited supply and increasing global demand. In addition to protein, lipids are essential nutrients in aquaculture feed, playing a crucial role in energy provision and enabling the protein-sparing effect, which allows dietary protein to be more efficiently used for growth (Putra et al 2022).

Fish oil, a conventional lipid source rich in omega-3 fatty acids, enhances feed quality and supports shrimp health (Febrantama et al 2020). However, declining availability and rising costs of fish oil have prompted the search for alternative lipid sources. One promising alternative is oil extracted from black soldier fly (BSF) (*Hermetia illucens*) larvae, commonly known as maggot oil. Maggot oil contains essential fatty acids such as EPA and DHA, as well as vitamins, minerals, and antioxidants that support shrimp growth and survival. Xu et al (2020) reported that maggot oil supplementation at 25 mL kg^{-1} in goldfish fry feed improved specific growth rate (SGR) to 2.70% day^{-1} and feed conversion ratio (FCR) to 1.31, outperforming other insect oils such as yellow caterpillar (*Doleschallia bisaltide*) and silk cocoon (*Bombyx mori*) oil. Similarly, Fawole et al (2021) found that maggot oil improved SGR in rainbow trout (*Oncorhynchus mykiss*) (2.51% day^{-1}) compared to soybean oil (2.07% day^{-1}). Li et al (2016) demonstrated that a 25% substitution of fish oil with maggot oil resulted in better growth than 50%, 75%, or full substitution, achieving an SGR of 3.30% day^{-1}. According to Putra & Manan (2014), shrimp at the PL-20 stage were used, whereas the present study focuses on the PL-10 stage. The aim is to determine the optimal rearing media composition for BSF larvae to produce maggot oil that supports the growth of PL-10 vannamei shrimp. Although maggot oil has been widely studied in freshwater and marine fish diets, its application in brackish water species remains limited. Considering the economic importance and diverse nutritional requirements of brackish water fish, further research is needed to explore the potential of maggot oil in this context. Additionally, brackish water aquaculture often faces environmental challenges such as fluctuations in salinity and water quality, making it essential to develop feeds that enhance resilience and performance (Dewi & Sylvia 2022; Nurdi et al 2023; Retno et al 2023). This study aimed to evaluate the effect of maggot oil, produced from black soldier fly larvae reared on different media compositions, as a partial addition to fish oil in the diet of developing vannamei shrimp.

Material and Method

Test shrimps. This research was conducted from April to June 2025. The test animals used in this study were healthy vannamei shrimp, stocked at a density of 15 individuals per container, with five containers used, giving a total of 75 shrimp, and an average initial weight of 1.95±0.005 g. The shrimp were active, exhibited normal swimming behavior, and showed no signs of physical damage or disease. Shrimp were reared in 10-liter containers equipped with continuous aeration, at a stocking density of 10 shrimp per container. The feed provided was supplemented with maggot oil and formed into 2 mm and 3 mm pellets. Feeding was conducted four times daily at 06:00, 10:00, 14:00, and 18:00 in Western Indonesian Time according to a pre-established feeding program. The rearing medium consisted of seawater with a salinity of 20-35 ppt, sterilized using chlorine and neutralized with sodium thiosulfate. For optimal maintenance of vannamei shrimp, salinity was maintained within the 30-35 ppt range, following Indonesian National Standard (SNI) (2014) and Rakhfid et al (2019). The experiment was carried out at the Marine Science Techno Park (MSTP), Jepara, Central Java Province, Indonesia.

Experimental design. A completely randomized design was used, consisting of five treatments with three replicates each. Each treatment of 15 shrimp with 3 replications was totalling 45 shrimp used per treatment. The treatments were as follows:

- control: commercial feed without maggot oil;
- treatment A: diet supplemented with maggot oil from BSF larvae reared on 150 g L^{-1} tofu waste;
- treatment B: diet supplemented with maggot oil from BSF larvae reared on 50 g L^{-1} fruit waste + 100 g L^{-1} tofu waste;
- treatment C: diet supplemented with maggot oil from BSF larvae reared on 50 g L^{-1} chicken manure + 100 g L^{-1} tofu waste;
- treatment D: diet supplemented with maggot oil from BSF larvae reared on 50 g L^{-1} chicken manure + 100 g L^{-1} vegetable waste.

The maggot oil inclusion rate was based on the findings of Fawole et al (2021).

