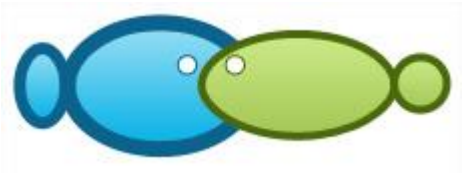

Effect of different ratios of maggot meal (*Hermetia illucens*) on growth performance and body composition of vannamei shrimp (*Litopennaeus vannamei*) post larvae

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Abstract. Maggots of *Hermetia illucens* have a high nutritional value and can partially replace fishmeal in aquaculture feeds. This study aims to determine the effects of different ratios of maggot flour in the feed of post-larvae vannamei shrimp on their growth, feed utilization efficiency, amino acid profile, and fatty acids. 320 vannamei shrimp had an average initial weight of 52 g This study used a completely randomized design (CRD) four treatments and three replications: A - control (no maggot meal); B - replacement of fishmeal with 8% maggot meal; C - replacement of fishmeal with 16% maggot meal; D - replacement of fish meal with 24% maggot meal. The absolute and relative weight growth rates, the total feed consumption, the feed utilization efficiency, the protein efficiency ratio, the survival rate, and the water quality were measured. The substitution of fishmeal with maggot flour significantly affected ($p<0.05$) the relative growth rate, total feed consumption, utilization efficiency, feed conversion ratio, and protein efficiency ratio of vannamei shrimp, but not their viability. The optimal ratio of fishmeal replacement with maggot meal was 16% (C), resulting in a relative growth rate of 7.55% day^{-1}, feed utilization efficiency of 55.87%, a food conversion ratio of 1.35, a protein efficiency ratio of 1.52%, and total feed consumption of 274.10 g. The substitution of fishmeal with 16% maggot meal (C) resulted in the best amino acid and fatty acid profile of shrimp, especially for lysine content, which was 11.85%, and DHA content, which was 7.9%.

Key Words: maggot, nutrition, production, vannamei.

Introduction. Vannamei shrimp (*Litopenaues vannamei*) is a fishery product with important economic value. Vannamei shrimp is responsive to feed, it is resistant to diseases under bad environmental circumstances, has a rapid development phase, a high survival rate under normal conditions, and a short maintenance period of 90 to 100 days (Purnamasari et al 2017). Shrimp growth is highly dependent on the nutrients contained in the feed. Fishmeal the main proteic feed ingredient. The high nutritional value of fishmeal is what makes it expensive (Idowu & Afolayan 2013). To limit the usage of fishmeal as a feed raw material, local raw resources that can be utilized as a source of animal protein in feed products must be developed as an alternative. Maggots are one of the local ingredients that may substitute fishmeal.

Under favorable conditions, the larva of the black army fly (*Hermetia illucens*) thrives in animal manure or organic waste. According to Cummins et al (2017), maggot meal can replace fishmeal because it has a similar nutritional content: its protein content is high, reaching 44.88%. It also has 14.65% fat, and 9.90% nitrogen free extract. In addition, maggot meal also contains complete essential and non-essential amino acids, arginine 6.06%, histidine 3.01%, isoleucine 3.05%, leucine 6.35%, lysine 4.23%, methionine 1.82%, phenylalanine 3.53%, threonine 2.09%, tryptophan 3.17%, valine 1.91%, alanine 3.84%, aspic acid 4.31%, cysteine 1.2%, glutamic acid 3.87%, glycine

2.76%, proline 1.58%, serine 3.14%, and tyrosine 2.47% (Hender et al 2021; Herawati et al 2020). Maggot in the pre-pupa phase can be used as a good source of nutrients for fish because, at this stage, the maggot has fasted, containing less harmful substances (Herawati et al 2020). Using alternative materials as a substitute for fishmeal is one strategy to save costs. In addition to abundant availability, the maggot is also very easy to cultivate using simple technology (Idowu & Afolayan 2013).

