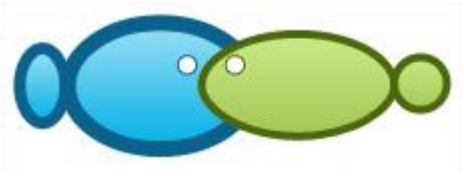

Optimal dietary maggot oil for juvenile white shrimp (*Litopenaeus vannamei*): Growth performance, feed utilization, and nutritional quality

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Abstract. Pacific white shrimp (*Litopenaeus vannamei*) is a relatively fast-growing crustacean. Maggot oil expects to replace fish oil with its fatty acid content that is good for shrimp growth. The application of maggot oil needs further study. This study aimed to determine the best growth performance, survival rate, feed utilization, and nutritional quality of shrimp with maggot oil supplemented in the feed. The Pacific white shrimp diet was formulated with graded levels of maggot oil, such as control (A), 1% (B), 1.5% (C), and 2% (D), as a fish oil substitution on a 100 g diet. The sample shrimp used were PL 20 weighing 0.13-0.14 g. Shrimp were reared for 42 days in a container with a volume of 15 L, at a density of 15 individuals per container, and fed four times daily. The use of maggot oil from *Hermetia illucens* in shrimp feed had a significant effect ($p<0.05$) on total feed consumption (TFC), the efficiency of feed utilization (EFU), protein efficiency ratio (PER), specific growth rate (SGR), absolute weight (AW), absolute length (AL), and protein retention (PR). Using maggot oil on shrimp had no significant effect ($p<0.05$) on survival rate. The best results were in treatment C, especially in growth performance, amino acid, and fatty acid profile.
Key Words: amino, fatty, *Hermetia*, nutrient, protein.

Introduction. White shrimp is a leading commodity with various advantages, one of which is its relatively fast growth. According to Merdekawati & Januardy (2021), the development of shrimp is relatively short, with around 60 days of maintenance. Its resistance to diseases is better than of other shrimps and adds to the attractiveness of this shrimp for the aquaculture sector and impacts the increasing production of shrimp. The increase in the productivity of shrimp greatly affects the production factor. The feed requirement is the main aspect of shrimp production that affects production costs.

An artificial diet is obtained by mixing various ingredients with specific processing and treatment to achieve the desired nutrition of the feed. Feed raw materials have a significant role, with the quality of nutrients influencing growth. The primary raw material is an essential ingredient in the manufacture of feed, with good nutritional content. Alternative raw materials are substitute raw materials in a diet, whose availability is more sustainable. The primary raw material as a source of fat in the artificial feed of shrimp comes is fish oil. The availability of fish oil has decreased due to high market demand, and based on Naylor et al (2009), the need for fish oil reached 88% in the last ten years. The high market demand has increased the price of fish oil. This also affects the price of shrimp feed itself. Maggot oil can be an alternative to fish oil (Herawati et al 2020b; Fawole et al 2021).

Maggot oil can be obtained from larvae of the species *Hermetia illucens*. Maggot oil contains EPA and DHA, which are suitable for growth. Previous research using maggot oil has been carried out on several fish. In the study of Xu et al (2020), using maggot oil in red tilapia (*Oreochromis niloticus*) at a dose of 25% can increase the specific growth rate

(SGR) by 2.27%, affecting growth. Hender et al (2021) carried out fishmeal substitution with maggot oil in *Lates calcalifer* feeds. The results obtained were an SGR value of 6.98% and the absolute weight value of 29.76 g, better than the control values. The research of Li et al (2016) explained that BSF fly larvae (maggot) oil contains a potential source of fat that is high in lauric acid (21.4-49.3%). Fawole et al (2021) stated that using maggot oil in rainbow trout (*Oncorhynchus mykiss*) feed resulted in a SGR of 2.51% per day and was better than soybean oil, which only resulted in an SGR of 2.47% per day. Maldonado-Othon et al (2022) stated that the substitution of fish oil with 30% maggot oil in juvenile *Totoaba macdonaldi* resulted in body weight gain (WG) and thermal growth coefficient (TGC) equivalent to feeding the fish with normal diets. Substitution of fish oil using maggot oil by 25% in the study of Li et al (2016) gave better results than 50%, 75%, and 100% substitutions, with a SGR of 3.3% per day. Feed enrichment using maggot oil as an alternative to fish oil has been widely practiced in fresh and marine fish, but has yet to be conducted in brackish water fish. According to Chen et al (2021), maggot flour has a better EPA content than fishmeal, and produces 100% shrimp survival at 30% maggot flour concentration, with a FCR at 20% maggot flour concentration of 1.55. Therefore, this is a further study on using maggot oil as a substitute for fish oil in shrimp feed. This study aims to determine the effect and best dose of fish oil substitution using maggot oil in the diet of *Litopena vannamei*.