Amino acid profile. Amino acid analysis was performed using an HPLC system (Type 1100) equipped with a Eurosphere 100-5 C18 column (250 × 4.6 mm, P/N: 1115Y535). The mobile phase consisted of 0.01 M acetate buffer at pH 5.9 and 0.01 M methanol at pH 5.9, mixed with tetrahydrofuran (THF) in a ratio of 80:15:5. Fluorescence detection was carried out with an excitation wavelength of 340 nm and an emission wavelength of 459 nm. Approximately 2.5 g of the sample was placed in a sealed beaker, to which 15 mL of 6 M HCl was added. The mixture was stirred until homogeneous and then hydrolyzed in an autoclave at 110 °C for 12 hours. After hydrolysis, the solution was cooled to room temperature and neutralized using 6 M NaOH. Subsequently, 2.5 mL of 40% acetate solution and 1 mL of 15% oxalic acid were added. Around 3 mL of the resulting solution was filtered through a 0.45 µm Millex-HV filter (Merck KGaA, Darmstadt, Germany). For derivatization, 25 µL of the filtrate was mixed with 475 µL of o-phthalaldehyde (OPA) anhydrase reagent, stirred, and incubated for 3 minutes. Finally, 30 µL of the prepared mixture was injected into the HPLC system for analysis, following the method described by AOAC (2005).

Fatty acid profile. Fish fatty acids were analyzed using a QP-2010 Gas Chromatograph–Mass Spectrometer (GC-MS) (Shimadzu, Japan) equipped with a 50 m Wall-Coated Open Tubular CP-SIL-88 column (Agilent, Santa Clara, CA, USA). The analysis was performed within a temperature range of 120-200°C using an in-situ transesterification method. A 100 mg portion of the fish sample was homogenized with 4 mL of distilled water, and 100 µL of the homogenate was transferred into a test tube. Subsequently, 100 µL of methylene chloride and 1 mL of 0.5 M NaOH in methanol were added. After purging with nitrogen, the test tube was sealed and heated at 90°C for 10 minutes. Following cooling to room temperature, 1 mL of 14% boron trifluoride (BF_3) in methanol was added. The tube was again purged with nitrogen, sealed, and reheated at 90°C for another 10 minutes. After a second cooling step, 1 mL of distilled water and 200-500 µL of hexane were added to extract the fatty acid methyl esters. The mixture was stirred for 1 minute, and after centrifugation, the upper (hexane) layer was collected and used for GC analysis, following the AOAC (2005) method.

Observed parameters. The data observed in this study included total feed consumption (TFC), feed utilization efficiency (FUE), protein efficiency ratio (PER), specific growth rate (SGR), weight gain, length gain, and survival rate (SR), all of which were calculated using the formulas described by Zonneveld et al (1991) and Tacon et al (1987).

Total feed consumption (TFC). Zonneveld et al (1991) provided a formula to determine feed consumption, which is as follows:

$$\mathrm{TFC} = F_1 + F_2 + \ldots + F_n \qquad (1)$$

where: TFC = total feed consumption (g);
F_1 = amount of feed on the first day (g);
F_2 = amount of feed on the second day (g);
F_n = amount of feed on the nth day (g).

Feed utilization efficiency (FUE). The efficiency of feed utilization (FUE) is calculated based on the method described by Zonneveld et al (1991):

$$\mathrm{FUE} = \frac{W_t - W_0}{F} \times 100 \quad (2)$$

where: FUE = feed utilization efficiency (%);
W_t = shrimp weight at the end of the study (g);
W_0 = shrimp weight at the start of the study (g);
F = amount of feed provided during maintenance (g).

Protein efficiency ratio (PER). To calculate the protein efficiency ratio (PER), the formula outlined by Tacon (1987) is applied:

$$PER = \frac{W_t - W_0}{P_i} \times 100 \qquad (3)$$

where: PER - protein efficiency ratio (%);
W_t = total weight of test shrimp at the end of the study (g);
W_0 = total weight of test shrimp at the beginning of the study (g);
P_i = weight of feed consumed x % of feed protein (g).

Specific growth rate (SGR). Zonneveld et al (1991) suggest the following method for determining the specific growth rate (SGR):

$$\mathrm{SGR} = \frac{\mathrm{Ln}\, W_t - \mathrm{Ln}\, W_0}{t} \times 100 \qquad (4)$$

where: SGR = specific growth rate (% day^{-1});
W_t = shrimp weight at the end of the study (g);
W_0 = shrimp weight at the start of the study (g);
T = length of the maintenance period (days).