Cummins et al (2017) investigated the impact of maggot meal as a replacement for fishmeal in vannamei shrimp feed. This study aims to determine the effect of maggot meal in replacing fishmeal in vannamei shrimp larvae feed on shrimp growth, amino acid profile, and fatty acid profile.

Material and Method. The test shrimp used in this study were vannamei shrimp from BBPBAP Jepara, Indonesia, with an average initial weight of 52 g. The age of the shrimp was 23 days. The test fish were chosen based on their weight, organ integrity, and absence of disease. Maggots that have developed into pre-pupae were dried and ground into flour. The artificial feed used in this study is in the form of pellets with a diameter of 0.5-1 mm. This study used a completely randomized design with four treatments and three replications: A - control (no fishmeal replacement); B - replacement of fishmeal with 8% maggot meal; C - replacement of fishmeal with 16% maggot meal; D - replacement of fish meal with 24% maggot meal. The test diet was administered four times per day at 08.00, 12.00, 16.00, and 20.00, with a feeding schedule fixed for 45 days. 360 test shrimp were used, with 30 shrimps per container.

Raw ingredients for the feed were prepared in advance. Fishmeal as a source of animal protein, maggot flour as a source of animal protein and as a substitute for fish meal, soybean meal as a source of vegetable protein, corn flour, bran flour, and wheat flour as sources of carbohydrates, fish oil, and palm oil as sources of fat, minerals and vitamin mix and (carboxymethyl cellulose) CMC as a binder were used to make the feed.

The proximate analysis of the feed ingredients was carried out to determine the nutritional content, used in preparing test feed formulations. The proximate chemical composition of the samples was determined using a standard using the standards AOAC methods (AOAC 2005). The proximate composition of the ingredients is presented in Table 1. Table 2 displays the proximate composition of the test feeds.

Table 1

Proximate composition of feed ingredients used in this research (% dry weight)

Ingredients	*Water*	*Ash*	*Fat*	*Crude fiber*	*Protein*	*NFE*	*Total*
Fishmeal (**)	9.17	20.19	5.43	3.10	58.01	4.20	100.00
Maggot meal (*)	7.25	13.50	14.65	9.82	44.88	9.90	100.00
Soy flour (**)	5.22	7.64	0.94	3.52	50.35	32.36	100.00
Cornstarch (*)	8.30	1.56	1.34	3.60	10.57	73.21	100.00
Flour (*)	5.17	0.72	1.06	1.31	11.29	80.45	100.00
Bran flour (*)	9.26	10.24	8.03	21.08	11.29	40.10	100.00

Note: NFE - nitrogen free extract; * - Laboratory of Animal Feed Science, Faculty of Animal Husbandry and Agriculture, Diponegoro University; ** - Laboratory BBPAP Jepara.

Among the data observed in this study were absolute growth rate (FWG), relative growth rate (RGR), total feed consumption (TFC), feed utilization efficiency (FUE), protein efficiency ratio (PER), survival rate (SR), and water quality parameters.

Table 2

Test feed formulation and proximate composition of test feed

Feed ingredients	*Composition*			
	A	*B*	*C*	*D*
Fish Flour	32.00	29.44	26.88	24.32
Maggot Flour	0.00	3.31	6.62	9.90
Soy Flour	26.00	26.00	26.00	26.00
Cornstarch	6.00	6.00	6.00	5.00
Bran Flour	11.00	10.05	10.00	10.00
Flour	17.50	18.00	17.50	18.15
Fish Oil	2.75	2.50	2.50	2.30
Palm Oil2	2.75	2.70	2.50	2.30
Vitamin Mix	1.00	1.00	1.00	1.00
CMC	1.00	1.00	1.00	1.00
Total	100	100	100	100
Protein (%)*	36.03	35.61	35.48	36.37
Fat (%)*	10.16	10.56	10.70	10.19
BETN (%)*	30.54	30.93	29.55	31.84
DE (kcal)[a]	284.75	287.47	284.69	289.43
Ratio E/P[b]	8.00	8.07	8.02	8.00

Note: [a] - calculated based on digestible energy; according to De Silva (1987), protein has 3.5 kcal g^{-1}, fat has 8.1 kcal g^{-1}, and carbohydrates have 2.5 kcal g^{-1}; according to De Silva (1987), the E/P value for optimal fish growth ranges from 8-12 kcal g^{-1}; * - Animal Feed Science Laboratory, Faculty of Animal Husbandry and Agriculture, Diponegoro University.

