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The Growth Performance and Nutrient Quality of Asian Swamp Eel *Monopterus albus* in Central Java Indonesia in a Freshwater Aquaculture System with Different Feeds

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ABSTRACT

The Asian swamp eel (*Monopterus albus*) is a high protein content fish with delicious taste that can survive for 6–8 months. The growth performance and nutrient quality of Asian swamp eels in a freshwater aquaculture system in Central Java, Indonesia was studied using a completely randomized design. Golden snails, snails, silkworms, and earthworms were the feeding treatments at 5% of total body weight. The test animals weighed 5.68 ± 0.35 g after a 60-day culture, and the density was 36 eels/m^2. Providing different types of feed had significant effects ($P < 0.05$) on relative growth rate (RGR), feed intake, and survival rate (SR) but did not significantly affect the protein efficiency ratio ($P > 0.05$). The best final weight, RGR, and SR results were 11.80 g, 2.64%, and 80.95% during a 60-day culture with silkworms used as feed. The nutrient quality in a similar treatment found with the best proximate composition was 76.90% protein, 3.24% fat, 25.19% palmitic acid, 15.41% oleic acid, 15.9% glutamic acid, 8.2% isoleucine, and 8.9% lysine.

KEYWORDS
Amino acid; Asian swamp eel; fatty acid; growth rate; natural feed

Introduction

Asian swamp eel is a type of food with a high protein content (approximately 81.25%). Most eels produced in Indonesia are exported to China, Hong Kong, Japan, Singapore, Taiwan, Korea, and Thailand. The demand for eels has been increasing every year. Asian swamp eel's production value reached 2,189 tons in 2013 and 2,676 tons in 2014. By the end of 2015, the value went up to 4,744 tons, marking a 77.2% increase compared to the previous year (Alit, 2009). Increased eel production has led to the provision of high-quality eels. Important aspects in Asian swamp eel aquaculture are feed and aquaculture system. Generally, the eel culture system uses mud as media, but in this study, freshwater was used. In addition, feed becomes an important factor to support Asian swamp eel's growth and nutrient quality. Feeding in accordance with eel's nutrient needs can stimulate growth, production, and higher nutrient content (Fujiani et al., 2015). Demand for eels as a high nutritional quality food has increased both domestically and abroad. Reliance on wild-caught eel may reduce the natural population in the future. In this study, the efforts to guarantee eel production were investigated by determining the best diet to meet nutritional needs.

Eels are frequently cultured in mud media aquaculture, which is used as a refuge. However, mud media aquaculture presents many challenges, such as difficulties in controlling eels and long preparation time. Alternative aquaculture systems are being built in a controlled environment,

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using freshwater media as the maintenance media. Feed and water quality can be controlled in the freshwater system to provide more optimal conditions and produce high nutrient value eels.

Feed with appropriate nutrient quality is important to meet the nutritional needs of the eels. Golden snails, snails, silkworms, and earthworms are naturally high protein feeds. Golden snails contain 51% protein, 13.61% fat, 6.09% fiber, and 24% ash (Mashuri et al., 2012). Snails also have high protein content of 51.2–62% (Asminatun, 2010). Golden snails and snails are now viewed as pests; therefore, the usage of golden snails as feed for eels is considered a pest control in the agricultural sector. Silkworm nutrient contents are 57% protein, 13.3% fat, 2.04% rough fiber, 3.6% ash, and 87.7% water (Pursetyo et al., 2011). The earthworm is another good protein source (64–76%) and has a simple reproduction method, making it suitable to be used as eel feed.

The objective of this study was to identify the amino acid and fatty acid profiles and conduct proximate and growth performance analysis of the Asian swamp eel (*M. albus*) in Central Java, Indonesia in a freshwater aquaculture system with different feed types to increase the eel's production and quality. The results of this study will help determine the nutrient quality and growth of Asian swamp eel in Central Java, Indonesia in a freshwater aquaculture system with different feed types. Samples were taken from Magelang Regency, Temanggung Regency, and Semarang Regency, Central Java Province, Indonesia for use in this study.

