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Effects of dietary insect (*Ephestia kuehniella*) egg meal on growth performance and fatty acid profile of common carp (*Cyprinus carpio*)

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Abstract: The effects of mill moth (*Ephestia kuehniella*) egg meal (IEM) upon growth performance and fatty acid profile of common carp (*Cyprinus carpio*) (1.12 ± 0.01 g) were evaluated in triplicate groups for 12 weeks. Three isonitrogenous (35% CP) and isocaloric (17 MJ kg^{-1}) diets were formulated replacing fishmeal with 0% (G-0), 50% (G-50), and 100% (G-100) IEM. The results of the trial indicated that G-50 had the highest growth performance values and a more efficient FCR (1.79). Replacement levels of IEM did not have any significant effect on survival. Total monounsaturated fatty acids (MUFA) were found to be statistically different for all diets, and Σ SFA in fish was decreased with the increasing IEM levels. The ratio of n3/n6 was higher in G-0 reflecting a better balance. The results suggested that 50% replacement of IEM with fishmeal enhanced growth performance in common carp without any adverse effect on fatty acid profile, but investigation of the long-term effects has still been needed.

Keywords: Common carp, fatty acid composition, growth, insect meal, insect oil

1. Introduction

Aquaculture has referred about half of the 178,528,817 million t (Mt) of global production provided by 82,095,054 Mt [1]. Balanced and appropriate diets essential to the nutrition and health of fish have played a major role for the development of aquaculture industry. Hereby, the overall production of aquaculture feed reached at 40.1 million Mt in 2018 [1]. Such an increasing trend has resulted in an immense pressure on feed industry since fish meal and fish oil are the major but limited resources in fish feeds.

The fishmeal and fish oil prices have increased significantly due to the decreasing supply. About 4–5 t of whole-fish is required for producing 1 t of fishmeal, and 20 million t of fish (12% of total catches) have been reduced to fishmeal and fish oil in 2016 [2].

Fish meal (FM) and soybean meal (SBM) are the primary protein sources among the aquatic feeds because most of the fish farmed are carnivores and require high protein in their diets. However, the increased demands for feeds and steady decline in catches have resulted in a rapid decrease in availability but the high price of fishmeal [3].

Since feed represents 30%–70% of total cost in aquaculture production, the main criterion for alternative protein sources is the competitive price of fishmeal and fish oil; however, sustainability, nutritional composition, antinutritional factors, palatability, and digestibility should also be considered. Many alternative protein sources such as plants [4], by-products [5], and various marine organisms [6, 7, 8] have become the subject of various research to replace fish meal.

Plant protein has been the most common alternative to fish meal, but amino acid deficiencies and antinutritional compounds impairing the immune function may cause health problems [9,10]. Food and Agricultural Organization of the United Nations have highlighted some insects as a potential feedstuff for animals [11], and insects have begun to play an important role in aquaculture due to their low carbon footprint, the ability to grow on waste and high protein levels with well-balanced essential amino acid profiles [12,13,14].

However, the researchers have mainly focused on the protein sources in aquatic feeds and used nondefatted [15] and defatted insect meals [16,17] in experimental diets; dietary lipids play an important role in fish nutrition as a source of energy and essential fatty acids [18]. Some insect species including high amounts of lipids have a high potential as alternative sources for aquafeeds [15,17,19]. Only *Hermetia illucens* oil replacement with fish and soybean oils has currently been studied in diets of Atlantic salmon, rainbow trout, mirror carp and Jian carp [14,17,19,20]. The use of seven insect species including black soldier fly (*Hermetia illucens*), housefly (*Musca*

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domestica), mealworm (*Tenebrio molitor*), lesser mealworm (*Alphitobius diaperinus*), house cricket (*Acheta domesticus*), tropical house cricket (*Gryllodes sigillatus*) and field cricket (*Gryllus assimilis*) in aquatic feeds has been permitted in the European Union since 2017. Even, mill moth cultured worldwide in biological pest control agent culture processes has not yet been included in this list. Due to its culture process including quality nutrient input and controlled yield steps, mill moth egg and larvae have the potential of being included in aquatic diets for safe and healthy production.