Absolute growth rate (FWG). In this study, the absolute growth rate was calculated using the following formula (Goddard 1996):

$$FWG=(W_t-W_0)/t$$

Where: FWG - absolute growth rate (g); W_0 - the biomass weight of the tested shrimp at the beginning of the study (g); Wt - test shrimp biomass weight at the end of the study (g); t - research duration (days).

Relative growth rate (RGR). The RGR was calculated using the formula used by Zonneveld et al (1991):

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

Where: RGR - relative growth rate (g day^{-1}); W_t - the average weight at the end of the study (g); W_0 - the average weight at the beginning (g); t - length of maintenance (days).

Total feed consumption (TFC). The total value of feed consumption was calculated using the formula of Okumus & Mazlum (2002):

$$FC = FG - FU$$

Where: FC - feed consumption (g); FG - amount of feed given (g); FU - amount of uneaten feed (g).

Feed utilization efficiency (FUE). The calculation of the value of feed utilization efficiency (FUE) can be determined by the following formula (Tacon 1987):

$$EPP=(Wt-W0)/F \times 100$$

Where: FUE - feed utilization efficiency (%); W_0 - the biomass weight of the tested shrimp at the beginning of the study (g); Wt - test shrimp biomass weight at the end of the study (g); F - amount of test shrimp feed consumed during the study (g).

Feed conversion ratio (FCR). Calculations to determine the feed conversion ratio during the rearing period were based on Zonneveld et al (1991):

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

Where: FCR - feed conversion ratio; W_0 - the biomass weight of the tested shrimp at the beginning of the study (g); Wt - test shrimp biomass weight at the end of the study (g); F - amount of test shrimp feed consumed during the study (g).

Protein efficiency ratio (PER). The calculation of the protein efficiency ratio (PER) was calculated using the Tacon (1987) formula, as follows:

$$PER=(Wt-W0)/Pi \times 100$$

Where: PER - protein efficiency ratio (%); W_0 - test shrimp biomass weight at the beginning of the study (g); Wt - test shrimp biomass weight at the end of the study (g); Pi - the amount of test feed consumed multiplied by the protein content of the test feed.

Survival rate (SR). Survival rate (SR) was calculated based on the following formula (Goddard 1996):

$$SR=(Nt/No)x100$$

Where: SR - survival rate (%); N0 - number of test shrimp at the beginning of the study; Nt - number of test shrimp at the end of the study.

The protein, fat, ash, carbohydrate, fiber, and water content of shrimp samples were determined via proximate analysis (AOAC 2005). The Kjeldahl method was used to analyze the protein content, whereas the Soxhlet method was used to analyze the fat content. The water and ash content was assessed using gravimetric principles. The carbohydrate content was calculated manually based on the results of the proximate analysis.

The amino acid profile was evaluated using an HPLC type 1100 instrument fitted with a Eurosphere 100-5 C18, 2504.6 mm column and a column P/N 1115Y535 as the starting column P/N. 0.01 M acetate buffer at pH 5.9 and 0.01 M MeOH acetate buffer at pH 5.9, THF>80:15:5 0.01 M acetate buffer in MeOH constituted the wastes. Fluorescence: extra: 340 mm Em: 450 nm. Approximately 2.5 g of sample were put in a closed glass, and 15 mL of 6M HCl were added. Before being neutralized with 6M NaOH and cooled to room temperature, the mixture was homogenized by vortexing and hydrolyzed at 110°C for 12 hours in an autoclave. After adding 2.5 mL of 40% lead acetate and 1 mL of 15% oxalic acid to the mixture, 3 mL was filtered using a 0.45 m Millex-HV filter (Merck KGaA, Darmstadt, Germany). 25 mL of the filtered mixture and 475 mL of the OPA anhydrase solution were mixed and incubated for 3 min before injection into the HPLC apparatus. The HPLC system was injected with 30 mL of the final combination (AOAC 2005).

