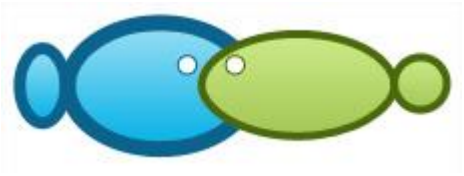

Addition of maggot oil in feed for improving feed efficiency, growth performance, and nutritional quality of snakehead *Channa striata* (Bloch, 1793)

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Abstract. Snakehead (*Channa striata*) have high economic value. One way to improve the quality of feed is to use animal oil sources such as maggot oil. Maggot oil contains linoleic fatty acid (18:2n-6) at a concentration of 3.6–4.5% and linolenic fatty acid (18:3n-3) at 0.08–0.74%, which freshwater fish can effectively utilize for growth. This research aimed to determine the effect of using maggot oil in artificial feed on the growth performance of snakehead fry and to determine the best dosage for using maggot oil in artificial feed on the performance and survival of snakehead fry. This research used an experimental method, using a completely randomized design, with 5 treatments and 3 replications. The treatments applied were treatments A, B, C, D, and E, each with the addition of maggot oil at a dose of 0%, 10%, 15%, 20%, and 25% kg^{-1} feed, respectively. The test fish used were snakehead, with an average weight of 0.7±0.01 g and a maintenance time was 49 days. The research results showed that the use of maggot oil in artificial feed had a significant effect ($p<0.05$) on total feed consumption (TFC), feed utilization efficiency (FUE), feed conversion ratio (FCR), protein efficiency ratio (PER), specific growth rate (SGR), but had no significant effect on survival rate. The best dose for using maggot oil was test feed with 25% maggot oil supplementation (E), capable of producing a TFC value of 12.16±0.56 g, an FUE of 35.11±4.16%, a FCR of 1.53±0.12, a PER of 0.87±0.10%, a SGR of 1.8±0.35% day^{-1}, and a SR of 70%. The results of the analysis of essential amino acid profiles in feed and fish showed that lysine and methionine showed high levels in feed (3.45% and 3.35%, respectively) and in fish (3.60% and 4.05%, respectively). Analysis of fatty acid profiles in feed and fish showed that linoleic and linolenic fatty acids showed high levels (5.10% and 5.25% in feed, respectively, and 5.10% and 5.94%, in snakehead, respectively).

Key Words: amino, fatty acid, nutrition, production, quality.

Introduction. Snakehead (*Channa striata*) is a freshwater fish that has high economic value. Sales of snakehead fish are profitable, with a sale value of 3-5 USD per kg in Indonesia. According to Permadi et al (2017), snakehead contains albumin compounds higher than other species of fish. The quality of feed is a crucial factor in promoting fish growth and can contribute to successful cultivation. Artificial fish feed is commonly utilized in aquaculture due to its diverse nutritional composition and availability.

When snakehead enters the fry stage, they require 35-43% protein and 6% fat (Fawole et al 2021). Optimal fish growth can be provided through quality feed, and one way to improve it is by using enriched animal oil sources in artificial feeds. The need for essential fatty acids in freshwater fish can be met through linoleic and linolenic fatty acids in feed (Pangkey 2011). Essential fatty acids are fatty acids that cannot be produced directly by the body and, therefore, must be available in fish feed (Tocher & Glencross 2015).

Black soldier fly (*Hermetia illucens*) larvae oil is a potential fat source for feed, and it has a high content of lauric acid (21.4-49.3%) (Li et al 2016). Lauric acid is an essential fatty acid that present antiviral and antibacterial properties. Maggot oil contains linoleate fatty acid (18:2n-6), with a concentration of 3.6-4.5%, and linolenic fatty acid (18:3n-3), with 0.08- -0.74%. According to Fawole et al (2021), black soldier fly larvae

(BSL) oil, has fatty acid chains that can be absorbed faster. It also has linoleic and linolenic acids that freshwater fish effectively utilize. According to Li et al (2016), utilization of 25% BSL oil in feed does not harm the growth of goldfish (*Carassius auratus*) juveniles, as well as increases total n-3 PUFA and decreases total n-6 PUFA of muscle. Bakar et al (2021) asserted that the utilization of 25% maggot oil results in the high growth and digestibility and produces high-quality meat with a balanced fatty acid profile. Fawole et al (2021) believed that BSL oil can be utilized as an alternative suitable source of lipids in rainbow trout (*Oncorhynchus mykiss*) feed without influencing the growth performance, feed efficiency, nutrition retention, and survival rate. An addition of 160 g kg^{-1} BSL oil as a substitution for fish oil or soybean oil in rainbow trout feed does not result in a loss in growth performance and essential fatty acid muscle deposition. Hence, it is imperative to investigate the impact of incorporating maggot oil into snakehead diets on its growth performance. This study aimed to assess the impact of incorporating maggot oil into artificial feed on the growing performance of snakehead fry. Additionally, the study attempted to identify the optimal dosage of maggot oil in artificial feed for enhancing the performance and survival of snakehead fry.

Material and Method

Preparation of the study. This research was conducted at the Mijen Fish Seed Center (BBI), Semarang, Central Java, Indonesia. The test animals in this study were snakehead fry weighing 0.7±0.01 g. The stocking density for maintenance was 10 fish per container. Feeding was carried out three times a day using the fixed feeding rate method (5% of the total weight). The cultivation period was 49 days. The containers used in the research had a capacity of 30 L. During the cultivation process, the following were used: hoses for aeration and siphons, aerators to produce oxygen, and a net used to cover containers.