Therefore, the objective of this study was to determine the effect of nondefatted mill moth (*Ephestia kuehniella*) egg meal (IEM) upon growth performance and fatty acid profile of common carp (*Cyprinus carpio*) to provide primary data for IEM as dietary protein and lipid source. The potential of an insect egg meal as a dietary ingredient in fish feeds was studied for the first time.

2. Materials and methods

2.1. Experimental diets

Three isonitrogenous (35% crude protein) and isocaloric (17 MJ kg^{-1}) diets were formulated replacing fish meal with 0%, 50%, and 100% mill moth egg meal (Table 1). Mill moth eggs were collected daily from the mass production incubator and stored at –20 °C. The egg yield was defrosted and dried at 35 °C for 12 h in an incubator (Biobase BJPX-H64II). Dry eggs were grounded into a fine powder using an electric grain mill (28,000 rpm). The biochemical composition of *E. kuehniella* eggs (Table 1) was analysed in terms of dry matter, crude protein, crude fat, and ash contents according to AOAC International [21]. Vegetable oil was used in the experimental diets in order to neutralize the effect of fish oil on the fatty acid profile and because it is preferred in practical carp feeds due to it is low price.

All feed ingredients were mixed in a batch mixer for 15 min, and water was added until the moisture content was 12%. The mixture was pelleted with a 4-kw pelleting machine into 2 mm diameter. The pellets were dried at 40 °C for 24 h in a fan dryer. The experimental feeds were stored at 4 °C in plastic bags.

2.2. Fish and experimental design

The 12 weeks feeding experiment was conducted in 3 triplicate groups. Totally 270 common carp (*Cyprinus carpio*) juveniles with an initial mean weight of 1.12 g and a total length of 3.18 cm were acclimated to the experimental conditions for 15 days prior to the experiment. The fish were randomly distributed into 9 glass aquariums of 96 L/each. The temperature was maintained at 26 ± 0.5 °C using thermostatic heaters. The water was filtered through sponge filters and replaced at 1/3 every week.

All aquariums were aerated by air-stones. A natural photoperiod sequence was provided by timer-controlled fluorescent daylight bulbs. The water quality parameters (water temperature, DO, pH and TDS) were measured daily using YSI-Proplus. The fish were handfed ad libitum with experimental diets (Table 1) twice a day (08:00–16:00).

2.3. Growth performance

All fish were anesthetized with 10 ppm eugenol [22] and weighted every 15 days to the nearest 0.001 g. Following equations were used for calculation:

Mean weight gain (WG) = $W_t - W_i$

Specific growth rate (SGR, % day^{-1}) = $[(\ln W_t - \ln W_i)/t] \times 100$

Feed conversion ratio (FCR) = Weight gain (WG)/Feed intake (FI)

Survival (%) = $(n_t/n_i) \times 100$

where W_i: Initial body weight (g), W_t: Final body weight (g), n_t: Final number of fish in each group, n_i: Initial number of fish in each group, and t: Experimental period in days.

2.4. Fatty acid profile

At the end of the feeding trial, 5 fish per tank were euthanized with an overdose of 40 ppm eugenol and immediately frozen at –20 °C until analysis. Total lipid was extracted from whole body homogenate via the soxhlet extraction. Methyl esters of fatty acids were separated and analysed by GC-FID (Agilent Technologies 7820 A). Methyl esters were identified with a standard (FAPAS), and the relative amount of each fatty acid was expressed as a percentage of the quantified total fatty acids [23].

2.5. Statistical analysis

Growth data were analyzed using IBM-SPSS v.23.0 for Windows and presented as mean ± standard error. One-way analysis of variance (ANOVA) was performed, and Duncan's multiple range test was used to compare differences among the mean values. The level of significant difference was set at 0.05.

In fatty acid data analyses, a normality test was performed to determine whether the data set was statistically parametric or nonparametric. Shapiro-Wilk and Skewness-Kurtosis values were analysed in the normality test. All values in the data set were used without excluding outliers. Pearson correlation analysis was used between groups. The descriptive statistics were presented as mean ± standard error (Average ± SE). The level of significant difference was set at 0.05. The analysis of covariance (ANCOVA) was performed between the groups (separately for fish and feed).