Weight gain (W). The approach for calculating weight gain is based on the formula introduced by Zonneveld et al (1991):

$$W = W_t - W_0 \qquad (5)$$

where: W = weight (g);
W_t = final body weight (g);
W_0 = initial body weight (g);

Length gain (L). The approach for calculating length gain is based on the formula introduced by Zonneveld et al (1991):

$$L = l_t - l_0 \qquad (6)$$

where: L = length (cm);
l_t = final body length (cm);
l_0 = initial body length (cm);

Survival rate (SR). Zonneveld et al (1991) proposed the following formula for estimating the survival rate in vannamei shrimp:

$$\mathrm{SR} = \frac{N_t}{N_0} \times 100 \qquad (7)$$

where: SR = survival rate (%);
N_t = number of shrimp at the end of the study;
N_0 = number of shrimp at the beginning of the study.

Data analysis. The data were analyzed using one-way ANOVA followed by Duncan's multiple range test to identify significant differences among treatments at a 95% confidence level ($p < 0.05$). Statistical analyses were performed using SPSS version 20. Data are presented as mean±standard error (SE).

Results. Based on the amino acid profile of the test feed administered to shrimp over the 45-day trial period, the highest levels of amino acids were found in treatment C, with methionine content at 9.19% and glutamic acid at 16.26%. The lowest amino acid levels were observed in treatment A, which contained 5.72% methionine and 10.45% glutamic acid (Table 1).

Table 1

The amino acid profile of the test feed.

Amino acids	*Req. (%)*	*Commercial feed (%)*	*A (%)*	*B (%)*	*C (%)*	*D (%)*
Aspartic acid	1.99	1.35±0.03^{a}	2.80±0.08^{a}	5.19±0.05^{a}	13.06±0.04^{b}	2.98±0.02^{a}
Serine	0.72	9.50±0.02^{a}	10.88±0.04^{a}	12.93±0.04^{a}	15.10±0.03^{b}	11.73±0.08^{a}
Glutamic acid	2.00	10.65±0.06^{a}	10.45±0.09^{a}	11.89±0.05^{a}	16.26±0.08^{b}	10.20±0.09^{a}
Glycine	1.22	8.30±0.09^{a}	11.37±0.03^{a}	12.93±0.05^{a}	12.26±0.06^{b}	11.79±0.05^{a}
Histidine	0.16	0.50±0.08^{a}	0.87±0.08^{a}	1.89±0.09^{a}	13.80±0.08^{b}	1.75±0.04^{a}
Arginine	0.81	2.60±0.04^{a}	2.85±0.05^{a}	4.36±0.02^{b}	4.97±0.07^{b}	3.56±0.03^{b}
Threonine	0.91	1.40±0.02^{a}	1.47±0.03^{a}	2.78±0.01^{b}	2.39±0.04^{b}	1.96±0.07^{a}
Alanine	1.23	1.47±0.05^{a}	1.51±0.01^{a}	3.27±0.05^{b}	2.95±0.08^{b}	2.23±0.02^{a}
Valine	0.95	1.10±0.08^{a}	1.08±0.08^{a}	4.87±0.07^{b}	4.75±0.07^{a}	2.92±0.01^{a}
Methionine	0.05	6.65±0.07^{a}	5.72±0.04^{a}	7.10±0.09^{b}	9.19±0.05^{b}	5.99±0.08^{b}
Lysine	1.47	3.70±0.04^{a}	3.89±0.09^{a}	8.83±0.04^{b}	7.09±0.02^{b}	5.98±0.04^{b}
Isoleucine	0.90	3.45±0.05^{a}	3.59±0.07^{a}	4.98±0.09^{b}	3.98±0.08^{a}	3.02±0.03^{a}
Phenylalanine	1.01	1.11±0.03^{a}	1.07±0.01^{a}	2.52±0.04^{b}	2.79±0.01^{a}	1.39±0.01^{a}
Leucine	1.39	2.50±0.02^{a}	2.47±0.09^{a}	3.25±0.03^{b}	2.78±0.05^{a}	2.17±0.02^{a}
Tryptophan	1.10	0.80±0.01^{a}	0.93±0.03^{a}	2.50±0.07^{b}	1.93±0.03^{a}	1.10±0.09^{a}

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$), Req. = requirement (Setiyorini et al 2018).

Based on the fatty acid profile of the test feed used for vannamei shrimp maintenance over a 45-day period, the highest eicosapentaenoic acid (EPA) content was found in treatment C, with an EPA level of 8.25%. In contrast, the lowest EPA content (4.80%) was found in treatment A (Table 2).