Materials and methods

Experimental design

This study had a completely randomized design, with four treatments and three repetitions. *M. albus* feeding treatments used golden snails, snails, silkworms, and earthworms fed at 5% of total body weight. The tested animal was the seedling of *M. albus*, with a weight of 5.68 ± 0.35 grams per each of *M. albus*. It was cultured in a cement pond covered with mulch plastic (50 cm × 40 cm × 40 cm) for a 60-day culture period at a spread density of 36 Asian swamp eels/m^2. The water quality measurements during the study are presented in Table 1. The eels were fed golden snails (Treatment A), snails (Treatment B), silkworms (Treatment C), and earthworms (Treatment D).

Proximate analysis

The proximate chemical composition of the samples was determined using standard procedure (Association of Official Analytical Chemists (AOAC), 2005). Crude protein content was calculated by multiplying the total nitrogen factor. Carbohydrate content was estimated by the difference.

Fatty acid profile

The fatty acid profile of sample meat (golden snail, snail, silkworm, earthworm, and Asian swamp eel) was determined by analyzing total fatty acid content using gas chromatography (GC; QP-2010) and mass spectrometry with a WCot fused Silica Counting CP-SIL-88 column

Table 1. Water quality measurements of Asian swamp eels (*M. albus*) cultured during the study.

Treatment	Water quality parameter value range		
	Temperature (°C)	pH	DO (mg/L)
A	26.6–26.5	7.05–7.85	4.00–4.58
B	26.7–26.3	7.06–7.84	4.03–4.56
C	26.6–26.3	7.06–7.80	4.08–4.51
D	26.7–26.3	7.06–7.84	4.03–4.56
Reference (properness)	25–28[a]	6–8.7[b]	3–5[c]

Notes: [a]Asminatun (2010); [b]Fujiani et al. (2015); [c]Alit (2009).

(50 m length, 0.22 mm diameter, and at 120°C–200°C column temperature). The method used was *in situ* transesterification. A 100 mg meat (golden snail, snail, silkworm, earthworm, and Asian swamp eel) sample was homogenized in 4 mL of water. The resulting 100 μL homogenate was then transferred to a reaction tube. Methylene chloride (100 μL) was added along with 1 mL 0.5 N NaOH in methanol. Once the nitrogen was added and the tube was sealed, it was heated to 90°C for 10 min. The reaction tube was then cooled, and 1 mL of 14% BF3 in methanol was added. After adding nitrogen, it was heated at the same temperature for the next 10 min. Then, the reaction tube was cooled to ambient temperature, and 1 mL of water and 200–500 μL of hexane were added. The mixture was vortexed for 1 min to extract the fatty acid methyl esters. After centrifugation, the upper layer of the sample was ready for GC analysis (AOAC, 2005).

Essential amino acid profile

The essential amino acid profile of the meat (golden snail, snail, silkworm, earthworm, and Asian swamp eel) sample was determined by examining its essential amino acid content. The essential amino acid analysis was performed using a high-performance liquid chromatographer (HPLC) type 1100 with a Eurospher 100-5 C18, 250 mm × 4.6 mm column with a P/N: 1115Y535 pre-column. The effluents 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: Ext: 340 mm Em: 450 nm. Approximately 2.5 g of sample was added to a sealed glass. Then, 15 mL of 6 N HCl was added. The mixture was vortexed and subjected to hydrolysis in an autoclave at 110°C for 12 h, before being cooled down to room temperature and neutralized with 6 N NaOH. After adding 2.5 mL of 40% lead acetate and 1 mL of 15% oxalate acid, the mixture was filtered through a 0.45 μm Millex filter. A 25 μL aliquot of the filtered mixture plus 475 μL of OPAA solution was vortexed and incubated for 3 min. Finally, a 30 μL aliquot of the final mixture was loaded on the HPLC column (AOAC, 2005).

Feeding of Asian swamp eels

A feeding container was placed on the side of a pond. The golden snails and snails were rinsed with clean water prior to separating the meat by breaking their shells. Subsequently, the meat was rinsed and cut into 0.5 cm pieces. *Tubifex* sp. silkworms and earthworms were cleaned with water. Any remaining feed was weighed the next morning. The Asian swamp eels were sampled after 60 days of culture.

Cultivation of Asian swamp eels

Asian swamp eels were cultured for 60 days and fed once a day at 18:00, at a feeding rate of 5% of total eel's body weight. The eel's weight and length were measured every 7 days. The physical and chemical condition of water as the cultivation media, including the temperature, was measured every day; pH and DO of water were measured every 7 days (Fujiani et al., 2015).