Material and Method

Experimental diet preparation. 10 kg of fresh maggots in the pre-pupa phase were selected and scalded with water at 80°C. The maggots were placed on nets and soaked in water at a temperature of 80°C. Soaking was done for 30 min. After soaking, the maggots were removed, dried and put in the oven at a temperature of 100°C. 1 kg of oil were produced from 10 kg of maggots. The nutritional content of the maggot oil used in this study is: protein 30.09%, fat 33.67%, crude fiber 9.37%. The fat is composed of lauric acid (C12) 58%, palmitic acid (C16) 9%, myristic acid (C14) 8%, omega 3 (ω3) 2.5%, omega 6 (ω6) 6%, omega 9 (ω9) 10%. The method used in this research is an experimental method with a completely randomized design (CRD) consisting of 5 treatments and three replications. The treatments tested were: A (control), B (1% maggot oil), C (1.5% maggot oil), D (2% maggot oil), E (2.5% maggot oil) on a 100 g diet. The diet composition is presented in Table 1.

Table 1

Experimental diet and proximate composition of the experimental diets

Fish diet ingredient	*Experimental diet composition (% maggot oil 100 g^{-1} feed)*				
	A (0%)	*B (1%)*	*C (1.5%)*	*D (2%)*	*E (2.5%)*
Fish meal	33.58	33.58	33.58	33.58	33.58
Soybean meal	22.09	22.09	22.09	22.09	22.09
Corn meal	4.06	4.06	4.06	4.06	4.06
Wheat flour	3.00	3.00	3.00	3.00	3.00
Rice bran meal	29.78	29.78	29.78	29.78	29.78
Fish oil	2.75	1.75	1.25	0.75	0.25
Corn oil	2.75	2.75	2.75	2.75	2.75
Maggot oil	0.00	1.00	1.50	2.00	2.50
Vit-Min mix	1.00	1.00	1.00	1.00	1.00
CMC (Carboxy Methyl Cellulose)	1.00	1.00	1.00	1.00	1.00
TOTAL (%)	100.00	100.00	100.00	100.00	100.00
Protein (%)*	37.87	40.26	42.95	39.76	39.48
Carbohydrate (%)*	16.44	11.51	10.55	13.06	13.25
Fat (%)*	20.63	23.73	25.14	23.01	22.66
Energy (kkal g^{-1})[a]	340.77	361.89	380.334	358.19	354.851
Ratio E/P[b]	8.99	8.98	8.85	9.00	8.98

Note: [a] - calculated based on digestible energy according to Watanabe (1988); 1 g of protein contains 5.6 kcal g^{-1}, 1 g of carbohydrates contains 4.1 kcal g^{-1}, and 1 g of fat contains 9.4 kcal g^{-1}; [b] - according to Steffens (1989), the E/P value for optimal growth of fish ranges from 8-12 kcal g^{-1}.

The nutritional content of the feed from an amino acid profile perspective is presented in Table 2.

Table 2

Amino acid profile of feed

Amino acids (%)	*Req*	*A (0% maggot oil)*	*B (1% maggot oil per kg of feed)*	*C (1.5% maggot oil per kg of feed)*	*D (2% maggot oil per kg of feed)*	*E (2.5% maggot oil per kg of feed)*
Aspartic acid	1.9	1.85±0.05	4.18±0.09	5.19±0.09	2.98±0.04	13.06±0.06
Serine	1.8	1.76±0.02	1.46±0.09	1.93±0.03	1.73±0.07	17.10±0.01
Glutamic acid	2.6	2.36±0.07	3.16±0.08	3.89±0.03	3.20±0.01	12.26±0.05
Glycine	2.6	1.33±0.02	1.98±0.05	2.93±0.06	1.79±0.09	16.26±0.07
Histidine	1.7	0.65±0.03	1.79±0.11	1.89±0.09	1.75±0.08	13.80±0.05
Arginine	2.9	2.85±0.07	3.77±0.02	4.36±0.08	3.56±0.02	3.97±0.07
Threonine	1.2	1.47±0.07	2.43±0.04	2.78±0.06	1.96±0.08	2.39±0.09
Alanine	1.2	1.51±0.01	2.17±0.03	3.20±0.09	2.23±0.09	2.95±0.08
Valine	3.1	1.08±0.09	3.84±0.03	5.87±0.07	2.92±0.01	3.75±0.09
Methionine	4.6	2.72±0.03	6.73±0.08	7.10±0.03	5.99±0.08	6.19±0.04
Lysine	4.2	3.89±0.06	6.88±0.03	8.83±0.05	5.98±0.03	6.09±0.03
Isoleucine	2.8	3.59±0.06	4.09±0.03	4.98±0.03	3.02±0.05	3.98±0.04
Phenylalanine	0.6	1.07±0.02	1.96±0.08	2.52±0.02	1.39±0.03	1.79±0.02
Leucine	2.8	2.47±0.05	2.83±0.02	3.25±0.03	2.17±0.01	2.78±0.01
Triphtophan	1.1	0.93±0.06	2.03±0.06	2.50±0.07	1.10±0.01	1.93±0.01

Note: Req - requirement (Watanabe 1988).