Table 2

The fatty acid profile of the test feed

Fatty acids	*Req. (%)*	*Commercial feed (%)*	*A (%)*	*B (%)*	*C (%)*	*D (%)*
Methyl butyrate	<0.1	1.30±0.02^{a}	1.67±0.02^{a}	2.81±0.09^{a}	3.68±0.08^{b}	1.50±0.09^{a}
Methyl hexanoate	<0.1	2.15±0.05^{b}	2.48±0.06^{b}	2.19±0.02^{a}	4.25±0.05^{b}	1.08±0.05^{a}
Methyl undecanoate	<0.1	4.05±0.03^{a}	4.09±0.05^{a}	6.14±0.07^{b}	8.09±0.09^{b}	4.12±0.09^{a}
Methyl laurate	0.23	1.12±0.06^{a}	1.65±0.04^{a}	2.71±0.02^{b}	3.11±0.04^{b}	2.08±0.06^{a}
Methyl tridecanoate	0.89	1.78±0.02^{a}	1.95±0.09^{a}	3.07±0.01^{b}	5.91±0.07^{b}	2.55±0.02^{a}
Methyl pentadecanoate	2.27	2.13±0.06^{a}	2.15±0.01^{a}	2.81±0.03^{a}	3.68±0.08^{b}	3.75±0.07^{b}
Methyl palmitate	0.73	3.16±0.09^{a}	3.75±0.04^{a}	6.15±0.09^{b}	7.95±0.09^{b}	5.83±0.05^{b}
Methyl heptadecanoate	0.97	1.30±0.08^{a}	1.68±0.05^{a}	2.28±0.06^{a}	3.19±0.04^{b}	2.19±0.04^{a}
Methyl arachidate	4.75	3.15±0.04^{a}	3.05±0.06^{a}	5.37±0.05^{b}	6.64±0.09^{b}	4.15±0.02^{b}
Methyl tricosanoate	1.26	1.20±0.03^{a}	1.36±0.04^{a}	1.85±0.03^{a}	2.55±0.03^{b}	1.93±0.04^{a}
Unsaturated fatty acids						
Linolenic acid	<0.1	3.60±0.03^{a}	3.80±0.04^{a}	2.75±0.02^{a}	4.88±0.09^{b}	3.49±0.02^{a}
Linoleic acid	<0.1	2.44±0.08^{a}	2.56±0.05^{a}	2.52±0.07^{a}	3.54±0.05^{b}	2.39±0.08^{a}
Arachidonic acid	2.93	0.30±0.06^{a}	0.15±0.07^{a}	2.07±0.05^{b}	2.13±0.08^{b}	0.06±0.07^{a}
Eicosapentaenoic acid (EPA)	0.93	4.94±0.05^{a}	4.80±0.01^{a}	6.05±0.03^{b}	8.25±0.08^{b}	5.03±0.04^{a}
Docosahexaenoic acid (DHA)	<0.1	1.11±0.03^{a}	1.08±0.08^{a}	3.83±0.08^{a}	5.07±0.09^{b}	2.39±0.09^{a}

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$).

The growth performance of vannamei shrimp after 45 days of rearing is presented in Table 4. Based on the results presented in Table 3, substituting fish oil with maggot oil derived from BSF larvae cultured in treatment C had a significant effect ($p < 0.05$) on TFC, length gain, weight gain, FUE, SGR, and PR. However, maggot oil inclusion did not significantly affect PER or SR ($p \geq 0.05$). The best performance was observed in treatment C, with a TFC of 86.45±3.54 g, FUE of 35.79±3.36%, SGR of 2.15±0.20% day^{-1}, weight gain of 3.17±0.45 g, length gain of 5.90±0.26 cm, and PR of 69.90±1.81%. In general, treatment C showed significant difference ($p < 0.05$) compared to treatment A in most parameters. In contrast, treatments B and D showed no significant differences ($p \geq 0.05$) compared to treatment A. Treatment A showed lower performance, with a FUE of 28.75±3.52%, a PER of 0.77±0.13%, a SGR of 1.83±0.32% day^{-1}, a weight gain of 2.50±0.32 g, and a PR of 67.28±0.95%, except for TFC, which showed a slightly higher result, with a value of 86.97±1.96 g. According to the Dunnett test, maggot oil treatments cultured in different media generally showed a significant difference ($p < 0.05$) from the control treatment (commercial feed), except for treatment A, which showed no significant difference ($p \geq 0.05$) compared to the control.