Statistical analysis

The eel's growth was measured at the end of the 60-day culture, and survival rate (SR) was determined by counting the number of eels at the beginning and end of the culture, presented by percentage (%). WG = FBW − IBW, where WG is the weight gain in grams, IBW is the initial body weight in grams, and FBW is the final body weight in grams. FI = Total feed consumption (g)/ number of fish, where FI is the feed intake in grams. Protein efficiency ratio (PER) and relative growth rate (RGR) are presented by percentage (%).

Data were analyzed using SPSS Statistic Software (SPSS Inc., Chicago, IL, USA). Treatment effects were subjected to one way analysis of variance (ANOVA), and significance level was determined at $\alpha = 0.05$.

Table 2. Proximate feed analysis of Asian swamp eels (*M. albus*).

	Golden snail		Snail		Silkworm		Earthworm	
Nutrient Content	%	SD	%	SD	%	SD	%	SD
Protein	52.23	0.02	55.45	0.03	73.40	0.09	66.45	0.06
Fat	6.23	0.04	7.57	0.09	9.74	0.06	7.89	0.01
Carbohydrate	14.69	0.04	15.30	0.06	12.77	0.02	12.68	0.05
Ash	9.80	0.08	9.90	0.02	3.64	0.07	8.79	0.03
Crude Fiber	17.05	0.03	11.78	0.01	0.45	0.01	4.19	0.08

Results

The water quality measurements during the study are presented in Table 1. Water quality during the study was in a suitable range for the aquaculture of the eel (*Monopterus albus*).

The nutrient quality and a proximate analysis of the feed during culture are presented in Table 2. The protein and fat proximate analyses revealed the highest levels in silkworms at 73.40% and 9.74%, respectively. Conversely, the lowest values were found for golden snails, with 52.23% protein and 6.23% fat. The feed given to the eels affected their growth performance and nutrient quality. The fatty acid profile of the feed given to the eels is presented in Table 3.

The highest fatty acid content was found in silkworms, with 14.59% palmitic acid and 6.57% of linoleic acid. Conversely, the lowest fatty acid content was found in golden snails, with 10.01% palmitic acid and 0.54% linoleic acid. The amino acid profile of the feed given to the eels is presented in Table 4.

The highest amino acid profile was found in silkworms, with 11.80% lysine, but the lowest amino acid content was found in golden snails and earthworms, with 0.3% cysteine. The growth performance of the Asian swamp eels after the 60-day culture is presented in Table 5.

The different natural feeds had a significant effect ($P < 0.05$) on the final weight, RGR, and SR of the eel. The FBW, RGR, and the highest SR in Asian swamp eel fed silkworms was 11.80 g, 2.64%, and 80.95%, respectively.

Feed intake of the different diets had a significant effect ($P < 0.05$) on the Asian swamp eels cultured in the freshwater system, but the PER was not significantly different ($P > 0.05$). Feed intake and the highest PER was 10.38 and 0.21%, respectively, in Asian swamp eels fed silkworms. Furthermore, the nutrient quality of the Asian swamp eel (*M. albus*) after the 60-day culture was analyzed. The proximate analysis of the Asian swamp eels given different feed types is presented in Table 6.

Table 3. Fatty acid profile of feed given to Asian swamp eels (*M. albus*).

	Golden snail		Snail		Silkworm		Earthworm	
Fatty acid profile	%	SD	%	SD	%	SD	%	SD
Myristic	0.28	0.04	0.49	0.04	0.41	0.09	0.482	0.02
Pentadecanoic	0.10	0.08	0.18	0.06	0.15	0.08	0.17	0.04
Palmitic	10.01	0.06	12.29	0.08	14.59	0.04	11.97	0.08
Stearic	0.41	0.07	1.65	0.02	2.91	0.09	0.52	0.03
Oleic/ω9	1.62	0.05	1.95	0.03	2.61	0.01	1.89	0.08
Linoleic/ω6	0.54	0.02	4.46	0.07	6.57	0.02	5.49	0.07
Linolenic/ω3	0.19	0.06	2.38	0.09	4.32	0.01	3.39	0.03
Arachidic	0.02	0.07	2.83	0.02	3.05	0.03	1.02	0.04
Arachidonic	0.07	0.01	0.15	0.05	0.13	0.08	0.15	0.02
Eicosapentaenoic	0.27	0.05	2.53	0.09	3.52	0.06	0.50	0.04
Omega 3	0.03	0.02	4.01	0.04	5.91	0.04	3.99	0.08
Omega 6	0.63	0.08	5.64	0.07	6.13	0.08	5.68	0.02
Omega 9	1.62	0.05	0.95	0.01	0.61	0.01	0.89	0.08
AA	0.08	0.09	0.15	0.04	0.13	0.07	0.15	0.09
DHA	0.06	0.02	0.08	0.04	1.07	0.03	0.07	0.01
EPA	0.27	0.03	1.53	0.02	2.52	0.06	1.75	0.07