Based on the amino acid profile result, the experimental diet has been able to meet the needs of amino acids of post-larvae white shrimp. Lysine had the highest level (8.83%) in the treatment C. The fatty acid profile of the diets is presented in Table 3.

Table 3

Fatty acid profile of feed using maggot (*Hermetia illucens*) oil

Fatty acids profile	*Treatment*					
	Req	*A (0% maggot oil)*	*B (1% maggot oil per kg of feed)*	*C (1.5% maggot oil per kg of feed)*	*D (2% maggot oil per kg of feed)*	*E (2.5% maggot oil per kg of feed)*
Methyl Butyrate	<0.1	1.49±0.04	2.81±0.05	3.68±0.09	1.50±0.05	2.51±0.02
Methyl Hexanoate	<0.1	2.18±0.06	1.19±0.06	2.25±0.08	1.08±0.02	0.17±0.304
Methyl Undecanoate	<0.1	4.09±0.08	6.14±0.09	8.09±0.04	4.12±0.01	4.97±0.08
Methyl Laurate	0.23	1.65±0.02	2.71±0.07	3.11±0.09	2.08±0.05	1.52±0.03
Methyl Tridecanoate	0.89	1.95±0.03	3.07±0.02	5.91±0.01	2.55±0.03	3.89±0.08
Methyl Pentadecanoate	2.27	2.15±0.08	2.81±0.05	3.68±0.09	3.75±0.09	2.51±0.02
Methyl Palmitate	0.73	3.75±0.02	6.15±0.02	7.95±0.02	5.83±0.06	5.65±0.02
Methyl Heptadecanoate	0.97	1.68±0.07	2.28±0.07	3.19±0.07	2.19±0.09	1.88±0.07
Methyl Arachidate	4.75	3.05±0.07	5.37±0.03	6.64±0.07	4.15±0.03	3.65±0.07
Methyl Tricosanoate	1.26	1.36±0.02	1.85±0.02	2.55±0.02	1.93±0.06	1.66±0.02
Unsaturated fatty acids						
Linolenat	<0.1	3.75±0.02	2.35±0.02	4.83±0.09	3.49±0.07	5.37±0.02
Linoleate	<0.1	2.56±0.07	2.52±0.05	3.54±0.05	2.39±0.03	4.32±0.01
Arachidonic	2.93	0.15±0.05	2.07±0.02	2.13±0.08	0.06±0.08	0.15±0.02
Eicosapentaenoate	0.93	4.94±0.07	6.05±0.02	8.25±0.08	5.03±0.05	5.68±0.02
Docosahexaenoate	<0.1	1.08±0.04	1.83±0.05	5.07±0.03	1.39±0.08	1.07±0.01

Note: Req - requirement (Watanabe 1988).

The fatty acid profile of the experimental diet can fulfill the fatty acid needs of post-larvae white shrimp. Based on the result, the highest essential fatty acid was eicosapentaenoic acid (8.25%) in the treatment C.

Proximate analysis. Proximate analysis (AOAC 2005) was used to determine the protein, fat, ash, carbohydrates, fiber, and water content of samples.

Amino acid analysis. The amino acid profile was determined using HPLC type 1100 apparatus with Eurosphere 100-5 C18, 250×4.6 mm column, with the initial 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 placed into a closed glass, and 15 mL of 6M HCl was added. The mixture was vortexed for homogeneity and hydrolyzed in an autoclave at 110ºC for 12 h 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, 3 mL of the mixture was filtered 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 min 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 determined using the QP-2010 Gas Chromatograph - Mass Spectrophotometer (GCMS) (Shimadzu), 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). Analyses were carried out over a column temperature range of 120-200°C. The method used was in-situ transesterification. 100 mg of the sample was homogenized using 4 mL of water. The homogenate (104 mg) obtained was transferred into the test tube. 100 µL of methylene chloride and 1 mL of 0.5M NaOH were added in methanol. They were heated to 90ºC for 10 min. The test tubes were cooled, and 1 mL of 14% BF3 in methanol was added. After adding nitrogen, it was heated at the same temperature for 10 min. The test tubes were cooled to ambient temperature, and 1 mL of water and 200-500 µL of hexane were added. The mixture was stirred for 1 min to extract the methyl esters from the fatty acids. After centrifugation, the top layer of the sample was ready for GC analysis (AOAC 2005).