Table 3

The growth performance of vannamei shrimp (*Litopenaeus vannamei*) after 45 days

Variable	*Commercial feed (%)*	*A (%)*	*B (%)*	*C (%)*	*D (%)*
TFC (gram)	99.59±0.9^{a}	86.97±1.96^{ab}	90.65±0.53^{b}	86.45±3.54^{c}	89.48±0.71^{ab}
FUE (%)	26.41±1.32^{a}	28.75±3.52^{ab}	31.04±1.34^{bc}	35.79±3.36^{b}	31.17±2.1^{bc}
PER (%)	0.71±0.04^{a}	0.77±0.13^{a}	0.74±0.06^{a}	0.85±0.08^{a}	0.79±0.05^{a}
SGR (% day^{-1})	1.71±0.08^{a}	1.83±0.32^{ab}	2.14±0.06^{c}	2.15±0.2^{c}	1.97±0.08^{bc}
WG (gram)	2.28±0.16^{a}	2.50±0.32^{ab}	3.17±0.12^{c}	3.17±0.45^{c}	2.79±0.19^{bc}
LG (cm)	5.12±0.10^{a*}	5.51±0.13^{b*}	5.79±0.37^{bc}	5.90±0.26^{c}	5.74±0.04^{bc}
PR (%)	65.29±0.29^{a}	67.28±0.95^{a}	66.78±1.21^{a}	69.90±1.81^{b}	67.25±1.94^{a}
SR (%)	93.33±5.44	95.00±3.35	96.67±3.85	98.33±1.34	95±4.38

Note: Superscript "a" indicates treatments with the lowest effect, while higher superscripts ("b" or "c") indicate greater effects of the treatments on the parameters. Treatments with two superscripts, e.g., "ab," mean that the effect of that treatment is not significantly different from treatments with either of those superscripts; PR = protein retention, WG = weight gain, LG = length gain.

Table 4 summarizes water quality parameters measured during the study, including salinity, temperature, pH, dissolved oxygen (DO), and total ammonia. The water quality results indicate that conditions during the maintenance period were optimal for aquaculture and supported the growth of vannamei shrimp.

Table 4

The water quality parameter results during the maintenance

Parameter	*Unit*	*Morning*	*Afternoon*	*Optimal values*
Temperature	°C	26.2-26.7	26.5-26.9	24-29^{a}
pH	-	7.71-7.8	7.71-7.91	7-8.5^{b}
Salinity	ppt	25-26	25-26	20-35^{c}
DO	mg L^{-1}	5.45-5.49	5.30-5.66	> 4^{b}
Total ammonia	mg L^{-1}	0.000-0.444	0.000-0.444	< 1^{b}

Note: ^{a}Farabi & Latuconsina (2023); ^{b}Putra et al (2023); ^{c}Rakhfid et al (2019).

The amino acid profile of vannamei shrimp reared for 45 days and fed with the test diets showed that the highest lysine content was observed in treatment C, with a value of 10.85%, while the lowest was recorded in the control group at 6.85% (Table 5).

Similarly, based on the fatty acid profile of the shrimp, the highest DHA content was found in treatment C, with a value of 7.56%. The lowest DHA content was recorded in the control treatment, with a value of 4.48% (Table 6).

Table 5

The amino acid profile of vannamei shrimp (*Litopenaeus vannamei*) after 45 days

Amino acids	*Commercial feed (%)*	*A (%)*	*B (%)*	*C (%)*	*D (%)*
Aspartic acid	2.05±0.02^{a}	2.47±0.05^{a}	5.38±0.05^{b}	6.52±0.08^{b}	4.65±0.08^{a}
Proline	3.10±0.05^{a}	3.25±0.06^{a}	3.94±0.09^{a}	4.89±0.09^{b}	5.29±0.06^{b}
Serine	4.20±0.02^{a}	4.86±0.03^{a}	5.76±0.04^{b}	5.29±0.08^{b}	4.59±0.02^{a}
Glutamic acid	5.15±0.01^{a}	5.26±0.07^{a}	6.18±0.08^{b}	9.38±0.02^{b}	6.38±0.02^{b}
Glycine	4.17±0.04^{a}	4.73±0.08^{a}	5.95±0.09^{b}	5.81±0.09^{b}	6.37±0.06^{b}
Histidine	4.06±0.08^{a}	4.15±0.02^{a}	4.84±0.06^{a}	5.90±0.08^{b}	4.68±0.09^{a}
Arginine	4.50±0.07^{a}	4.80±0.09^{a}	6.38±0.08^{b}	6.36±0.07^{b}	5.84±0.08^{b}
Threonine	4.45±0.03^{a}	4.95±0.09^{a}	6.79±0.07^{b}	7.79±0.08^{b}	6.48±0.09^{b}
Alanine	5.43±0.04^{b}	5.77±0.02^{b}	5.20±0.09^{b}	5.25±0.05^{b}	6.54±0.08^{b}
Valine	4.14±0.02^{a}	4.22±0.09^{a}	6.98±0.08^{b}	7.19±0.08^{b}	4.75±0.06^{a}
Methionine	3.56±0.08^{a}	3.85±0.03^{a}	5.89±0.09^{b}	8.39±0.08^{b}	4.73±0.05^{a}
Lysine	6.70±0.01^{a}	6.85±0.09^{a}	8.93±0.06^{b}	10.85±0.05^{b}	6.88±0.08^{a}
Isoleucine	4.84±0.03^{a}	4.87±0.04^{a}	4.97±0.05^{a}	5.23±0.02^{b}	5.19±0.05^{b}
Phenylalanine	4.56±0.02^{a}	4.81±0.09^{a}	4.83±0.03^{a}	5.48±0.08^{b}	4.44±0.08^{a}
Leucine	4.13±0.03^{a}	4.37±0.02^{a}	5.10±0.01^{b}	4.75±0.08^{a}	5.38±0.05^{b}
L-Tryptophan	3.12±0.09^{a}	3.43±0.08^{a}	3.55±0.08^{a}	4.10±0.04^{a}	6.35±0.06^{b}