This research used 5 treatments, and each treatment was repeated 3 times. The treatment structure was as follows: treatment A - test feed without maggot oil; treatment B - test feed with 10% maggot oil supplementation; treatment C - test feed with 15% maggot oil supplementation; treatment D - test feed with 20% maggot oil supplementation; treatment E - test feed with 25% maggot oil supplementation. Composition and proximate analysis of test feeds in this research (% dry weight) are presented in Table 1.

Table 1

Composition and proximate analysis of test feeds in this research (% dry weight)

Types of feed compounding materials	*Feed composition (g 100 g^{-1} feed)*				
	A(0%)	*B(10%)*	*C(15%)*	*D(20%)*	*E(25%)*
Fish meal	31	31	31	31	31
Soybean flour	28	28	28	28	28
Corn flour	5	5	5	5	5
Bran flour	14	14	14	14	14
Wheat flour	13	13	13	13	13
Fish oil	3	3	3	3	3
Corn oil	2	2	2	2	2
Vitamin-mineral mix	3	3	3	3	3
Carboxymethyl cellulose (CMC)	1	1	1	1	1
Total (%)	100	100	100	100	100
Maggot oil	-	0.765	1.15	1.53	1.91
Proximate analysis (%)****					
Protein (%)	38.38	38.22	42.59	41.68	40.52
NNFE (%)	15.93	15.74	11.56	13.07	12.45
Fat (%)	20.92	20.34	23.54	21.28	21.94
Energy (kcal)**	343.607	337.874	368.639	350.923	350.659
Ratio E/P***	8.95	8.84	8.66	8.42	8.65

Note: ** - calculated based on digestible energy; according to Wilson (1982), 1 g of protein is 3.5 kcal g^{-1}, 1 g of carbohydrates is 2.5 kcal g^{-1} and 1 g of fat is 8.1 kcal g^{-1}; *** - according to De Silva (1987), the E/P value for optimal fish growth ranges between 8-12 kcal g^{-1}; **** - Saraswanti Indo Genetech Laboratory, Bogor, West Java, Indonesia (2024); NNFE - non nitrogen free extract.

Observed parameters. Specific growth rate (SGR) can be calculated using the formula (Tacon 1987):

$SGR = [(\ln W_t - \ln W_0)/t)] \times 100$

Where: SGR - specific growth rate (% per day); W_t - final weight of fish (g); W_0 - initial weight of fish (g); t - maintenance time (days).

Total feed consumption (TFC) was calculated using the formula (Tacon 1993):

$TFC=C-S$

Where: TFC - total feed consumption (g); C - administered feed (g); S - remaining feed (g).

Feed utilization efficiency (FUE) was calculated using the formula (Zonneveld et al 1991):

$FUE = (W_t-W_0)/F \times 100$

Where: FUE - feed utilization efficiency (%); W_t - weight of fish at the end of the rearing period (g); W_0 - fish weight at the beginning of the rearing period (g); F - weight of feed administered (g).

The feed conversion ratio (FCR) was calculated using the formula (Tacon 1987):

$FCR = F/(W_t+D-W_0)$

Where: FCR - feed conversion ratio; W_t - final weight of fish (g); W_0 - initial weight of fish (g); D - weight of dead fish (g); F - amount of feed consumed (g).

Protein efficiency ratio (PER) was calculated using the formula (Tacon 1987):

$PER = (W_t-W_0)/P_i \times 100$

Where: PER - protein efficiency ratio (%); W_t - biomass at the end of the study (g); W_0 - biomass at the beginning of the study (g); P_i - weight of feed consumed x % protein in feed (g).

The survival rate (SR) was calculated using the formula (Tacon 1993):

$SR = N_t/N_0 \times 100$

Where: SR - survival rate (%); N_t - number of fish at the end of rearing; N_0 - number of fish at the beginning of the study.

Water quality measurements. Water quality measurements include temperature measured with a thermometer, pH measured with a pH meter, dissolved oxygen (DO) with a DO meter (twice a day), and ammonia (once a week) in a laboratory.

Proximate analysis. Proximate analysis (AOAC 2005) was used to describe the protein, fat, ash, carbohydrates, and water content in the sample. Fresh fish samples (only the body parts were taken) were then dried at a temperature of 40-60^{o}C, then crushed and analyzed. The protein analysis was conducted using the Kjeldahl method, while the fat content was determined using the Soxhlet method. Analysis of water and ash content was conducted using gravimetric principles. Analysis of carbohydrates was carried out manually based on the results of the proximate analysis.

Amino acid analysis. The amino acid profile was analyzed using a HPLC type 1100 apparatus with Eurosphere 100-5 C18, 250×4.6 mm column, with an initial column P/N: 1115Y535. The wastes were: A) 0.01 M acetate buffer at pH 5.9 and B) 0.01 M MeOH acetate buffer at pH 5.9; THF>80:15:5 Λ Fluorescence: Extra: 340 mm Em: 450 nm.