3. Results

During the 12-week trial, the mean water temperature was measured as 24.0 ± 1.0 °C, dissolved oxygen as 8.40 ± 0.03

Table 1. Formulation (g kg^{-1} dry matter) and proximate composition of experimental diets.

		G-0* (0%)	G-50 (50%)	G-100 (100%)
Fish meal (65%-Anchovy)		220	110	0
Soybean meal (46-Expel)		410	450	550
Corn starch		100	55	35
Wheat (12 CP)		220	215	200
Sunflower oil		10	20	30
Binder		20	20	5
Mineral premix[1]		10	10	5
Vitamin premix[2]		10	10	5
IEM[3]		0	110	170
PROXIMATE COMPOSITION (N=3)	**IEM**	**G-0**	**G-50**	**G-100**
Crude protein %	55.9	35.06	35.32	35.11
Lipid %	31.7	4.95	8.59	10.84
Crude ash %	13.57	6.52	7.45	7.42
Fibre %	7.12	3.24	3.34	3.81
Gross energy (MJ kg^{-1})	19.37	17.71	17.04	16.93

[1]Mineral premix: Mn 60,000 mg, Fe 10,000 mg, Zn 75,000 mg, Cu 5000 mg, Co 1000 mg, I 2500 mg, Se 100 mg, Mg 65,000 mg
[2]Vitamin premix: Vit.A 4,000,000 IU, VitD3 800,000 IU, VitE 40,000 mg, VitK3 2400 mg, VitB1 5000 mg, VitB2 8000 mg, Niacin 5000 mg, Ca Pantothenate 9000 mg, VitB6 4000 mg, VitB12 12 mg, Biotin 50 mg, Folic acid 1400 mg, VitC 40,000 mg
[3]Insect Egg Meal (*Ephestia kuehniella*)
*__G-0__: Fish meal replacement 0%; __G-50__: Fish meal replacement 50%; __G-100__: Fish meal replacement 100%

mg L^{-1} (saturation 78.4%), pH as 7.16 ± 0.2, conductivity as 1417.7 ± 0.005 µS, and TDS as 694.82 ± 0.01 ppm.

The growth parameters of juvenile carp fed with three different diets are presented in Table 2. The final mean body weights recorded in G-0, G-50, and G-100 were 12.05 g, 12.49 g, and 11.98 g, respectively. The highest final body weight with 12.49 ± 0.017 g was observed in G-50 and found to be significantly different ($p < 0.05$). Similarly, G-50 had the highest live weight gain ($p < 0.05$). A decrease in body weight gain was noted when the substitution level of IEM in the experimental feed for fishmeal was 100%. G-100 had the same specific growth rate (SGR) value as in the G-0, but G-50 was significantly higher with an SGR value of 2.68% day^{-1}. G-50 had a more efficient FCR with a lower value of 1.79 ($p < 0.05$) whereas G-100 and the G-0 were found to be similar ($p > 0.05$). The survival rates varied between 85% and 95% at the end of the experiment but replacement levels of IEM did not have any significant effect on fish survival ($p > 0.05$).

The fatty acid contents of three different diets (Table 3) and the fish from different groups fed with these diets (Table 4) under standard experimental conditions were determined. The pretest results were revealed to determine the parametric status of the data. It was determined in the normality test performed at the 95% significance level that Shapiro-Wilk values indicated homogeneity and the Kurtosis-Skewness values were between ± 2, whereas the Pearson correlation results were found to be strongly linear between the groups. As these values were in accordance with the parametric model, an analysis of covariance (ANCOVA) was administered. The fatty acid composition of the diets indicated a significant difference. Total saturated fatty acids (Σ SFA) were higher in groups rather than G-0, and palmitic acid (C16:0) had the highest percentages in all diets. A decrease in saturated fatty acids was observed with the increasing substitution level of IEM. While all groups were found to be statistically different in SFA levels, G-50 was the highest with a level of Σ SFA 32.62 ± 0.04. Total monounsaturated fatty acids (MUFA) were found to be statistically different for all diets with the best result in G-50 having the most abundant oleic acid, as well (C 18:1 ω9). Total polyunsaturated fatty acids (PUFA) revealed a significantly lower value in G-50 with the lowest level of linoleic acid (C18:2 n6) content.