Note: Different superscripts within the same row indicate significant differences ($p < 0.05$).

Table 6

The fatty acid profile of vannamei shrimp (*Litopenaeus vannamei*) after 45 days

Fatty acid	*Commercial feed (%)*	*A (%)*	*B (%)*	*C (%)*	*D (%)*
C14:0 (Myristic)	3.20±0.04^{a}	3.69±0.05^{a}	3.77±0.05^{a}	6.89±0.08^{b}	6.57±0.04^{b}
C15:0 (Pentadecanoic)	2.16±0.03^{a}	2.28±0.08^{a}	2.48±0.06^{a}	3.15±0.06^{b}	2.38±0.05^{a}
C16:0 (Palmitic)	3.76±0.05^{a}	4.19±0.06^{a}	4.62±0.08^{a}	6.99±0.03^{b}	4.77±0.08^{a}
C18:0 (Stearic)	4.20±0.03^{a}	4.57±0.02^{a}	5.99±0.07^{b}	6.25±0.08^{b}	5.75±0.03^{b}
C18:1n-9 (Oleic/ω9)	1.47±0.02^{a}	1.75±0.05^{a}	3.97±0.02^{b}	4.99±0.07^{b}	2.90±0.05^{a}
C18:2n-6 (Linoleic/ω6)	1.30±0.06^{a}	1.26±0.08^{a}	5.19±0.04^{b}	6.38±0.07^{b}	5.30±0.09^{a}
C18:3n-3 (Linolenic/ω3)	1.47±0.03^{a}	1.77±0.02^{a}	4.29±0.08^{b}	4.75±0.08^{b}	4.30±0.03^{a}
C20:0 (Arachidic)	1.56±0.07^{a}	1.79±0.05^{a}	3.26±0.09^{a}	4.27±0.09^{b}	2.50±0.05^{a}
C20:4n-6 (Arachidonic)	3.20±0.04^{b}	3.40±0.08^{b}	4.56±0.03^{a}	4.98±0.03^{a}	4.19±0.04^{a}
C20:5n-3 (EPA)	2.60±0.02^{a}	2.75±0.05^{a}	5.25±0.08^{b}	9.77±0.02^{b}	3.03±0.09^{a}
C22:6n-3 (DHA)	4.50±0.02^{a}	4.48±0.06^{a}	6.77±0.05^{b}	7.56±0.05^{b}	6.96±0.08^{b}

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$).

Discussion. The results of this experiment showed that vannamei shrimp fed a diet containing maggot oil derived from black soldier fly (*Hermetia illucens*) larvae, cultured in different media compositions, exhibited a significant effect in TFC. The highest TFC was observed in treatment B, with a value of 90.65±0.53 g, while the lowest was in treatment C, at 86.45±3.54 g. This may be attributed to the potential of maggot oil to act as a natural attractant, likely due to its fishy aroma. This finding aligns with Raharjo et al (2014), who reported that maggot oil can enhance feed palatability.

In addition, lauric acid, a major component in BSF larvae, serves as an antioxidant and has antimicrobial properties that help protect shrimp from various pathogens (Sandhya et al 2016). As an antioxidant, lauric acid supports the repair and maintenance of shrimp body cells. This is supported by Mukhlis et al (2020), who reported that lauric acid helps prevent cellular damage and aids in cell regeneration, thereby enhancing protein function and promoting shrimp growth.