Water quality. Water quality measurements included temperature, pH, salinity, and dissolved oxygen (DO), measured using a Water Quality Checker (WQC). Ammonia was tested at the Environmental Quality Laboratory of the Center for Brackish Water Aquaculture (BBPBAP) in Jepara, Indonesia. Measurements of temperature, salinity, and pH were carried out twice daily, oxygen was measured once a day, and ammonia was measured once a week.

Experimental setup. The research was conducted in July-November 2022 at the Center for Brackish Water Aquaculture (BBPBAP) Jepara. White shrimp originating from BBPBAP Jepara hatcheries weighing 0.13-0.14 g, 2-2.1 cm long were used. They were in PL stadia 20. The experimental shrimp were healthy, actively swimming, and had no physical injuries. The density of shrimp in the rearing container was 15 ind per container. 15 containers with a volume of 15 L of water and equipped with aeration systems were used. The rearing medium was 25-26 ppt salinity seawater sterilized with chlorine and neutralized with sodium thiosulfate. The salinity suitable for white shrimp farming is 20-35 ppt (Rakhfid et al 2019). Feeding was done 4 times daily at 06.00, 10.00, 14.00, and 18.00, with a maintenance period of 42 days.

Observed parameters. Sampling once every week was done to observe the parameters of the growth performance, which consist of total feed consumption (TFC), efficiency of feed utilization (EFU), protein efficiency ratio (PER), specific growth rate (SGR), absolute weight (AW), absolute length (AL), protein retention (PR) and survival rate (SR). Each parameter was calculated using the following formulas (Tacon 1993; Pereira et al 2007; National Research Council 2011).

TFC(g) = initial amounts of diets – final amounts of diets

EFU(%) = [(final body weight – initial body weight) / diets fed] x 100

PER(%) = [(final body weight – initial body weight)/(diets fed x protein content)] x 100

SGR(%) = (Ln final body weight – Ln initial body weight)/time period (in days) x 100

AW(g) = final body weight – initial body weight

AL(cm) = final body length – initial body length

PR(%) = [(final protein - initial protein)/ total protein consumed] x 100

SR(%) = (final number of shrimp/initial number of shrimp) x 100

Data analysis. Data were analyzed using analysis of variance (ANOVA) with the SPSS software. A normality, homogeneity, and additivity test were performed to evaluate whether the data were typical, homogenous, and additive. If significant differences were discovered ($p<0.05$), Duncan's Multiple Area Test was performed to identify the groups with significant differences. The water quality data were descriptively examined.

Results. The growth performance of white shrimp after 42 days of maintenance is presented in Table 4.

Table 4

The growth performance of white shrimp (*Litopenaeus vannamei*) after 42 days of maintenance

Variable	*Treatment*				
	A (0% maggot oil)	*B (1% maggot oil per kg of feed)*	*C (1.5% maggot oil per kg of feed)*	*D (2% maggot oil per kg of feed)*	*E (2.5% maggot oil per kg of feed)*
TFC (g)	74.24±1.09^{a}	79.66±0.81^{cd}	80.67±1.15^{d}	74.74±1.51^{ab}	78.67±0.68^{c}
EFU (%)	25.33±0.92^{a}	34.05±0.93^{d}	34.70±0.85^{d}	28.56±0.64^{b}	30.67±0.91^{c}
PER (%)	0.67±0.03^{a}	0.84±0.02^{cd}	0.81±0.02^{d}	0.72±0.02^{ab}	0.78±0.03^{bc}
SGR (% day^{-1})	5.99±0.27^{a}	6.62±0.17^{c}	6.69±0.46^{c}	6.18±0.32^{ab}	6.49±0.09^{bc}
AW (g)	21.05±0.07^{a}	28.82±0.04^{cd}	29.80±2.84^{d}	23.05±2.33^{ab}	25.76±1.99^{bc}
AL (cm)	5.00±0.03^{a}	5.57±0.59^{bc}	5.83±0.25^{d}	5.39±0.11^{ab}	5.64±0.04^{cd}
PR (%)	66.39±0.03^{a}	67.88±0.09^{b}	69.90±0.02^{c}	67.48±0.04^{b}	67.25±0.06^{b}
SR (%)	91.11±3.85^{a}	95.55±3.85^{a}	95.55±3.85^{a}	91.11±3.85^{a}	91.11±3.85^{a}

Note: TFC - total feed consumption; EFU - efficiency of feed utilization; PER - protein efficiency ratio; SGR - specific growth rate; AW - absolute weight; AL - absolute length; PR - protein retention; SR - survival rate; different superscripts indicate significant differences ($p<0.05$).