Table 4. Amino acid profile of the feed given to Asian swamp eel (*M. albus*).

	Golden snail		Snail		Silkworm		Earthworm	
Amino Acid Profile	(%)	SD	(%)	SD	(%)	SD	(%)	SD
L-Histidine	1.4	0.09	1.3	0.08	3.3	0.05	2.6	0.06
L-Serine	3.8	0.04	2.9	0.09	4.1	0.08	3.9	0.01
L-Arginine	4.7	0.06	3.3	0.06	6.6	0.06	3.4	0.02
Glycine	7.6	0.03	5.2	0.04	7.6	0.09	5.0	0.08
L-Aspartic Acid	6.1	0.08	7.5	0.09	8.5	0.04	6.9	0.04
L-Glutamic Acid	10.0	0.09	7.4	0.05	11.2	0.02	8.9	0.01
L-Threonine	5.4	0.03	5.9	0.07	5.2	0.08	4.7	0.02
L-Alanine	10.6	0.06	10.4	0.06	10.1	0.03	9.1	0.06
L-Proline	5.7	0.04	6.3	0.09	6.8	0.09	5.7	0.04
L-Cystine	0.3	0.01	0.4	0.05	0.8	0.07	0.3	0.05
L-Lysine	10.1	0.09	10.8	0.07	11.8	0.03	9.5	0.03
L-Tyrosine	3.5	0.08	4.1	0.04	4.9	0.05	5.0	0.08
L-Methionine	1.8	0.05	3.0	0.08	4.4	0.06	5.6	0.01
L-Valine	7.7	0.08	8.1	0.05	9.5	0.04	8.7	0.05
L-Isoleucine	6.1	0.05	7.9	0.02	9.3	0.02	8.9	0.03
L-Leucine	6.9	0.09	7.8	0.08	8.2	0.08	5.8	0.06
L-Phenylalanine	6.6	0.05	6.8	0.09	7.2	0.09	5.6	0.09
Tryptophan	1.7	0.09	1.5	0.08	1.9	0.05	1.5	0.01

Table 5. Growth rate of the Asian swamp eels (*M. albus*) after the 60-day culture.

	Golden snail		Snail		Silkworm		Earthworm		
Parameters		SD		SD		SD		SD	Grouping
IBW	5.67 g	0.46	5.95 g	0.09	5.43 g	0.67	5.33 g	0.62	a
FBW	8.44 g	0.26	9.19 g	0.22	11.80 g	0.19	10.37 g	0.34	ab
WG	2.77 g	0.59	3.24 g	0.43	6.38 g	0.19	5.37 g	0.50	ab
RGR	0.84%	0.21	1.31%	0.14	2.64%	0.33	1.87%	0.11	ab
FI	4.48 g	0.56	5.19 g	0.52	10.38 g	0.19	7.87 g	0.06	ab
PER	0.10%	0.02	0.16%	0.02	0.21%	0.06	0.1%	0.01	b
SR	61.90%	8.25	66.67%	8.25	80.95%	8.25	66.67%	8.25	ab

Values are mean ± standard deviation (SD). Values in the same row with different grouping are significantly different ($P < 0.05$).

Table 6. Proximate analysis of the Asian swamp eels (*M. albus*) fed different diets.