Table 2. Growth performance of experimental fish (*Cyprinus carpio*) in 12-weeks trial (mean ± SE).

	G-0*	**G-50**	**G-100**
Initial body weight (g)	1.12 ± 0.01	1.12 ± 0.01	1.12 ± 0.01
Final body weight (g)	12.05 ± 0.32^{b**}	12.49 ± 0.28^{a}	11.98 ± 0.38^{c}
Live weight gain (g)	10.93 ± 0.31^{b}	11.37 ± 0.37^{a}	10.87 ± 0.15^{b}
SGR (Specific growth rate; % day^{-1})	2.64 ± 0.02^{b}	2.68 ± 0.03^{a}	2.64 ± 0.02^{b}
FCR (Feed conversion ratio)	1.96 ± 0.19^{b}	1.79 ± 0.00^{a}	1.99 ± 0.53^{b}
Survival rate (%)	95.00^{a}	85.00^{a}	95.00^{a}

***G-0**: Fish meal replacement 0%; **G-50**: Fish meal replacement 50%; **G-100**: Fish meal replacement 100%

**Different superscripts in a row indicate significant statistical differences ($p < 0.05$).

Table 3. The fatty acid profile of experimental feeds (mean ± SE).

Fatty acids	**G-0***	**G-50**	**G-100**	**Average**
C 14:0	4.17 ± 0.04^{a**}	2.72 ± 0.05^{b}	3.54 ± 0.05^{b}	3.48 ± 0.63
C 16:0	17.83 ± 0.11^{b}	22.70 ± 0.10^{a}	20.90 ± 0.11^{ab}	20.47 ± 2.13
C 18:0	4.85 ± 0.05^{c}	6.81 ± 0.09^{b}	5.85 ± 0.05^{a}	5.83 ± 0.85
C 20:0	0.39 ± 0.02^{b}	0.42 ± 0.04^{a}	0.41 ± 0.03^{a}	0.41 ± 0.03
∑ SFA* **	**28.04 ± 0.044^{c}**	**32.62 ± 0.04^{ab}**	**30.68 ± 0.04^{a}**	**30.45 ± 1.99**
C 18:1 ω9	29.09 ± 0.12^{b}	32.80 ± 0.095^{a}	27.41 ± 0.06^{b}	29.77 ± 2.39
C 20:1 ω9	1.74 ± 0.05^{b}	0.60 ± 0.065^{a}	0.87 ± 0.11^{a}	1.07 ± 0.52
∑ MUFA	**36.12 ± 0.015^{c}**	**37.06 ± 0.057^{b}**	**32.21 ± 0.02^{a}**	**35.13 ± 2.23**
C 18:2 ω6	12.97 ± 0.08^{c}	11.69 ± 0.06^{ab}	17.07 ± 0.06^{a}	13.91 ± 2.43
C 18:3 ω3	4.57 ± 0.07^{c}	9.27 ± 0.06^{b}	5.45 ± 0.05^{a}	6.43 ± 2.16
C 20:5 ω3	7.50 ± 0.03^{c}	4.67 ± 0.10^{ab}	7.14 ± 0.04^{a}	6.44 ± 1.33
C 22:6 ω3	6.54 ± 0.055^{b}	4.718 ± 0.06^{a}	5.09 ± 0.06^{a}	5.45 ± 0.83
∑ PUFA	**35.03 ± 0.10^{c}**	**30.33 ± 0.02^{ab}**	**35.61 ± 0.03^{a}**	**33.66 ± 2.51**
ω3	**19.44 ± 0.04**	**18.66 ± 0.05**	**18.04 ± 0.03**	**18.72 ± 0.61**
ω6	**15.60 ± 0.04**	**11.69 ± 0.05**	**17.56 ± 0.03**	**14.95 ± 2.59**
ω3 / ω6	**1.25 ± 0.02**	**1.59 ± 0.04**	**1.03 ± 0.03**	**1.29 ± 0.25**