Approximately 2.5 g of the samples were put into a closed glass, and 15 mL of 6M HCl was added. Furthermore, the mixture was vortexed for homogeneity and hydrolyzed in an autoclave at 110ºC for 12 hours before being cooled to room temperature and neutralized with 6M NaOH. After adding 2.5 mL of 40% lead acetate and 1 mL of 15% oxalic acid, about 3 mL of the mixture was filtered off with a 0.45 µm Millex-HV filter (Merck KGaA, Darmstadt, Germany). 25 µL of the filtered mixture plus 475 µL of the OPA anhydrase solution were stirred and incubated for 3 minutes for injection into the HPLC system. Finally, 30 µL of the final mixture was placed into the HPLC system (AOAC 2005).

Fatty acid analysis. The fatty acid profile was analyzed using the QP-2010 Gas Chromatograph-Mass Spectrophotometer (GCMS) (Shimadzu) and Mass Spectrophotometer, which has a length of 50 m, a diameter of 0.22 mm Wall Coat Open Tubular CP-SIL-88 column (Agilent, Santa Clara, CA, USA), with analyses carried out over a column temperature range of 120-200°C. The method used is in-situ trans-certification. 100 mg of the fish sample were homogenized using 4 mL of water. The 100 µL homogenate obtained was then transferred into the test tube. 100 µL of methylene chloride were then added, along with 1 mL of 0.5M NaOH in methanol. After nitrogen was added and the tubes tightly closed, they were heated to 90ºC for 10 minutes. The test tube was then cooled, and 1 mL 14% BF3 in methanol was added. After adding nitrogen, it was heated at the same temperature for 10 minutes. After that, the test tube was cooled to ambient temperature, and 1 mL of water and 200-500 µL of hexane were added. The mixture was stirred for 1 minute to extract the methyl ester from the fatty acids. After centrifugation, the top layer of the sample was ready for GC analysis (AOAC 2005).

Statistical analysis. SGR, absolute length growth, biomass weight, SR, proximate analysis results, amino acid analysis results, and fatty acid analysis results were statistically analyzed using the normality, homogeneity, and additivity tests before being tested by analysis of variance (ANOVA). If differences were observed, further tests using Duncan's multiple range test were conducted. Then the data was entered into an orthogonal polynomial test to determine the optimal dose of maggot oil that can be added to artificial feed. Water quality parameters were analyzed descriptively and compared with references.

Results. Treatment E showed the best value for TFC (12.16 g), SGR (1.8% day^{-1}), FUE (15.11%), FCR (1.53), PER (0.87%), and SR (70%). The values are presented in Table 2.

Table 2

Parameters of *Channa striata* during the study

Parameters	*Treatments*				
	A	*B*	*C*	*D*	*E*
SGR (%)	0.77 ± 0.12^{ab}	0.68 ± 0.13^{a}	1.56 ± 0.18^{c}	1.57 ± 0.06^{cd}	1.80 ± 0.35^{d}
TFC (g)	9.80 ± 0.97^{a}	10.06 ± 0.55^{ab}	10.16 ± 0.40^{bc}	10.15 ± 0.52^{bc}	12.16 ± 0.56^{c}
FUE(%)	31.16 ± 4.12^{ab}	30.24 ± 5.21^{a}	34.51 ± 4.12^{c}	32.97 ± 4.31^{c}	35.11 ± 4.16^{c}
FCR	2.32 ± 0.40^{c}	2.33 ± 0.29^{c}	1.56 ± 0.24^{ab}	1.70 ± 0.14^{b}	1.53 ± 0.12^{a}
PER (%)	0.31 ± 0.11^{ab}	0.30 ± 0.14^{a}	0.81 ± 0.26^{c}	0.69 ± 0.11^{c}	0.87 ± 0.10^{c}
SR (%)	53.33 ± 5.77^{a}	56.67 ± 15.28^{a}	66.67 ± 5.77^{a}	56.67 ± 5.77^{a}	70.00 ± 0.00^{a}

Note: SGR - specific growth rate; TFC - total feed consumption; FUE - feed utilization efficiency; FCR - feed conversion ratio; PER - protein efficiency ratio; SR - survival rate; A - test feed without maggot oil; B - test feed with 10% maggot oil; C - test feed with 15% maggot oil; D - test feed with 20% maggot oil; E - test feed with 25% maggot oil; different superscripts indicate significant differences ($p<0.05$).

The results of analysis of variance and orthogonal polynomials show that the application dose of maggot oil in feed has a significant effect on feed utilization efficiency and specific growth rate. Based on the orthogonal polynomial test, a quadratic relationship (SGR) was obtained: $Y = -0.0011x^2 + 0.0206x + 0.6985$, with $R^2 = 0.7101$. The R^2 value shows that 71.01% of

SGR was influenced by the use of maggot oil in artificial feed. The optimum point of specific growth rate in treatment E (25%) was obtained by adding the dose of maggot oil that was obtained from this equation, which was 24.36%, capable of producing a maximum SGR of 1.98% day^{-1}. The orthogonal polynomial graph of the use of maggot oil in artificial feed for SGR of snakehead is presented in Figure 2.