	Golden snail		Snail		Silkworm		Earthworm	
Nutrient Content	%	SD	%	SD	%	SD	%	SD
Protein	72.23	0.03	73.45	0.04	76.90	0.04	74.15	0.02
Fat	1.23	0.05	1.57	0.06	3.24	0.08	3.19	0.05
Carbohydrate	20.69	0.02	19.30	0.03	15.77	0.01	17.68	0.07
Ash	2.80	0.01	2.90	0.07	1.64	0.09	1.79	0.09
Crude fiber	3.05	0.05	2.78	0.08	2.45	0.03	3.19	0.01

The highest protein and fat content observed in eels fed silkworms was 76.90% and 3.24%, respectively. The lowest content was found in eels fed golden snails (72.23% protein; 1.23% fat). The total fatty acid profile of the Asian swamp eels fed different diets is presented in Table 7.

The fatty acid profile showed that eels fed silkworms had the highest palmitic acid (25.19%), oleic acid (15.41%), linoleic acid (5.37%), and omega 3 (6.91%) contents. The lowest contents in eels fed golden snails were palmitic acid (15.85%) and oleic acid (12.62%). The amino acid profile of Asian swamp eels fed different diets is presented in Table 8.

The highest glutamic acid (15.9%), isoleucine (8.8%), and lysine (8.9%) contents were found in eels fed silkworms, whereas the lowest glutamic acid (13.4%) and isoleucine (7.5%) contents were in eels fed golden snails.

Table 7. Fatty acid profiles of the Asian swamp eels (*M. albus*) fed different diets.

	Golden snail		Snail		Silkworm		Earthworm	
Fatty acids profile	%	SD	%	SD	%	SD	%	SD
Myristic	2.28	0.03	2.49	0.01	2.41	0.07	2.82	0.09
Pentadecanoic	0.75	0.05	1.18	0.06	1.15	0.03	1.17	0.03
Palmitic	15.85	0.02	17.29	0.03	25.19	0.08	21.97	0.02
Stearic	5.41	0.06	5.65	0.08	6.91	0.09	6.52	0.08
Oleic/ω9	12.62	0.01	13.95	0.02	15.41	0.03	13.89	0.02
Linoleic/ω6	3.54	0.02	4.46	0.03	5.37	0.02	4.49	0.01
Linolenic/ω3	1.19	0.06	2.38	0.09	4.32	0.01	3.39	0.07
Arachidic	0.22	0.03	1.83	0.01	3.05	0.06	2.02	0.03
Arachidonic	0.07	0.08	0.15	0.04	0.23	0.03	0.15	0.07
Eicosapentaenoic	0.77	0.01	2.53	0.02	3.52	0.09	2.50	0.06
Omega 3	3.03	0.07	4.0	0.04	6.91	0.02	4.99	0.07
Omega 6	2.63	0.03	2.74	0.05	3.53	0.08	2.68	0.02
Omega 9	1.62	0.02	1.95	0.01	1.61	0.07	1.89	0.03
AA	2.08	0.09	2.15	0.02	3.13	0.02	2.15	0.06
DHA	1.26	0.03	2.08	0.09	3.07	0.09	2.07	0.08
EPA	0.27	0.01	1.53	0.08	2.52	0.02	1.50	0.09

Table 8. Amino acid profile of the Asian swamp eels (*M. albus*) fed different diets.

	Golden snail		Snail		Silkworm		Earthworm	
Amino acids profile	(%)	SD	(%)	SD	(%)	SD	(%)	SD
L-Histidine	1.9	0.07	2.6	0.02	3.0	0.03	3.6	0.03
L-Serine	3.8	0.05	3.9	0.04	4.1	0.05	4.9	0.05
L-Arginine	5.7	0.04	6.3	0.06	5.6	0.04	6.9	0.02
Glycine	7.6	0.03	2.5	0.02	4.6	0.01	8.0	0.01
L-Aspartic Acid	10.6	0.01	12.2	0.07	8.5	0.08	12.9	0.07
L-Glutamic Acid	13.4	0.03	14.4	0.03	15.9	0.04	14.2	0.03
L-Threonine	3.4	0.05	4.9	0.01	5.2	0.03	5.7	0.09
L-Alanine	7.6	0.02	5.4	0.08	6.1	0.09	7.1	0.05
L-Proline	2.3	0.09	3.4	0.01	3.8	0.04	3.3	0.07
L-Cystine	6.1	0.02	7.4	0.03	8.2	0.09	7.5	0.03
L-Lysine	8.5	0.03	7.5	0.09	8.9	0.01	7.9	0.08
L-Tyrosine	2.8	0.02	3.0	0.02	3.4	0.04	3.6	0.03
L-Methionine	3.7	0.07	4.1	0.05	4.5	0.06	5.7	0.05
L-Valine	3.5	0.01	3.9	0.03	4.3	0.02	3.9	0.01
L-Isoleucine	7.5	0.03	7.8	0.05	8.2	0.05	8.8	0.03
L-Leucine	3.6	0.01	4.8	0.02	5.2	0.09	3.6	0.01
L-Phenylalanine	1.7	0.08	2.3	0.09	2.2	0.01	2.5	0.09
Tryptophan	2.9	0.03	2.6	0.03	3.0	0.03	3.6	0.02