***G-0**: Fish meal replacement 0%; **G-50**: Fish meal replacement 50%; **G-100**: Fish meal replacement 100%

**Different superscripts in a row indicated significant statistical differences ($p < 0.05$).

***∑ SFA**: Total saturated fatty acids; **∑ MUFA**: Total mono-unsaturated fatty acids; **∑ PUFA**: Total poly-unsaturated fatty acids

The highest linoleic acid and total PUFA levels were both observed in G-100 where the fish meal was fully replaced with IEM. The ratio of n3/n6 was higher in G-50.

The fatty acid composition of the fish also indicated a significant statistical difference (Table 4). A decrease was observed in total saturated fatty acids (Σ SFA) with the increasing substitution levels of IEM. Palmitic acid (C16:0) had the highest percentage in all diets. Whereas all groups were found to be statistically different in SFA levels, G-0 was the highest with a level of Σ SFA 27.27 ± 0.045. Total monounsaturated fatty acids (MUFA) were found to be statistically different for all diets with the highest in G-100 that had the most abundant oleic acid (C18:1 n9) of 37.25 ± 0.03. Total polyunsaturated fatty acids (PUFA) in fish showed a significantly higher value in IEM fed groups with the highest level in G-100 where linoleic acid (C18:2

Table 4. The fatty acid profile of experimental fish (mean ± SE).

Fatty acids	G-0*	G-50	G-100	Average
C 12:0	0.22 ± 0.01^{bc**}	1.43 ± 0.006^{bc}	0.19 ± 0.02^{a}	0.61 ± 0.61
C 14:0	2.83 ± 0.02^{bc}	2.29 ± 0.03^{bc}	0.85 ± 0.04^{a}	1.99 ± 0.89
C 15:0	0.34 ± 0.02^{c}	0.31 ± 0.006^{b}	0.17 ± 0.02^{a}	0.27 ± 0.08
C 16:0	18.22 ± 0.01^{bc}	15.76 ± 0.03^{bc}	14.41 ± 0.004^{a}	16.13 ± 1.673
C 18:0	4.98 ± 0.01^{b}	5.55 ± 0.04^{b}	3.84 ± 0.05^{a}	4.79 ± 0.76
Σ SFA* **	**27.27 ± 0.04^{5}c**	**25.34 ± 0.027^{b}**	**20.51 ± 0.037^{a}**	**24.371 ± 3.015**
C 15:1 ω6	0.49 ± 0.05^{ab}	1.03 ± 0.03^{ab}	0.47 ± 0.02^{ab}	0.66 ± 0.28
C 16:1 ω7	5.15 ± 0.008^{c}	2.75 ± 0.01^{ab}	2.86 ± 0.02^{ab}	3.59 ± 1.18
C 18:1 ω9	29.97 ± 0.15^{bc}	32.05 ± 0.04^{bc}	37.25 ± 0.03^{a}	33.09 ± 3.25
C 20:1 ω9	2.27 ± 0.02^{c}	1.63 ± 0.01^{ab}	1.53 ± 0.02^{ab}	1.81 ± 0.35
C 22:1 ω9	0.08 ± 0.001^{bc}	0.15 ± 0.003^{bc}	0.06 ± 0.002^{a}	0.10 ± 0.04
Σ MUFA	**37.97 ± 0.015^{c}**	**37.51 ± 0.013^{b}**	**42.16 ± 0.09^{a}**	**39.22 ± 2.22**
C 18:2 ω6	26.14 ± 0.03^{bc}	29.27 ± 0.02^{bc}	21.54 ± 0.02^{a}	18.98 ± 13.15
C 18:3 ω3	1.89 ± 0.02^{c}	1.58 ± 0.03^{ab}	1.54 ± 0.03^{ab}	1.67 ± 0.17
C 20:2 ω6	0.63 ± 0.005^{bc}	0.66 ± 0.004^{bc}	0.54 ± 0.005^{a}	0.61 ± 0.05
C 20:3 ω6	0.64 ± 0.004^{bc}	0.78 ± 0.005^{bc}	0.82 ± 0.005^{a}	0.75 ± 0.08
C 20:5 ω3	1.78 ± 0.006^{c}	1.02 ± 0.010^{b}	0.24 ± 0.005^{a}	1.01 ± 0.66
Σ PUFA	**34.26 ± 0.005^{c}**	**35.03 ± 0.01^{ab}**	**37.22 ± 0.03^{a}**	**35.50 ± 1.33**
ω3	**6.64 ± 0.01^{c}**	**2.58 ± 0.03^{ab}**	**2.42 ± 0.02^{ab}**	**3.88 ± 2.07**
ω6	**27.62 ± 0.02^{c}**	**32.43 ± 0.015^{b}**	**34.82 ± 0.02^{a}**	**31.62 ± 3.18**
ω3 / ω6	**0.24 ± 0.004^{c}**	**0.08 ± 0.003^{ab}**	**0.07 ± 0.003^{ab}**	**0.13 ± 0.08**