The fatty acid profile was measured using a QP-2010 Gas Chromatograph - Mass Spectrophotometer (GCMS) (Shimadzu) with a 50 m, 0.22 mm Wall Coat Open Tubular CP-SIL-88 column (Agilent, Santa Clara, CA, USA). Analyses were undertaken at column temperatures ranging from 120 to 200°C. The approach adopted was in-situ transesterification. 100 mg of sample was homogenized with 4 mL of water. 104 mg of the homogenate was transferred to a test tube. There was an addition of 100 mL of methylene chloride and 1 mL of 0.5M NaOH in methanol. After adding nitrogen, the tubes were firmly sealed. They were kept at 90°C for 10 min. After the test tubes had been cooled, 1 mL of 14% BF3 in methanol was added. After adding nitrogen, it was kept at the same temperature for 10 min. Once the test tubes reached room temperature, 1 mL of water

and 200-500 mL of hexane were added. One minute of stirring separated the methyl esters from the fatty acids. The sample's top layer was prepared for GC analysis after centrifugation (AOAC 2005).

Temperature, pH, salinity, and dissolved oxygen (DO) were measured to determine water quality 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 a day, oxygen was measured once a day, and ammonia was measured once a week.

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

Results. Based on the results of the study, the highest growth performance was observed in treatment C, where: Wt 189.50 g, weight gain was 3.04 g, RGR was 7.55% per day, TFC was 274.1 g, FUE was 55.87%, FCR was 1.35%, PER was 1.72% and SR was 100%. The lowest growth performance was in the control, with a Wt of 174.16 g, a weight gain of 2.7 g, RGR of 6.60% per day, TFC of 212.22 g, FUE of 50.33%, FCR of 1.99%, PER of 1.3% and SR of 100%. The growth performances in the treatments are presented in Table 3.

Table 3

Growth of vannamei shrimp (*Litopenaeus vannamei*) during the study

Variable	*Treatment*			
	A (0%)	*B (8%)*	*C (16%)*	*D (24%)*
W_0 (g)	52.42 ± 0.32^{a}	52.57 ± 0.13^{a}	52.49 ± 0.11^{a}	52.93 ± 0.03^{a}
Wt (g)	174.16 ± 1.77^{d}	179.13 ± 2^{c}	189.5 ± 1.56^{a}	183.71 ± 1.99^{b}
FWg (g)	2.7 ± 0.77^{d}	2.81 ± 0.2^{c}	3.04 ± 0.56^{a}	2.9 ± 0.09^{b}
RGR (%/day)	6.6 ± 0.15^{c}	6.88 ± 0.09^{b}	7.55 ± 0.07^{a}	7.06 ± 0.11^{b}
TFC (g)	212.22 ± 1.57^{c}	256.89 ± 1.73^{ab}	274.1 ± 1.55^{a}	242.11 ± 1.97^{bc}
FUE (%)	50.33 ± 1.02^{c}	51.26 ± 0.41^{bc}	55.87 ± 0.82^{a}	51.87 ± 0.39^{b}
FCR	1.99 ± 0.04^{c}	1.6 ± 0.02^{bc}	1.35 ± 0.03^{a}	1.8 ± 0.01^{b}
PER (%)	1.3 ± 0.03^{c}	1.64 ± 0.01^{b}	1.72 ± 0.02^{a}	1.5 ± 0.01^{bc}
SR (%)	100^{a}	100^{a}	100^{a}	100^{a}

Note: W_0 - initial body weight; Wt - final body weight; FWg - weight gain; RGR - relative growth rate; FUE - feed utilization efficiency; FCR - feed conversion ratio; PER - protein efficiency ratio; SR - survival rate; different superscripts show significant differences ($p<0.05$).