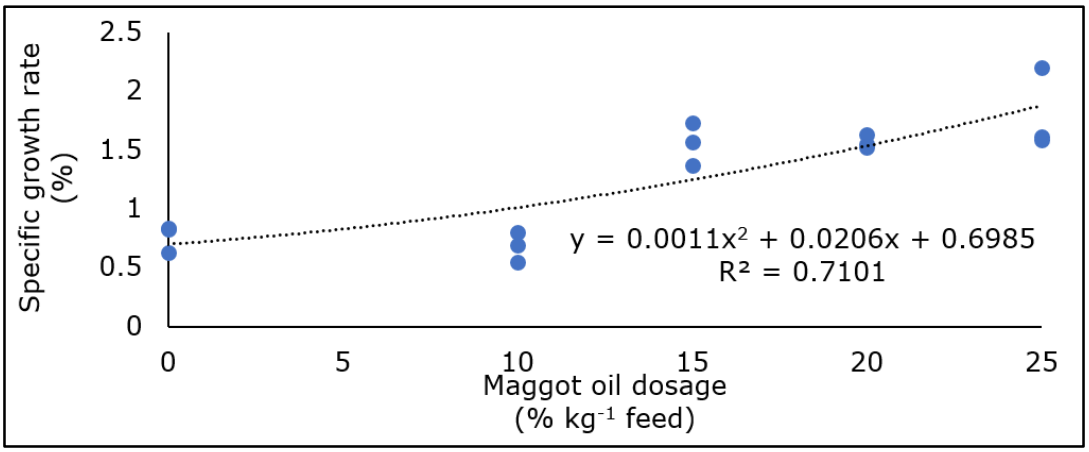

Figure 2. The relationship between the use of maggot oil in artificial feed and the specific growth rate (SGR) of snakehead (*Channa striata*).

Based on the orthogonal polynomial test, a quadratic relationship for TFC was obtained ($Y = -0.0068x^2 + 0.1876x + 9.6753$) and $R^2 = 0.2455$. The R^2 value shows that 24.55% of TFC was influenced by the use of maggot oil in artificial feed. The optimum point for TFC in treatment E was obtained by increasing the dose of maggot oil. The result obtained from this equation is 23.79%, which was capable of producing a maximum TFC of 11.97 g. The orthogonal polynomial graph of the use of maggot oil in artificial feed and the TFC of snakehead is presented in Figure 3.

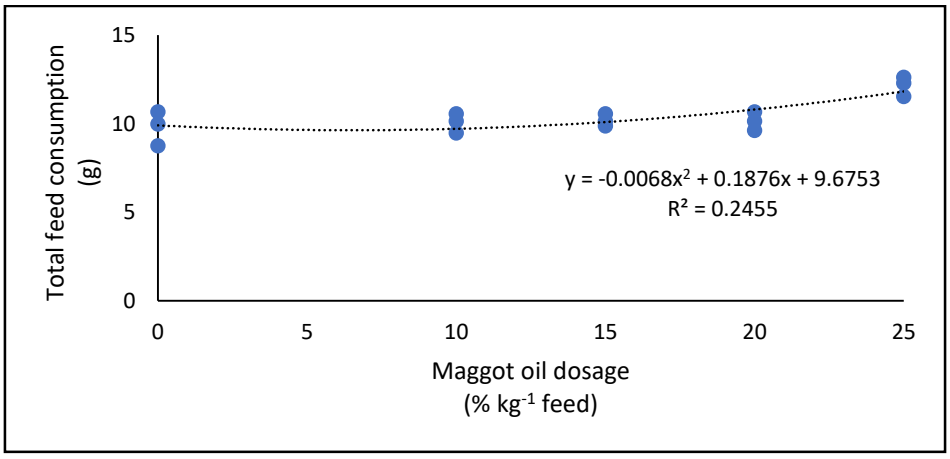

Figure 3. The relationship between the use of maggot oil in artificial feed and the total feed consumption (TFC) snakehead (*Channa striata*).

The orthogonal polynomial graph of the use of maggot oil in artificial feeding for FUE of snakehead is presented in Figure 4. The R^2 value shows that 56.19% of FUE was influenced by the use of maggot oil in artificial feed.

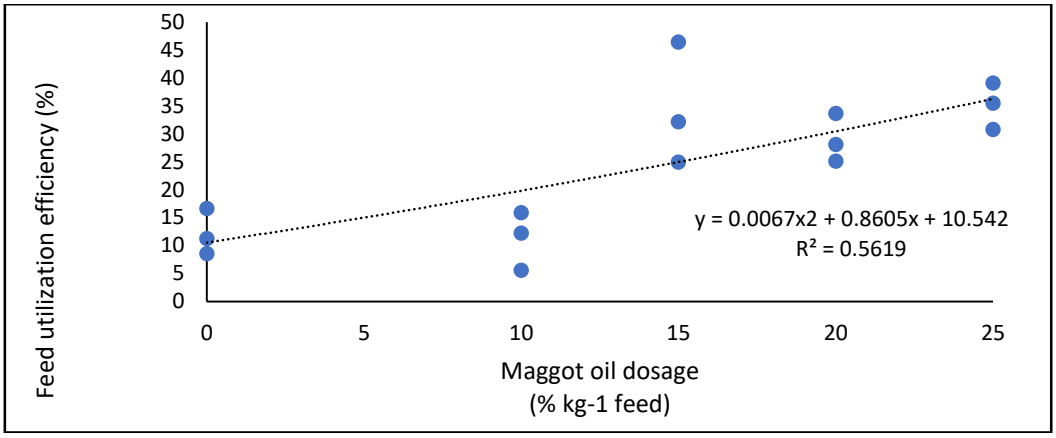

Figure 4. The relationship between the use of maggot oil in artificial feed and the feed utilization efficiency (FUE) of snakehead (*Channa striata*).