Discussion

RGR represents the change in weight over a certain period of time. Based on analysis of the variety of the RGR values, different feed types had a significant effect on the Asian swamp eel (*M. albus*). The results showed that the highest average RGR was found in Asian swamp eels fed silkworms at 2.64%/day and the lowest was in the golden snails diet at 0.84%/day. RGR in Asian swamp eels fed silkworms provided the highest result, because silkworms fulfilled the Asian swamp eel's nutrient content and could be absorbed maximally. Based on the results, the highest eel weight was 11.80 g, which is a similar result to previous research stating that the higher the level of feed ingestion, the more the nutrients used by the fish (Alit, 2009).

RGR in this study was higher than in a study in which Asian swamp eels were fed a combination of golden snails and pellets (0.71%/day) (Manurung et al., 2015). This study showed high results due to the high protein (73.40%), fat (12.77%), linoleic acid (6.57%), and lysine (18.8%) contents in the diets.

The level of feed intake in the Asian swamp eels was calculated as the difference in feed offered and feed remaining every morning. The highest study result for the treatment of Asian swamp eels fed with silkworms was 10.38%. Furthermore, analysis of variance showed that the different types of natural feed had a significant effect ($P < 0.05$) on feed efficiency of the Asian swamp eels. The feed intake of a species is determined by the quality of the feed nutrients; thus, high-quality feed is digested well (Khanh and Ngan, 2010). Fish consumed silkworms the most, as the silkworms have no skeleton and are easy to digest, with minimal movement and small size. In addition, *Tubifex* sp. has to be digested within 1.5–2 h (Pursetyo et al., 2011). The high level of silkworms feed intake by fish reflects efficient feeding; therefore, if the feed has low protein content, it is only sufficient to support growth and cannot be used to replace damaged cells. This is supported by previous research reporting that feed intake level is determined by fish species, age of fish, quality of the feed given, and the frequency and amount of feed given (Fujiani et al., 2015).

The different types of feed had no significant effect on the PER value ($P > 0.05$). The highest PER value was found in the silkworm treatment (0.21%), because protein quality of silkworms was higher than other feeds (earthworms, golden snails, and snails). This result is supported by previous research stating that consuming high-quality feed efficiently triggers rapid growth (Hepher, 1988).

Golden snails and snails produced a lower PER value, because both had protein quality similar to or lower than silkworms. The amount and quality of protein can determine the growth rate. If protein quality is insufficient, then the protein would be used to maintain functions of more important organs (Mashuri and Abidin, 2012). Conversely, if the protein feed is excessive and not used to synthesize protein in the fish body, then it will be excreted as nitrogenous waste in the form of ammonia.

PER value in this research was higher than found (0.23% ± 0.01%) in other studies on Sangkuriang catfish (*Clarias gariepinus*) fed by silkworms (Chahyaningrum et al., 2014). The difference was assumed to be due to a difference in the ability to absorb the nutrients contained in the silkworm. Therefore, feed quality is not only determined by how much of the nutrient is present but also by the ability to digest and absorb the feed (Fujiani et al., 2015; Mashuri and Abidin, 2012).

The lowest SR of Asian swamp eel (*M. albus*) was 61.90% in the golden snail treatment and the highest (80.94%) was in the silkworm treatment. A high SR during the 60-day culture was observed because of the 1-week acclimatization provided before treatment. Asian swamp eels prefer a muddy habitat, but fresh water was used in this study. A new environment can be stressful; therefore, the 1-week adaptation period was important (Chan and Phillips, 1967). This result is supported by other research stating that changing the habitat of Asian swamp eels to water without a substrate affected its physiological condition (Syarif, 2015). The process of organism adaptation from nature to aquaculture system would influence the physiological response and behavior.