The analysis found that the best proximate composition in shrimp was in treatment C: 56.35% protein, 24.84% fat, and 7.75% carbohydrate. The lowest protein and fat content were found in treatment A: 48.19% protein and 19.98% fat. Table 5 shows the proximate composition of white shrimp after 42 days of maintenance.

Table 5

Proximate composition of white shrimp (*Litopenaeus vannamei*) after 42 days of maintenance

Proximate composition (%)	*Treatments (%)*					
	Before treatment	*A (0% maggot oil)*	*B (1% maggot oil per kg of feed)*	*C (1.5% maggot oil per kg of feed)*	*D (2% maggot oil per kg of feed)*	*E (2.5% maggot oil per kg of feed)*
Protein	43.19±004	48.19±0.04^{a}	54.12±0.03^{b}	56.35±0.05^{b}	53.16±0.06^{b}	43.65±0.03^{a}
Fat	19.98±0.03	19.98±0.03^{a}	22.22±0.02^{b}	24.84±0.02^{bc}	18.59±0.04^{a}	21.04±0.09^{b}
Crude fiber	10.89±0.02	10.89±0.02^{b}	6.92±0.07^{a}	5.19±0.05^{a}	10.82±0.02^{b}	10.65±0.07^{b}
Ash	10.17±0.04	10.57±0.04^{b}	8.91±0.01^{ab}	6.09±0.0 ^{a}	8.63±0.08^{ab}	7.18±0.09^{a}
Carbohydrate	15.77±0.01	10.37±0.01^{b}	7.53±0.02^{a}	7.53±0.01^{a}	7.80±0.01^{a}	7.48±0.01^{a}

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

Based on the amino acid profile of shrimp after 42 days of maintenance, the highest level of lysine was 10.74% in shrimp from treatment C, while the lowest was found in shrimp from treatment A (6.9%). The amino acid content of the white shrimp after 42 days for each treatment is presented in Table 6.

Table 6

Amino acid profile analysis of white shrimp (*Litopenaeus vannamei*) after 42 days of maintenance

Table	*Treatments*				
	A (0% maggot oil)	*B (1% maggot oil per kg of feed)*	*C (1.5% maggot oil per kg of feed)*	*D (2% maggot oil per kg of feed)*	*E (2.5% maggot oil per kg of feed)*
Aspartic acid	2.13±0.04^{a}	5.18±0.07^{b}	6.31±0.09^{b}	4.63±0.05^{a}	6.06±0.06^{b}
Proline	3.35±0.07^{a}	3.94±0.02^{a}	4.87±0.07^{b}	5.28±0.09^{b}	5.75±0.09^{b}
Serine	4.56±0.09^{a}	5.46±0.05^{b}	5.19±0.03^{b}	4.56±0.02^{a}	4.10±0.01^{a}
Glutamic acid	5.26±0.02^{a}	6.16±0.04^{b}	7.30±0.03^{b}	6.36±0.07^{b}	5.85±0.05^{a}
Glycine	4.53±0.01^{a}	5.91±0.08^{b}	5.75±0.06^{b}	6.33±0.02^{b}	6.26±0.07^{b}
Histidine	4.05±0.02^{a}	4.80±0.12^{a}	5.90±0.09^{b}	4.65±0.03^{a}	5.30±0.05^{b}
Arginine	4.70±0.09^{a}	6.30±0.02^{b}	6.36±0.08^{b}	5.85±0.07^{b}	6.28±0.07^{b}
Threonine	4.75±0.04^{a}	6.75±0.06^{b}	7.78±0.06^{b}	6.47±0.07^{b}	5.89±0.09^{b}
Alanine	5.67±0.05^{b}	5.17±0.03^{b}	5.20±0.09^{b}	6.51±0.01^{b}	4.95±0.08^{a}
Valine	4.02±0.05^{a}	6.98±0.05^{b}	7.10±0.03^{b}	4.72±0.03^{a}	4.90±0.04^{a}
Methionine	3.95±0.09^{a}	5.88±0.07^{b}	8.33±0.05^{b}	4.70±0.06^{a}	5.09±0.03^{a}
Lysine	6.90±0.08^{a}	8.90±0.02^{b}	10.74±0.03^{b}	6.89±0.06^{a}	7.80±0.04^{a}
Isoleucine	4.97±0.01^{a}	4.95±0.07^{a}	5.23±0.02^{b}	5.17±0.02^{b}	4.49±0.02^{a}
Phenylalanine	4.61±0.05^{a}	4.80±0.02^{a}	5.48±0.01^{b}	4.41±0.07^{a}	4.58±0.09^{a}
Leucine	4.17±0.04^{a}	5.07±0.05^{b}	4.75±0.03^{a}	5.37±0.05^{b}	3.38±0.01^{a}
L-Tryptophan	3.03±0.02^{a}	3.50±0.09^{a}	4.10±0.01^{a}	6.33±0.06^{b}	7.93±0.01^{b}

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

Based on the fatty acid profile of shrimp after 42 days of maintenance, the highest content of DHA is 8.75% in shrimp from treatment C, while the lowest was found in shrimp from treatment A (4.46%). The fatty acid content of white shrimp in each treatment is presented in Table 7.