Based on the orthogonal polynomial test, a quadratic relationship for protein efficiency ratio (PER) was obtained ($Y = 0.0003x^2 + 0.017x + 0.2798$), with $R^2=0.5785$. The optimum point of PER in treatment E was obtained from the additional dose of maggot oil obtained from this equation, namely 24.33%, which can produce a maximum PER of 0.82%. The orthogonal polynomial graph of the use of maggot oil in artificial feed with the PER of snakehead is presented in Figure 5. The R^2 value shows that 57.85% of PER was influenced by the use of maggot oil in artificial feed.

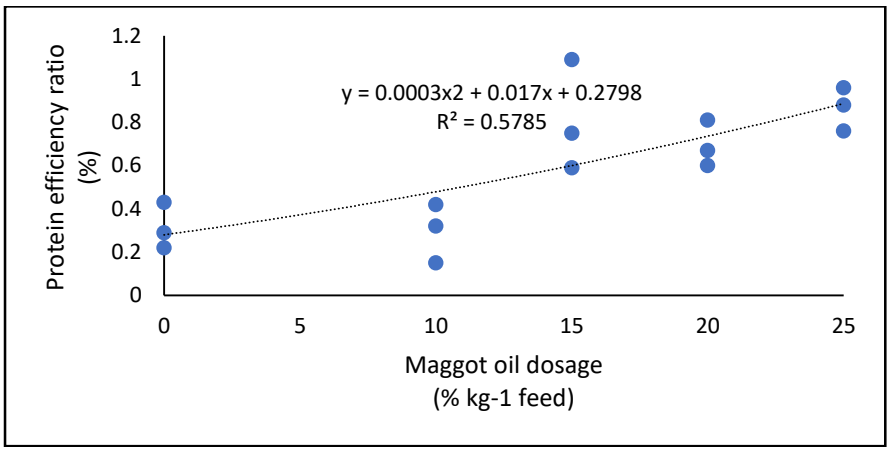

Figure 5. The relationship between the use of maggot oil in artificial feed and the protein efficiency ratio (PER) in snakehead (*Channa striata*).

The amino acid profile (% dry matter) in each feed and amino acid requirements of snakehead can be seen in Table 3. Lysine and methionine showed high levels (3.45 and 3.35%, respectively) in test feed with 25% maggot oil supplementation (E).

Table 3

Amino acid profile (% dry matter) in each feed and amino acid requirements of snakehead (*Channa striata*)

Amino acid	*A (0%)*	*B (10%)*	*C (15%)*	*D (20%)*	*E (25%)*
Arginine	1.50±0.03^{a}	1.85±0.11^{a}	2.20±0.06^{b}	2.05±0.10^{a}	2.38±0.07^{b}
Histidine	0.68±0.14^{a}	1.14±0.13^{a}	1.22±0.13^{a}	1.10±0.12^{a}	1.37±0.11^{b}
Isoleucine	1.55±0.19^{a}	1.90±0.05^{a}	2.20±0.11^{b}	1.70±0.07^{a}	2.38±0.12^{b}
Lysine	2.39±0.13^{a}	2.70±0.17^{a}	3.35±0.12^{b}	3.04±0.08^{a}	3.45±0.15^{b}
Leucine	1.77±0.11^{a}	2.20±0.18^{a}	2.55±0.17^{a}	2.30±0.15^{a}	2.70±0.17^{b}
Methionine	1.09±0.10^{a}	1.11±0.12^{a}	3.24±0.15^{b}	2.25±0.08^{a}	3.35±0.19^{b}
Phenylalanine	1.60±0.13^{a}	1.13±0.12^{a}	2.25±0.09^{a}	2.05±0.03^{a}	2.34±0.11^{b}
Threonine	1.50±0.12^{a}	1.50±0.09^{a}	1.79±0.04^{a}	1.45±0.12^{a}	2.15±0.12^{b}
Tryptophan	0.65±0.14^{a}	1.06±0.11^{a}	1.20±0.15^{a}	1.10±0.14^{a}	1.57±0.15^{b}
Valine	1.49±0.05^{a}	1.70±0.17^{a}	2.10±0.19^{b}	2.05±0.15^{a}	2.25±0.11^{b}

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

The amino acid profile of snakehead after experimental treatments is presented in Table 4.

Analysis of the essential amino acid profile showed that lysine and methionine had high levels (3.60% and 4.05%, respectively) in test feed with 25% maggot oil supplementation (E). The profile of fatty acids contained in feed with the addition of maggot oil is presented in Table 5.

Fatty acid profile analysis showed that linoleic and linolenic fatty acids had high levels (3.10% and 5.25%, respectively) in test feed with 25% maggot oil supplementation (E).

The fatty acid profile of snakehead fed with the addition of maggot oil is presented in Table 6. Fatty acid profile analysis showed that linoleic and linolenic fatty acids showed high levels (5.10% and 5.94%, respectively) in snakehead fish (*C. striata*) fed with maggot oil.