The SR in this study was 11.11% ± 7.7%, which is higher than that of other research on Asian swamp eels cultured in fresh water (Manurung et al., 2015). Acclimatization likely decreased mortality, as shown by studies reporting that the mortality increases in the absence of acclimatization in the beginning of a study (Syarif, 2015). This is in agreement with other research showing that acclimatization helps animals adapt to a new environment and that no disease is introduced by the previous habitat (Alit, 2009).

The nutrient quality of Asian swamp eel (*M. albus*) was determined by a proximate analysis and fatty acid and amino acid profiles. The proximate analysis of Asian swamp eels fed by silkworms showed that the highest protein and fat contents were 76.90% and 3.24%. In contrast, the lowest protein and fat contents were 72.23% and 1.23%, respectively, in Asian swamp eels fed by golden snails. The silkworm feed contains high nutrients: 73.40% protein, 12.77% fat, 6.57% linoleic acid, and 18.8% lysine. The content of protein in eel is very high because eels have a high capacity to digest, allowing the nutrient in the silkworm to be absorbed maximally. This result agrees with other studies that reported the protein content of the eels to be higher than beef (Astiana et al., 2015).

Oleic acid has the highest content among the fatty acids in the eels fed silkworms, with 25.19% palmitic acid, 15.41% oleic acid, 5.37% linoleic acid, and 6.91% omega-3 fatty acids. Oleic fatty acid is a protein denaturation substrate and catalyst extender and is involved in the biosynthesis of polyunsaturated fatty acids (PUFAs) (Pratiwi et al., 2009). The biosynthesis of PUFAs starts with oleic acid, which is converted to linoleic acid as the basic substrate to form long-chain omega-6 fatty acid and linoleic acid as the basic substrate to form long-chain omega-3 fatty acids.

Oleic acid is an energy source and antioxidant that helps defend against cancer, reduces the level of cholesterol, and functions as a solvent for vitamins A, D, E, and K (Spallholz et al., 1998). Oleic acid is synthesized into PUFAs, which are used in cell components, particularly nerve cells and retinal cells. Linoleic acid functions as an unsaturated omega-6 fatty acid and is required for healthy brain and skin function as well as bone density, energy production, and reproductive health (Hilditch, 1949). The Asian swamp eel (*M. albus*) contained 6.91% omega-3 fatty acids. The range of omega-3 fatty acids previously reported in eels is 4.48–11.80%, and omega-3 content depends highly on the type, age, feed supply, and area of fish capture (Astiana et al., 2015).

Based on the result, glutamic acid content was 15.9%. Glutamic acid plays an important role as part of proteins and amino sugars that maintain immune system function, cell volume, and as a recycled protein substrate to improve the synthesis of other proteins. Other functions of glutamic acid are maintenance of the digestive tube, absorption of nutrients, and balancing the level of alkali acid (Ovie and Eze, 2013; Spallholz et al., 1998). In addition, glutamine helps remove ammonia toxin from the liver, transports nitrogen, provides glycogen to muscles, helps prevent damage to muscle, and promotes cell division. It also acts to form immune system cells, such as thymocytes, lymphoid cells, and macrophages.

Isoleucine (8.2%) and lysine (8.9%) were the most prominent essential amino acids. The functions of isoleucine are to increase body energy, increase stamina, and repair damaged muscle tissues (Spallholz et al., 1998). Isoleucine also plays a role in the production of carnitine and collagen. The functions of carnitine are to stimulate growth by increasing collagen and supporting production of other proteins, such as enzymes, antibodies, and hormones. In addition, lysine enhances calcium absorption and converts fatty acids into energy. Previous studies have reported that lysine acts as the frame to form vitamin B1, acts as an antivirus, absorbs calcium, stimulates the appetite, and helps carnitine convert fatty acids into energy (Herawati et al., 2015; Ovie and Eze, 2013).

Conclusion

Growth rate and nutrient quality of Asian swamp eels in freshwater aquaculture are influenced by natural feed. The best natural feed for Asian swamp eels found in this study was silkworms, with the eel's final weight, RGR, and SR as 11.80 g, 2.64%, and 80.95%, respectively, and the proximate analysis of 76.90% protein, 3.24% fat, 25.19% palmitic acid, 15.41% oleic acid, 15.9% glutamic acid, 8.2% isoleucine, and 8.9% lysine.

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