The results showed that the substitution of fishmeal with maggot meal had a significant effect ($p<0.05$) on FW, RGR, TFC, FUE, FCR and PER, but had no significant effect ($p>0.05$) on the SR of vannamei shrimp.

The results show that W_0 was not significantly different among treatments, with the highest value of 52.93 g in treatment D and the lowest with 52.19 g in treatment C. Wt was highest in treatment C (189.3 g) and lowest in treatment A (174.16 g), all treatments showing significant differences. RGR was significantly different in treatment A compared to treatments B, C, and D. There was no significant difference between treatment B and treatment D. The highest RGR was obtained in treatment C (7.55% per day), while the lowest in treatment A (6.60% per day). In terms of TFC, treatment A was significantly different from treatments B and C, but not significantly different from treatment D, with the highest result found in treatment C (274.1 g) and the lowest in treatment A (212.22 g). Regarding FUE, treatment A was not significantly different from treatment B, but significantly different from treatments C and D, where the highest value was found in treatment C (55.87%) and the lowest in treatment A (50.33%). FCR in treatment A was not significantly different from treatment B, but significantly different from treatments C and D, with the highest value in treatment A (1.99%) and the lowest in treatment C

(1.35%). PER in treatment A was significantly different from PER in treatments B and C, but not significantly different from that of treatment D, where the highest result was obtained in treatment C (1.72%) and the lowest in treatment A (1.3%). The SR was not significantly different among treatments, being 100%.

The nutritional quality of vannamei shrimp had the better results in treatment C, with 52.35% protein and 24.64% fat (of dry matter). The lowest values were in the control, with 48.16% protein and 18.59% fat (of dry matter) (Table 4).

Table 4

Proximate analysis of vannamei shrimp (*Litopenaeus vannamei*) for 45 maintenance days

Chemical composition	*Before treatments*	*A*	*B*	*C*	*D*
Protein	33.19± 004	48.16±0.06	50.12± 0.03	49.65± 0.03	52.35± 0.05
Fat	19.98± 0.03	18.59±0.04	22.22± 0.02	21.04± 0.09	24.64± 0.02
Crude fibre	15.89± 0.02	15.82±0.02	10.92± 0.07	14.65± 0.07	9.19± 0.05
Ash	15.57± 0.04	8.83±0.08	8.91± 0.01	7.18± 0.09	6.09± 0.02
Carbohydrate	15.37± 0.01	7.60± 0.01	7.53± 0.02	7.48± 0.01	7.73± 0.01

The nutritional quality of the test feed given to vannamei shrimp resulted in a balanced amino acid profile in treatment C, with 8.95% lysine content. Treatment A presented only 5.6% lysine content. The essential amino acid profile of the test feeds is presented in Table 5.

Table 5

The essential amino acid content of feed for each treatment and amino acid requirements for vannamei shrimp (*Litopenaeus vannamei*) post larvae

Essential amino acids	*Requirement*	*A (0%)*	*B (8%)*	*C (16%)*	*D (24%)*
Arginine	2.9	3.86±0.05	4.97±0.06	7.19±0.05	6.28±0.04
Histidine	1.7	1.55±0.08	2.51±0.03	4.23±0.04	3.65±0.01
Isoleucine	2.8	3.83±0.02	4.17±0.04	5.78±0.03	5.20±0.02
Lysine	4.2	5.60±0.46	6.93±0.09	8.95±0.08	7.08±0.07
Methionine	3.1	2.08±0.01	2.45±0.02	3.24±0.07	2.77±0.02
Phenylalanine	0.6	3.79±0.02	4.19±0.04	6.39±0.05	5.92±0.05
Threonine	1.2	3.25±0.05	3.78±0.01	4.75±0.01	3.92±0.02
Tryptophan	1.1	1.98±0.01	2.97±0.03	3.77±0.03	3.06±0.06
Valine	2.2	4.63±0.04	4.96±0.02	6.72±0.07	5.19±0.07
Leucine	2.8	5.31±0.01	6.65±0.06	8.17±0.08	7.03±0.01

Note: reference for requirements: De Silva (1987).