Table 7

Fatty acid profile analysis of white shrimp (*Litopenaeus vannamei*) after 42 days of maintenance

Fatty acid profile (%)	*Treatments*				
	A (0% maggot oil)	*B (1% maggot oil per kg of feed)*	*C (1.5% maggot oil per kg of feed)*	*D (2% maggot oil per kg of feed)*	*E (2.5% maggot oil per kg of feed)*
C14:0 (Myristic)	3.66±0.03^{a}	3.75±0.02^{a}	6.88±0.08^{b}	6.57±0.04^{b}	4.75±0.05^{a}
C15:0 (Pentadecanoic)	2.08±0.02^{a}	2.45±0.03^{a}	3.10±0.07^{b}	2.38±0.06^{a}	1.72±0.06^{a}
C16:0 (Palmitic)	4.17±0.07^{a}	4.60±0.05^{a}	6.99±0.03^{b}	4.77±0.08^{a}	5.14±0.09^{b}
C18:0 (Stearic)	4.55±0.04^{a}	5.98±0.07^{b}	6.23±0.07^{b}	5.75±0.02^{b}	2.71±0.07^{a}
C18:1 n-9 (Oleic/ω9)	1.75±0.02^{a}	3.98±0.06^{b}	4.95±0.01^{b}	2.90±0.03^{a}	3.37±0.02^{b}
C18:2 n-6 (Linoleic/ω6)	1.25±0.08^{a}	5.18±0.08^{b}	6.37±0.02^{b}	2.30±0.07^{a}	4.60±0.09^{b}
C18:3 n-3 (Linolenic/ω3)	1.80±0.03^{a}	4.05±0.05^{b}	4.75±0.05^{b}	2.30±0.09^{a}	2.54±0.05^{a}
C20:0 (Arachidic)	1.78±0.07^{a}	3.23±0.07^{a}	4.23±0.06^{b}	2.50±0.02^{a}	2.30±0.08^{a}
C20:4 n-6 (Arachidonic)	3.39±0.06^{b}	4.54±0.07^{a}	4.97±0.09^{a}	4.19±0.05^{a}	4.07±0.02^{a}
C20:5 n-3 (EPA)	2.73±0.05^{a}	5.23±0.05^{b}	6.92±0.04^{b}	3.03±0.04^{a}	4.53±0.05^{b}
C22:6 n-3 (DHA)	4.46±0.05^{a}	6.75±0.02^{b}	8.75±0.02^{b}	5.96±0.07^{b}	6.53±0.02^{b}

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

The results of water quality measurements during the experiments are presented in Table 8. The water quality parameter values were in suitable condition for cultivating white shrimp.

Table 8

Water quality during the study

No	*Parameter*	*Unit*	*Result*		*Optimal values*
			Morning	*Afternoon*	
1	Temperature	^{o}C	26.2-26.7	26.5-26.9	25.8-30.4[a]
2	pH	-	7.71-7.8	7.71-7.91	7.5-8.5[b]
3	Salinity	ppt	25-26	25-26	20-35[c]
4	DO	mg L^{-1}	5.45-5.49	5.30-5.66	>4[b]

Note: DO - dissolved oxygen; [a] - Putra & Manan (2014); [b] - Hermsen et al (2021); [c] - Rakhfid et al (2019).

Discussion. The growth of white shrimp can be influenced by several factors during maintenance, mainly feed and water quality. The TFC and EFU can show the quality of a feed. The highest TFC was in treatment C, due to the fatty acid content of the maggot oil. Maggot oil from *H. illucens* contains 40.1% lauric acid (C12:0), 13.1% palmitic acid (C16:0), 9.88% myristic acid (C14:0), 3.6%-4.5% linoleic acid (18:2n-6), and 0.08%-0.74% linolenic acid (18:3n-3) (Li et al 2016; Fawole et al 2021). Lauric acid found in maggot oil is not present in fish oil. Lauric acid functions as an antioxidant, antimicrobial and combats various types of pathogens (Fawole et al 2021).