Table 4

Amino acid profile (% dry matter) in snakehead (*Channa striata*) after 49 days of research

Amino acid	*Requirement**	*A (0%)*	*B (10%)*	*C (15%)*	*D (20%)*	*E (25%)*
Arginine	1.74	1.40±0.09^{a}	1.90±0.19^{a}	2.05±0.13^{a}	2.12±0.11^{b}	2.49±0.08^{b}
Histidine	0.78	0.75±0.11^{a}	1.25±0.18^{a}	1.20±0.12^{a}	1.18±0.13^{a}	1.59±0.11^{b}
Isoleucine	0.99	1.15±0.16^{a}	1.50±0.07^{ab}	1.80±0.17^{a}	1.90±0.17^{b}	2.05±0.14^{b}
Leucine	1.01	1.39±0.15^{a}	1.50±0.15^{a}	1.75±0.15^{a}	1.38±0.19^{a}	2.05±0.12^{b}
Lysine	2.16	3.76±0.13^{a}	2.10±0.14^{a}	3.23±0.13^{b}	3.05±0.18^{a}	3.60±0.15^{b}
Methionine	1.07	3.15±0.18^{a}	2.10±0.18^{a}	3.86±0.17^{a}	3.54±0.05^{a}	4.05±0.13^{b}
Phenylalanine	1.64	1.78±0.14^{a}	2.02±0.13^{a}	2.15±0.05^{b}	2.09±0.09^{a}	2.20±0.17^{b}
Threonine	0.90	1.19±0.15^{a}	1.66±0.19^{a}	2.04±0.09^{a}	1.70±0.11^{a}	2.15±0.19^{b}
Tryptophan	1.91	0.75±0.19^{a}	1.03±0.14^{a}	1.19±0.13^{a}	1.06±0.12^{a}	1.57±0.11^{b}
Valine	0.96	1.30±0.08^{a}	1.76±0.13^{ab}	2.03±0.18^{b}	1.80±0.10^{a}	2.15±0.13^{b}

Note: different superscripts in the same row indicate significant differences ($p<0.05$); * - Tacon (1987).

Table 5

The fatty acid profile (% dry matter) in each feed and the fatty acid requirements of snakehead (*Channa striata*)

Saturated fatty acid	*Sample*					
	*Requirement**	*A (0%)*	*B (10%)*	*C (20%)*	*D (30%)*	*E (25%)*
Methyl butyrate	<0.1	0.63±0.09^{a}	0.88±0.06^{a}	2.66±0.02^{b}	0.88±0.09^{a}	2.76±0.02^{b}
Methyl hexanoate	<0.1	1.59±0.03^{a}	1.93±0.02^{a}	3.52±0.07^{b}	1.89±0.03^{a}	3.62±0.07^{b}
Methyl undecanoate	<0.1	1.09±0.02^{a}	2.25±0.09^{a}	3.47±0.03^{b}	3.09±0.02^{a}	3.70±0.03^{b}
Methyl laurate	0.23	1.83±0.02^{a}	1.90±0.08^{a}	2.82±0.04^{b}	1.83±0.02^{a}	2.80±0.04^{b}
Methyl tridecanoate	0.89	3.82±0.06^{a}	2.65±0.08^{a}	4.78±0.03^{b}	3.82±0.06^{a}	4.75±0.03^{b}
Methyl pentadecanoate	2.27	3.46±0.08^{a}	3.75±0.09^{a}	4.99±0.01^{b}	3.86±0.08^{a}	4.83±0.01^{b}
Methyl palmitate	0.73	3.85±0.02^{a}	3.93±0.06^{a}	4.09±0.03^{a}	3.85±0.02^{a}	4.99±0.03^{b}
Methyl heptadecanoate	0.97	1.28±0.07^{a}	1.80±0.09^{a}	2.15±0.05^{a}	1.28±0.07^{a}	2.40±0.05^{b}
Methyl arachidate	4.75	3.73±0.07^{a}	3.45±0.03^{a}	4.65±0.02^{b}	4.37±0.07^{a}	4.90±0.02^{b}
Methyl tricosanoate	1.26	1.35±0.02^{a}	1.93±0.06^{a}	2.09±0.03^{a}	1.85±0.02^{a}	2.39±0.03^{b}
Unsaturated fatty acids						
Linoleic	<0.1	2.06±0.02^{a}	2.97±0.06^{a}	4.55±0.04^{b}	4.17±0.02^{a}	5.10±0.04^{b}
Linolenic	<0.1	2.74±0.05^{a}	3.08±0.09^{a}	4.96±0.06^{b}	3.74±0.05^{a}	5.25±0.06^{b}
Erucate	2.93	1.63±0.02^{a}	2.62±0.05^{a}	3.05±0.01^{b}	2.83±0.02^{a}	3.17±0.01^{ab}
Eicosapentaenoic	0.93	1.08±0.04^{a}	2.07±0.03^{a}	2.67±0.01^{b}	1.98±0.04^{a}	2.87±0.01^{ab}
Docosahexaenoic	<0.1	0.72±0.02^{a}	1.15±0.06^{a}	1.59±0.07^{b}	1.22±0.02^{a}	1.98±0.07^{b}

Note: different superscripts in the same row indicate significant differences ($p<0.05$); * - Tacon (1987).