Palatability, defined as the attractiveness of feed to shrimp, is influenced by its protein and lipid content. Higher feed consumption indicates better palatability (Putra et al 2020). According to Rolin et al (2015), optimal feed should also have good buoyancy, a homogeneous texture, and be resistant to breaking down in water to ensure effective consumption. Furthermore, Anastasia et al (2020) emphasized that the amount of feed consumed and the organism's ability to utilize it directly influences shrimp growth rates.

The addition of maggot oil derived from BSF larvae cultured in different media had a significant effect ($p < 0.05$) on FUE, PER, and SGR, while it did not significantly affect the SR ($p \geq 0.05$). The results showed that treatment C achieved the highest FUE at 35.79±3.36%. FUE reflects how effectively the consumed feed is metabolized and converted into growth. According to Trisnawati & Sudaryono (2014), a higher FUE indicates that the feed is of good quality and is efficiently utilized by the organism.

Maggot oil contains digestive enzymes such as lipase, which aid in breaking down fats and improving nutrient absorption in shrimp. This is supported by Kim et al (2011), who reported that BSF larvae contain protease, lipase, and amylase in their digestive systems.

Furthermore, the culture media consisting of chicken manure and tofu waste likely contributed to the superior nutritional quality of the maggot oil. Compared to media such as fruit waste + tofu waste or chicken manure + vegetable waste, the combination of chicken manure and tofu waste provides higher nutrient content. According to Damle & Chari (2011), chicken manure contains elevated levels of nitrogen (7%), phosphorus (0.31%), and potassium (0.23%). The high nitrate and phosphate levels in this medium may enhance the lipid content and composition of the BSF larvae, contributing to improved growth performance in shrimp.

The highest PER was observed in treatment C, with a value of 0.85±0.08%. This result is associated with the high eicosapentaenoic acid (EPA) content in the maggot oil used in treatment C, which reached 8.25±0.08%. The high EPA content indicates that the feed was efficiently utilized, promoting greater growth through enhanced energy storage and tissue synthesis. Zonneveld et al (1991) support this finding, noting that energy storage for body tissue synthesis is a complex process that requires feed energy to be digested and absorbed before being used in biosynthesis. Since body tissue is composed of cells requiring essential nutrients, including fatty acids like EPA, their presence in the feed is critical. Moreover, lipid and fatty acid content play a role in the protein-sparing effect, which helps reduce the use of protein as an energy source and allows it to be used more effectively for growth (Herawati et al 2020).

Carbohydrates and lipids contribute to stabilizing protein utilization by providing alternative energy sources for metabolism and maintenance (Munisa et al 2015). Additionally, BSF meal contains digestive enzymes such as amylase, protease, and lipase, which enhance feed digestibility in the anterior intestine during metabolic processes (Frøyland et al 2013). Protease hydrolyzes proteins, while amylase breaks down carbohydrates (Pangkey 2011). These enzymatic activities contribute to more efficient nutrient absorption and ultimately accelerate the growth of vannamei shrimp.

The SGR results from this study showed the best performance in treatment C, with a value of 2.15±0.2% day^{-1}. Maggot oil contains glutamic acid, which plays an important role in metabolic processes. According to Azizah et al (2019), glutamic acid present in BSF larvae can enhance metabolism within the digestive system. Supporting this, a study by Pereira et al (2017) demonstrated that glutamic acid can improve both growth and immune response in fish.

In the present study, treatment C had a higher glutamic acid content compared to the other treatments, including the control group (fed with commercial feed), which likely contributed to the observed increase in SGR. Arifin et al (2020) further support this finding, stating that maggot oil contains essential amino acids such as methionine, which can enhance the utilization of other amino acids, thereby optimize overall protein efficiency and supporting better growth.

The highest SR in this experiment was recorded in treatment C, with a value of 98.33±1.34%. However, based on the analysis of variance, substituting fish oil with maggot oil in the diet did not have a significant effect ($p \geq 0.05$) on the SR of vannamei shrimp. SR is influenced by multiple factors, including parasites, stocking density, water quality (physical and chemical parameters), and the organism's metabolic capacity, which is largely affected by nutritional intake. Pradika et al (2021) also highlighted that SRs are closely linked to stocking density, environmental conditions, and the fish’s metabolic efficiency, which is affected by the quality of feed. Nutrient composition in the diet plays an essential role in supporting survival. Lipids serve as macronutrients that not only promote growth but also assist in the regeneration of damaged tissues caused by disease or stress. Additionally, vitamin C functions as an immunostimulant, enhancing the shrimp’s immune defense (Munisa et al 2015).

Throughout the experiment, the water quality parameters remained within optimal ranges for shrimp cultivation, further supporting the high SR. Other contributing factors may include the shrimp’s age, size, and ability to adapt to environmental changes.