The high lauric acid in maggot oil acts an antioxidant and antimicrobial, combats various types of pathogens, and increases HDL (high-density lipoprotein) to minimize the constriction of blood vessels due to fat (Sandhya et al 2016). Increased HDL can reduce cholesterol levels and accelerate shrimp metabolism (Sandhya et al 2016). Lauric acid, as an antioxidant, can prevent and repair body cells. According to Basir et al (2022), protein generates energy that mainly functions to form body tissues, repair body cells, and for metabolism, the remaining energy being used for growth.

Shrimp, in general, have a high response to food (Renitasari et al 2021). Shrimp can respond to feed when triggered by the taste and smell of the feed. Shrimp could determine the quality of feed based on the taste and smell of the feed (Filawati et al 2018). Palatability is related to the attractant contained in the diet. Maggot oil can function as an attractant because it has a distinctive odor. At the suitable composition, attractants can lead to the rapid absorption of feed.

TFC, utilized efficiently by shrimp, will produce optimal growth. The best EFU value was in treatments B and C. EFU in the treatments using maggot oil had better values than in the control. Maggot oil contains lauric acid, which acts as an antioxidant and increases HDL (Sandhya et al 2016). The lauric acid content in treatments B and C, which had more than 40% protein content, causes a more efficient energy absorption for growth. Renitasari et al (2021) indicated that shrimp generally require 35-40% protein. A good value of utilization efficiency for farmed cultivars is more than 50% (Craig & Helfrich 2017). A higher EFU indicates that the administered feed can be digested and used for growth (Craig & Helfrich 2017). High EFU is influenced by the source of nutrients and the quantity of each component of the nutrient source in the feed (Herawati et al 2020b).

The growth in weight and length of white shrimp can be influenced by TFC, EFU, and the content of macro and micronutrients in the diet. White shrimp requires 12-15% fat, 35-40% protein, and at least 40% carbohydrate in the feed (Zainuddin et al 2014; Renitasari et al 2021).

Fat contains essential and non-essential fatty acids that function as energy sources and solvents for vitamins A, D, E, and K (Li et al 2018). Shrimp use fat as a reserve energy source in the metabolic processes. The fat content in maggot oil is good for to aquaculture cultivars because it contains lauric acid (C12:0), palmitic acid (C16:0), myristic acid (C14:0), linoleic acid (18:2n-6), and linolenic acid (18:3n-3). According to Fawole et al (2021), *H. illucens* oil contains 40.1% lauric acid, 13.1% palmitic acid, and 9.88% myristic acid. This is also supported by Li et al (2016), who state that maggot oil contains 3.6-4.5%

linoleic acid and 0.08-0.74% linolenic acids. Lauric acid functions as an antioxidant and antimicrobial agent, combating various types of pathogens, increasing HDL (high-density lipoprotein), which minimizes the constriction of blood vessels (Sandhya et al 2016). Palmitic acid functions to regulate energy storage, linoleic acid functions to form EPA, and linolenic acid functions to include DHA. The content of omega-3 unsaturated fats in maggot oil in the form of EPA and DHA of 2.16% and 1.89% accelerates growth and metabolism in shrimp. The content of EPA and DHA in maggot oil is considered suitable for white shrimp. Shrimp require a minimum EPA and DHA of 0.2% and 0.1-0.3%, respectively, for growth (Hermsen et al 2021).

Growth and metabolism in white shrimp depend on the protein and carbohydrate content of the diet. Protein is necessary for the body to repair cells, build muscle tissue, and grow. Protein in the diet provided to shrimp during the study has met the requirements of shrimp for more than 35% protein. The excess fat and protein in the diet can compensate for the lack of carbohydrates. The diet's energy stored from fat and protein can be utilized for activity and growth. Energy can come from the diet's fat, protein, and carbohydrate content (Renitasari et al 2021).

The growth of white shrimp is directly proportional to the SGR. The maximum expansion of shrimp can be obtained if SGR is maximized. The SGR in the treatments had higher values than in the control. According to Fawole et al (2021), substituting fish oil using maggot oil can produce a SGR in fish of 2.51% per day. The feed and water quality influence SGR. The higher the energy available in the diet, the greater the possibility of a good SGR. The SGR is related to the efficiency of feed utilization. The more efficient a diet is, the more SGR increases. Diet using maggot oil is better because it contains 40.1% lauric fatty acid (C12:0), which is not found in fish oil (Fawole et al 2021). The high content of lauric acid can prevent and repair damage to cells in the shrimp body, and allow growth. The high content in palmitic acid also promotes growth.