Table 6

Fatty acid contents in snakehead (*Channa striata*) during 49 days of research

Saturated fatty acid	*Sample*					
	*Requirement**	*A (0%)*	*B (10%)*	*C (20%)*	*D (30%)*	*E (25%)*
Methyl butyrate	< 0.1	0.63±0.09^{a}	0.88±0.06^{a}	2.66±0.02^{b}	0.88±0.09^{a}	2.76±0.03^{b}
Methyl hexanoate	< 0.1	1.59±0.03^{a}	1.93±0.02^{a}	3.52±0.07^{b}	1.89±0.03^{a}	3.62±0.05^{b}
Methyl undecanoate	< 0.1	1.09±0.02^{a}	2.25±0.09^{a}	3.47±0.03^{b}	3.09±0.02^{a}	3.70±0.01^{b}
Methyl laurate	0.23	1.83±0.02^{a}	1.90±0.08^{a}	2.82±0.04^{b}	1.83±0.02^{a}	2.80±0.04^{b}
Methyl tridecanoate	0.89	3.82±0.06^{a}	2.65±0.08^{a}	4.78±0.03^{b}	3.82±0.06^{a}	4.75±0.02^{b}
Methyl pentadecanoate	2.27	3.46±0.08^{a}	3.75±0.09^{a}	4.99±0.01^{b}	3.86±0.08^{a}	4.83±0.07^{b}
Methyl palmitate	0.73	3.85±0.02^{a}	3.93±0.06^{a}	4.09±0.03^{b}	3.85±0.02^{a}	4.99±0.02^{b}
Methyl heptadecanoate	0.97	1.28±0.07^{a}	1.80±0.09^{a}	2.15±0.05^{b}	1.28±0.07^{a}	2.40±0.09^{b}
Methyl arachidate	4.75	3.73±0.07^{a}	3.45±0.03^{a}	4.65±0.02^{b}	4.37±0.07^{a}	4.90±0.00^{b}
Methyl tricosanoate	1.26	1.35±0.02^{a}	1.93±0.06^{a}	2.09±0.03^{b}	1.85±0.02^{a}	2.39±0.03^{b}
Unsaturated fatty acids						
Linoleic	< 0.1	2.06±0.02^{a}	2.97±0.06^{a}	4.55±0.04^{a}	4.17±0.02^{a}	5.10±0.09^{b}
Linolenic	< 0.1	2.74±0.05^{a}	3.08±0.09^{a}	4.96±0.06^{b}	3.74±0.05^{a}	5.94±0.02^{b}
Erucate	2.93	1.63±0.02^{a}	2.62±0.05^{a}	3.05±0.01^{b}	2.83±0.02^{a}	3.17±0.09^{b}
Eicosapentaenoic	0.93	1.08±0.04^{a}	2.07±0.03^{ab}	2.67±0.01^{b}	1.98±0.04^{a}	2.87±0.01^{b}
Docosahexaenoic	< 0.1	0.72±0.02^{a}	1.15±0.06^{a}	1.59±0.07^{a}	1.22±0.02^{a}	1.98±0.05^{b}

Note: different superscripts in the same row indicate significant differences ($p<0.05$); * - Tacon (1987)

Water quality. The water quality values obtained are presented in Table 7.

Table 7

Water quality during maintenance

Variables	*Units*	*Results*	*Feasibility*
Temperature	^{0}C	24-28	27-32*
pH	-	7-7.4	5.2-7.8*
DO	mg L^{-1}	2.97-3.05	>3**
Ammonia	mg L^{-1}	0.035-0.293	0.2-2***

Note: DO - dissolved oxygen; * - Fariedah & Widodo (2016); ** - Widiyati et al (2020); *** - Bich et al (2020).

The temperature ranged between 27–28°C. This temperature range was within the tolerance limit for snakehead. The pH value obtained was between 7–7.4, within the tolerance limit of snakehead. The ammonia content during the research ranged from 0.035–0.293 mg L^{-1}; the ammonia content for rearing snakehead fry of 0.2–2.0 mg L^{-1} was tolerable. The DO levels were between 2.97–3.05 mg L^{-1}. The DO levels in this study were considered normal.

Discussion. Maggot is a promising, good-quality, efficient, and sustainable alternative material as feed that has not been optimally utilized. Maggot oil's nutritional composition is similar to that of fish oil. Several previous studies have revealed the suitability of maggot larvae as a nutritional ingredient for clownfish, *Amphiprion ocellaris* (Vargas-Abundez et al 2019), rainbow trout (Elia et al 2018; Dumas et al 2018), juvenile jian carp, *Cyprinus caprio* var Jian (Li et al 2016; Zhou et al 2018), Pacific white shrimp, *Litopenaeus vannamei* (Cummins et al 2017), European seabass *Dicentrarchus labrax* (Magalhaes et al 2017), barramundi *Lates calcarifer* (Katya et al 2017), and *Psetta maxima* (Kroeckel et al 2012). However, these studies have several obstacles, including palatability, digestibility, chitin content, bioaccumulation toxicity, and deficiency of essential amino acids, or long-chain fatty acids. In addition, a high percentage of lipids in maggot larvae can cause difficulties in the feed industry, such as susceptibility to oxidation, excess energy, and decreased stability of feed pellets (Henry et al 2015). These obstacles can limit the use of maggot larvae as a substitute for fishmeal in aquatic feed. However, several processing techniques, such as hydrolysis, drying, fat removal, or ensiling, can increase palatability, digestibility, and nutrient availability (Tacon 1993). This results in a high-fat percentage of maggot oil products rich in medium-chain fatty acids (MCFA) with lauric acid accounting for 21.4–49.3% of the total fatty acids (Windarto et al 2023). There has been research on the addition of maggot oil in the feed of juvenile *Totoaba macdonaldi* (Maldonado-Othon et al 2022), rainbow trout (Fawole et al 2021), juvenile barramundi (Hender et al 2021) and tilapia *Oreochromis niloticus* (Bakar et al 2021).