Based on the experimental results, maggot oil derived from BSF larvae in treatment C produced the highest levels of both non-essential and essential amino acids. The feed contained 16.26% glutamic acid and 9.19% methionine, while the shrimp body composition reflected 9.38% glutamic acid and 8.39% methionine.

Glutamic acid is a non-essential amino acid and is quantitatively one of the most abundant free amino acids in blood plasma and muscle tissue. Its derivative, glutamine, serves as a substrate for several aminotransferases involved in the biosynthesis of purines, glucosamine, pyrimidines, and asparagine (Jusadi et al 2015). Glutamine also functions as an energy source and plays key roles in glucose metabolism, the synthesis of sugar amines and glutathione, and in maintaining intestinal structure and function. In shrimp larvae, which possess underdeveloped digestive systems, the addition of glutamine is particularly beneficial for enhancing intestinal performance and digestion (Jusadi et al 2015).

Methionine, an essential amino acid, acts as a chemoattractant, stimulating appetite and promoting growth. It also enhances and stabilizes the utilization of other amino acids and supports protein synthesis and overall physiological function. According to Bhagavan (1992), methionine is essential for nucleic acid and tissue development, protein synthesis, and works synergistically with vitamin B12 and folic acid to regulate protein metabolism, especially under high-protein diets. Methionine plays a crucial role in somatic growth (Belghit et al 2014), and its inclusion in feed has been shown to significantly enhance both growth performance and immune response (Yuan et al 2011; Kuang et al 2012; Boonyoung et al 2013; Ma et al 2013). Rolland et al (2015) also noted that methionine deficiency can result in reduced growth, lower SRs, and physical deformities (Takagi et al 2001).

The best treatment for the fatty acid profile of the test shrimp after 45 days was observed in treatment C, which yielded an EPA content of 9.77%. This result surpasses the findings of Herawati et al (2022), who reported 4.97% EPA using 30% non-fermented *Nereis virens* meal. EPA functions as an essential component of phospholipids in cellular membranes and nervous tissue. It plays a critical role in promoting shrimp growth, development, and survival. These findings align with Lim et al (2011), who emphasized that EPA (20:5n-3), an essential fatty acid, significantly contributes to shrimp survival and growth. High EPA levels have the potential to enhance physiological performance and stress tolerance in shrimp. Renitasari et al (2021) also reported that dietary fatty acids, particularly EPA, positively influence shrimp survival and growth. Moreover, the presence of n-3 highly unsaturated fatty acids (HUFAs), such as EPA and DHA, in shrimp diets supports better adaptability to environmental stressors, including fluctuations in temperature and salinity (Rudtanatip et al 2019). This suggests that EPA and DHA are more biologically active than other fatty acids such as linoleic and linolenic acid. Supporting this, Herawati et al (2024) noted that n-3 HUFAs enhance shrimp resilience to stress, thereby improving survival rates. In particular, arachidonic acid (AA), alongside EPA and DHA, is essential. AA acts as a precursor to eicosanoids - such as prostaglandins, thromboxanes, and leukotrienes - and is a key component of membrane phospholipids like phosphatidylinositol and phosphatidylcholine. These molecules play vital roles in regulating immune responses (Yui et al 2015). To conclude, the presence of EPA, DHA, and AA in the diet significantly influences shrimp adaptability, immune function, and overall survival.

Conclusions. The addition of maggot oil in artificial feed using *Hermetia illucens* (BSF) larvae cultured in different media had a significant effect ($p < 0.05$) on vannamei shrimp's total feed consumption (TFC), feed utilization efficiency (FUE), protein efficiency ratio (PER), specific growth rate (SGR), weight gain, length gain, and survival rate (SR). The best performance was observed in treatment C, where the maggot oil was derived from BSF larvae cultured in 50 g L^{-1} chicken manure + 100 g L^{-1} tofu waste, resulting in TFC (86.45±3.54 g), FUE (35.79±3.36%), PER (0.85±0.08), length gain (5.90±0.26 cm), weight gain (3.17±0.45 g), SGR (2.15±0.20% day^{-1}), PR (69.90±1.81%), and SR (98.33±1.34%). These results demonstrate that BSF-derived maggot oil, especially when produced from larvae cultured in optimized organic waste, holds strong potential as a sustainable and effective alternative to fish oil in shrimp aquaculture. Future research should focus on evaluating its long-term impact, cost-effectiveness, and influence on shrimp product quality in commercial-scale applications.

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Conflict of interest. The authors declare that there is no conflict of interest.

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