Table 6 displays the amino acid profiles of vannamei shrimp exposed to the treatments. It revealed that the highest lysine concentration was in the shrimp of treatment C (11.14%) and the lowest in treatment A (6.89%).

The fatty acid content of each treatment feed and the amino acid requirements of post-larvae of vannamei shrimp are presented in Table 7. Based on the fatty acid profile of the test feed, it was possible to satisfy the fatty acid requirements of vannamei shrimp post-larvae.

The fatty acid profiles of vannamei shrimp under different treatments are shown in Table 8. Shrimp from treatment C had the greatest concentration of EPA (6.92%), whereas shrimp from treatment A contained the lowest quantity (3.03%).

Table 6

Amino acid profiles of *Litopenaeus vannamei* under different treatments

Amino acid (%)	*Treatments*			
	A (0%)	*B (8%)*	*C (16%)*	*D (24%)*
Aspartic acid	4.63±0.05	5.18±0.09	5.19±0.09	6.06±0.06
Proline	5.28±0.09	3.94±0.03	4.87±0.07	5.75±0.09
Serine	6.56±0.02	6.46±0.09	6.31±0.03	6.10±0.01
Glutamic acid	6.36±0.07	6.16±0.08	5.30±0.03	5.85±0.05
Glycine	6.33±0.02	5.91±0.05	5.75±0.06	6.26±0.07
Histidine	4.65±0.03	4.80±0.11	5.90±0.09	5.30±0.05
Arginine	5.85±0.07	6.30±0.02	6.36±0.08	6.28±0.07
Threonine	6.47±0.07	6.75±0.04	7.78±0.06	5.89±0.09
Alanine	6.51±0.01	5.17±0.03	5.20±0.09	4.95±0.08
Valine	4.72±0.03	6.98±0.08	7.10±0.03	4.90±0.04
Methionine	4.70±0.06	5.88±0.03	8.33±0.05	5.09±0.03
Lysine	6.89±0.06	8.90±0.03	11.14±0.03	7.80±0.04
Isoleucine	5.17±0.02	4.95±0.08	5.23±0.02	4.49±0.02
Phenylalanine	4.41±0.07	4.80±0.07	5.48±0.01	4.58±0.09
Leucine	5.37±0.05	5.07±0.02	4.75±0.03	3.38±0.01
L-Tryptophan	6.33±0.06	7.50±0.07	4.10±0.01	7.93±0.01

Table 7

The fatty acid content of feed for each treatment and amino acid requirements for vannamei shrimp (*Litopenaeus vannamei*) post larvae

No	*Saturated fatty acids*	*Requirement*	*A (0%)*	*B (8%)*	*C (16%)*	*D (24%)*
1	Butyrate	<0.1	0.73±0.09	0.33±0.06	1.95±0.09	0.88±0.03
2	Hexanoate	<0.1	1.64±0.03	1.63±0.02	2.75±0.03	2.09±0.04
3	Undecanoate	<0.1	1.23±0.02	1.85±0.09	3.09±0.02	2.74±0.06
4	Laurate	0.23	1.44±0.02	1.90±0.08	2.83±0.02	2.16±0.02
5	Tridecanoate	0.89	2.78±0.06	2.95±0.08	4.19±0.06	3.82±0.05
6	Pentadecanoate	2.27	3.13±0.08	3.75±0.09	4.95±0.08	3.86±0.07
7	Palmitate	0.73	5.65±0.02	5.83±0.06	7.95±0.02	6.15±0.02
8	Heptadecanoate	0.97	1.88±0.07	2.19±0.09	3.19±0.07	2.28±0.07
9	Arachidonate	4.75	3.65±0.07	4.15±0.03	6.64±0.07	5.37±0.03
10	Tricosanoate	1.26	1.66±0.02	1.93±0.06	2.55±0.02	1.85±0.02
	Unsaturated fatty acids					
1	Linolenic	<0.1	2.35±0.02	2.97±0.06	3.85±0.04	3.75±0.07
2	Linoleate	<0.1	2.52±0.05	3.58±0.09	4.90±0.06	3.06±0.05
3	Erucate	2.93	1.32±0.02	2.62±0.05	4.95±0.01	3.05±0.02
4	Eicosapentaenoic	1.93	1.23±0.04	4.57±0.03	5.17±0.01	4.15±0.03
5	Docosahexaenoic	<0.1	1.23±0.02	3.15±0.06	4.59±0.07	3.09±0.08