The treatment with 25% maggot oil (E) provided the best growth. Maggot oil contains high levels of palmitic and lauric fatty acids compared to fish oil. The function of lauric fatty acid is as an anti-oxidant, as an anti-microbial, to fight various types of pathogens, and to increase HDL (high-density lipoprotein), which functions to minimize the narrowing of blood vessels due to fat (Sandhya et al 2016). *H. illucens* oil contains 40.1% lauric acid, 13.1% palmitic acid, and 9.88% myristic acid (Fawole et al 2021). This is also confirmed by Li et al (2016), who note that maggot oil contains 3.6–4.5% linoleic acid, and 0.08–0.74% linolenic acid.

Feed consumption is the amount of feed consumed by fish. The increase in TFC was proportional to the additional dose of maggot oil. The increase in the total feed consumption value is thought to occur because maggot oil can be an attractant. Attractants are ingredients mixed into feed in small quantities and function to increase food intake and growth. The fish's response to feed begins with olfactory stimuli, which are captured by particular neurons located in the olfactory epithelium and are called olfactory sensory neurons (OSNs). Then, OSNs transmit sensory information to the nervous system (Khasani 2013). The level of TFC is one of the factors that influence growth (Sulasi et al 2018).

Overall, the weight gain of *C. striata* increased at various levels of maggot oil substitution. The specific growth rate values of snakehead given the experimental diets were higher than that of snakehead fed control. The growth rate of fish can be influenced by the protein and fat content of the feed, as well as the quality of the feed provided. The specific growth rate (SGR) value of 1.8±0.35% is directly proportional to the feed utilization efficiency (FUE) value of 35.11±4.16%, so a high feed utilization efficiency value is followed by a high SGR value. Adding maggot oil to artificial feed increases the growth rate of snakehead, but not significantly. According to Isnawati et al (2015), a high growth rate is influenced by an increase in protein and body fat content, which function as a builder of cells and tissues, as well as a source of energy. A growth rate

with a high value is related to high feed efficiency, thus indicating the efficient use of feed.

High feed utilization value indicates good quality feed content, more than 25% (Giri et al 2016). However, feed efficiency depends not only on the quality of the ingredients. The factors that determine the high or low value of feed efficiency are the type of nutrient source and the amount of each component of the nutrient source in the feed. Factors that influence feed efficiency include environmental conditions, feed age, the feed raw materials, the proximate content of the feed, among others. According to Putri et al (2021), a good FUE value shows that the feed consumed is of good quality. Based on the results obtained, the use of maggot oil can increase the efficiency of feed utilization, which shows that the use of maggot oil in artificial feed formulations can increase growth values better than artificial feed without maggot oil (Zulkhasyni et al 2017; Putri et al 2021; Wulandari et al 2021). Fish use maggot oil for growth. According to Xu et al (2020), adding maggot oil has better growth results than adding other insect oils.

The best feed conversion ratio (FCR) value obtained in the research was 1.53. Feed conversion compares the amount of feed given to fish and the total weight of the fish (Zulkhasyni et al 2017). According to Mubaraq et al (2021), the FCR value for fish is considered efficient if it has a value lower than 3. Usually, a lower dose of feed produces a lower FCR. According to Haryati et al (2021) the best level of FUE will be achieved at the lowest FCR.

The results of the variance analysis regarding the survival of snakehead showed that adding maggot oil did not have a significant effect. The highest survival value in treatment E was 70%, and the lowest value was in treatment A, 53.33±5.77%. According to Akbar et al (2020), the survival value for snakehead fry ≥50% is good, between 30–50% is moderate, and <30% is not good.

The analysis of fatty acid composition revealed that the treatment with 25% maggot oil (E) had the highest levels of linoleic and linolenic fatty acids, at 5.10% and 5.94% respectively. Linoleic fatty acid plays a crucial role as a necessary component in the synthesis of long-chain polyunsaturated fatty acids. The research findings indicate that the treatment's amino acid composition was enhanced by the use of 25% maggot oil (E), resulting in a lysine content of 4.05%, which is an important amino acid. Lysine actions as a building block for vitamin B1, helps in calcium absorption, stimulates appetite, and helps in the production of carnitine to convert fatty acids into energy (Ovie & Eze 2013; Valverde et al 2013; Herawati et al 2015).

Conclusions. The research results showed that using maggot oil in artificial feed had a significant effect ($p<0.05$) on TFC, FUE, FCR, PER, and SGR, but had no significant effect on SR. Based on these results, it was found that the best dose for using maggot oil was around 7.9–24.33% of feed, capable of producing a TFC value of 12.16±0.56 g, a FUE of 35.11±4.16%, a FCR of 1.53±0.12, a PER of 0.87±0.1%, a SGR of 1.8±0.35% day^{-1}, and a SR of 70%. The analysis of essential amino acid profiles in feed and fish showed that lysine and methionine showed high levels in feed (3.45% and 3.35%, respectively) and in fish (3.6% and 4.05%, respectively). Analysis of fatty acid profiles in feed and fish showed that linoleic and linolenic fatty acids showed high levels in feed (5.10% and 5.25%, respectively) and in snakehead (5.1% and 5.94%, respectively).

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

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