Protein in the diet plays a role in shrimp's growth, energy balance, and immunity conditions. Protein retention is the amount of protein derived from feed stored in the body and utilized for building or repairing damaged body cells or for daily metabolism (Jusadi et al 2015). The value of protein retention will be directly proportional to the EFU value. In this study, the lowest protein retention was found in treatment A at 66.39%, with a feed protein content of 37.87%. The highest protein retention was in treatment C at 69.90%, with a feed protein content of 42.95%. Protein retention is influenced by the protein intake and the protein lost at the metabolic level.

According to Webster & Lim (2002), the value of feed protein retention is determined by the source of protein used in the diet. It is closely related to the quality of protein determined by the composition of amino acids and requirements for these amino acids. Feed utilization will be more efficient if the digestibility of feed increases. Protein retention in this study was higher than in the research of Ekaputri et al (2018), where the value of white shrimp protein retention ranged from 45.41-67.8%, with the feed protein content of 48.13-57.38%.

Another supporting factor for shrimp growth is water quality. The temperature during the study ranged from 26.2-26.7^{o}C in the morning and 26.5-26.9^{o}C in the afternoon. According to Putra & Manan (2014), the optimum temperature for white shrimp growth is between 25.8-30.4^{o}C. The temperature during the maintenance period tended to be the same. The temperature in this range can increase appetite and minimize shrimp disease.

There were no significant differences between treatments regarding survival. The range of the survival rate was 91-95%. Water quality is influential for the survival of white shrimp. At low salinity, white shrimp will have difficulty in molting, and imperfect molting can slowly undergo death. According to Rakhfid et al (2019), the optimum salinity value for white shrimp farming is between 20-35 ppt. Salinity during the maintenance period was suitable for the needs of shrimp in the range of 25-26 ppt. Temperatures that tend to be stable can enhance the immune system of white shrimp and increase endurance. The temperature during maintenance ranged from 26.2-26.9^{o}C. According to (Putra & Manan 2014), the temperature for shrimp culture should be between 25-30.4^{o}C.

The suitability of water quality and diet for white shrimp can maintain the stability of the body condition (Herawati et al 2020a). The pH value during the study in the morning

was 7.71-7.8, and in the afternoon, 7.71-7.91. The DO during the study in the morning was 5.45-5.49 mg L^{-1}, and in the afternoon, 5.30-5.66 mg L^{-1}. The proximate composition of shrimp fed experimental diets in this study was better than that of shrimp fed a diet with maggot meal (Herawati et al 2020c). However, the results of this study are lower in the content of lysine, but EPA has a higher content. Herawati et al (2020c) obtained 11.85% lysine and 7.9% DHA contents in post-larvae shrimp fed using diets with maggot flour.

The highest level of lysine in this study was obtained in treatment C. Soares et al (2015) stated that the need for lysine in post-larval stadia of shrimp is 4.2%. The role of lysine in the diet is to form carnitine, which functions as a growth promoter, protects against ammonia poisoning, and increases the body's defense against extreme temperature changes (Ovie & Eze 2010). In addition, lysine also functions as an essential ingredient for blood antibodies, strengthening the circulatory system and maintaining average cell growth (Baeza-Rojano et al 2013). The energy content, as well as lysine in the diet, can increase the digestibility in the ileum, resulting in a high growth rate and increasing diet efficiency (Baki et al 2015). Lysine can increase the digestibility of other amino acids, one of which is the non-essential amino acid tyrosine, regulating appetite and the body's response to stress (Herawati et al 2018).

The highest EPA and DHA content in this study were observed in shrimp from treatment D. EPA and DHA can affect the growth rate of white shrimp. The HUFA fatty acids (EPA and DHA) contribute to the metabolic function of cells. The ability of shrimp to withstand a range of parameters values is strongly influenced by the nutritional quality of the feed consumed, especially the content of essential n-3 HUFAs such as EPA and DHA (Rudtanatip et al 2019). In addition, according to Rudtanatip et al (2019), n-3 essential HUFA is very important in supporting shrimp survival as well as improving the ability of shrimp to respond to stress.

Conclusions. This study determined the effect of fish oil substitution with maggot oil in shrimp feed on the growth performance, survival rate, feed utilization and nutritional quality of shrimp. The best results in this study were present in the treatment with 1.5% maggot oil (C), with a TFC of 80.67 g, 34.7% EFU, 0.81% PER, a SGR of 6.69% day^{-1}, absolute weight of 29.8 g, absolute length of 5.83 cm, and protein retention of 69.9%. Using maggot oil in the treatments had no significant effect ($p<0.05$) on survival rate. Alternative raw materials such as maggot oil as a substitute for fish oil could increase production and the nutritional quality of white shrimp. However, there is a need for further research on the combination of maggot oil and maggot flour to increase the production of white shrimp.

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

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