Note: reference for requirements: De Silva (1987).

The values of the water quality parameters during the investigation are presented in Table 9. During the experiments, the water quality was adequate for post-larval vannamei shrimp production. According to the literature on optimal water quality conditions for vannamei shrimp, the water quality during the study was acceptable for shrimp culture.

Table 8

Fatty acid profiles of *Litopenaues vannamei* under different treatments

Fatty acid profile (%)	*Treatments*			
	A (0%)	*B (8%)*	*C (16%)*	*D (24%)*
C14:0 (Myristic)	6.57±0.04	3.50±0.02	4.68±0.09	4.75±0.05
C15:0 (Pentadecanoic)	2.38±0.06	2.27±0.04	2.45±0.08	1.72±0.06
C16:0 (Palmitic)	4.77±0.08	4.97±0.08	8.09±0.04	5.14±0.09
C18:0 (Stearic)	5.75±0.02	5.52±0.03	3.11±0.09	2.71±0.07
C18:1 n-9 (Oleic/ω9)	1.90±0.03	3.59±0.08	5.85±0.01	3.37±0.02
C18:2 n-6 (Linoleic/ω6)	2.30±0.07	4.49±0.07	5.37±0.02	4.60±0.09
C18:3 n-3 (Linolenic/ω3)	2.30±0.09	3.39±0.03	4.32±0.01	2.54±0.05
C20:0 (Arachidic)	2.50±0.02	2.12±0.04	4.05±0.03	2.30±0.08
C20:4 n-6 (Arachidonic)	4.19±0.05	4.15±0.02	5.13±0.08	4.07±0.02
C20:5 n-3 (EPA)	3.03±0.04	4.37±0.01	6.92±0.03	4.53±0.05
C22:6 n-3 (DHA)	4.46±0.07	5.58±0.02	7.90±0.08	4.53±0.02

Table 9

Water quality measurements during the study

Variable	*Measurement unit*	*Interval*	*Reference*
Temperature	^{o}C	27.9-29.9	26-32[b]
Dissolved oxygen	mg L^{-1}	4.09-5.82	>3[a]
pH	-	7.43-8.1	7-8.5[a]
Salinity	Ppt	30-33	5-35[b]
Ammonia	mg L^{-1}	0.023-0.09	≤0.1[a]

Note: [a] - Rudtanatip et al (2019); [b] - Rakhfid et al (2018).

Discussion. The highest growth performance of vannamei shrimp was observed in treatment C. Shrimp require a protein content in the feed ranging from 35 to 40% and fat from 6 to 15%. According to Moreno-Arias et al (2017), vannamei shrimp need feed with a protein content of 35-40%, fat 7-15%, crude fiber 4-5%, and energy 17 kJ/g. Nutrients in the feed are used by the body for metabolic processes to increase growth (Chen et al 2021). The test feed in the study had a nutritional content following the nutritional needs of vannamei shrimp. According to Basir et al (2022), the metabolic processes occur through tissue accretion from mitotic cell division, and excess nutrients in the feed are used for energy and protein input. The amount of feed and feed nutrients affect the growth performance of vannamei shrimp. According to Sahrijanna & Sahabuddin (2014), the shrimp growth rate is strongly influenced by the quality of water and the quantity of feed. If the environmental conditions are good and the feed is of good quality, the growth rate of shrimp will be higher.

In addition to the nutritional content of the test feed from treatment C, we also believe the test feed had a higher palatability for vannamei shrimp, as it this treatment had the highest TFC. Abidin et al (2015) stated that several factors, including the physical properties of feed, such as smell, taste, size, and color, influence TFC in fish. The value of FUE is in line with the value of the shrimp growth rate. A higher FUE brings a higher growth rate. According to Amin et al (2011), the more feed consumed and the more efficient use of feed will increase the retention of protein in the body, increasing growth.

The average value of vannamei shrimp survival in each treatment during the study was 100%. Thus, the substitutution of fishmeal with maggot meal in feeds does not affect the SR of vannamei shrimp. Mortality of vannamei shrimp in farming is usually due to the cannibalism. Zainuddin et al (2014) stated that feeding done four times per day allows vannamei shrimp to avoid cannibalism and food competition. The SR in this study is higher than values obtained in other similar studies. Cummins et al (2017) obtained a SR value of 91.11% and Sookying et al (2011) obtained a value of 96.1%. According to Henditama

et al (2015), the survival rate is strongly influenced by environmental factors such as oxygen content, temperature, pH, disease, genetic factors and stocking density.

Lysine reached 8.95% in treatment C. This result is in line with the statement of Lovell (1988), who noted that in the post-larval stage of shrimp the requirement for lysine is 6.97%. Lysine helps in the formation of carnitine, increases growth, protects against ammonia poisoning and increases the body's defense against extreme temperature changes (Lovell 1988; Ovie & Eze 2013; Herawati et al 2018). In addition, lysine in feed can increase protein synthesis rate in the shrimp, so that its protein content will increase and improve its growth and survival (Valverde et al 2013). Lysine also functions as an essential ingredient for blood antibodies, helping the circulatory system and maintaining average cell growth (Baeza-Rojano et al 2013). It can improve the digestibility of other amino acids, like tyrosine, regulating fish's appetite and the body's response to stress (Baki et al 2015). Valverde et al (2013) describe how lysine helps in the structural framework of vitamin B1, helps absorb calcium, stimulates appetite, and helps converting fatty acids into energy. It can also increase the content of PUFA, because lysine can produce carnitine, which is a key factor in fatty acid metabolism in shrimp.

The EPA highest content was found in treatment C, 6.92%. This may suggest that the high concentration of EPA in the meal can potentially promote shrimp growth, development, and survival. Santoso (2006) showed that a high level of fatty acids in shrimp feed might enhance shrimp growth. HUFAs are more active than linoleic and linolenic acids, as stated by Sinclair (1993). The nutritional quality of the feed, notably the concentration of essential n-3 HUFAs, such as EPA and DHA, seems to have a significant impact on the shrimp's ability to survive (Rudtanatip et al 2019). Hender et al (2021) noted that n-3 HUFA might boost the ability of the shrimp to adapt to stress and enhance their survival. Arachidonic acid (20:4n-6; AA) is a precursor to eicosanoic fatty acids (prostaglandins, thromboxanes, and leukotrienes) and a major component of phosphatidylinositol in shrimp (Meyer et al 2004).

Conclusions. This research showed that replacing fish meal with maggot meal had a significant impact ($p<0.05$) on the relative growth rate, total feed intake, utilization efficiency, feed conversion ratio, and protein efficiency ratio, but had no effect ($p>0.05$) on vannamei shrimp survival. The optimal ratio of maggot meal as a replacement for the fishmeal was 16%. This ratio also produced the highest lysine and DHA content. Based on the findings of this study, it is necessary to conduct additional research on substituting fishmeal with maggot meal to determine the optimal composition and effect of this substitution on the growth and feed utilization efficiency of vannamei shrimp.

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

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