*__G-0__: Fish meal replacement 0%; __G-50__: Fish meal replacement 50%; __G-100__: Fish meal replacement 100%

**Different superscripts in a row indicated significant statistical differences ($p < 0.05$).

***__Σ SFA__: Total saturated fatty acids; __Σ MUFA__: Total mono-unsaturated fatty acids; __Σ PUFA__: Total poly-unsaturated fatty acids

n6) content was also higher than all groups. The ratio of n3/n6 was higher in G-0 reflecting a better balance.

4. Discussion

Alternative feedstuff has been studied and criticized for economic and environmentally sustainable aquaculture since feed is one of the key components of the aquaculture industry. The current studies have mainly focused on promising sources like insect meal and oil. The common species are *Hermetia illucens* (black soldier fly) and *Tenebrio molitor* (mealworm) due to their highly similar nutritional composition to fish meal.

To the best of our knowledge, this paper is the first report on the dietary replacement of fish meal with mill moth egg meal (*Ephestia kuehniella*) in common carp diets.

A 12-week feeding experiment was conducted to test the effects of FM substitution with insect meal in growth performance and fatty acid profile of common carp juvenile. The growth performance of fish investigated in this study was significantly affected by dietary insect meal inclusion. As tested in two substitution levels (50% and 100%) against a control diet (0%), the experimental G-50 (IEM 50%) revealed the best results with the highest final mean body weight, SGR, and better FCR; however, the higher inclusion level (100%) of IEM tended to impair growth performance.

The potential of insects, particularly BSF and mealworms as an alternative protein source for aquafeeds, was evaluated in some aquatic species. Carnivorous fish in which animal protein was used in high portions were the focal point for the FM substitution experiments. The majority of these articles reported no adverse effects or slightly better performance in fish growth with diets including insect meal. Different replacement levels of FM with insect meal were concluded both in marine and freshwater species. Black soldier fly *Hermetia illucens* was

reported to be used in fish feeds successfully up to 50% for Nile tilapia (*Oreochromis niloticus*) [24], 25% for yellow catfish (*Pelteobagrus fulvidraco*) [25], 50% for African catfish (*Clarias gariepinus*) [26], 40% for rainbow trout (*Oncorhynchus mykiss*) [27], 100% for Jian carp (*Cyprinus carpio*) [28], 30% for European sea bass (*Dicentrarchus labrax*) [29], and 100% for Atlantic salmon (*Salmo salar*) [19]. Another common species of potential insects for fish nutrition, mealworm *Tenebrio molitor,* was also tested in aquatic feeds; despite revealing positive results with inclusion levels of 50% for rainbow trout (*Oncorhynchus mykiss*) [13] and 20% for sea trout (*Salmo trutta*) [30], some research concluded negative effects of 50% or upper levels of insect meal inclusion in sea bass [31]. The growth performance results of the previous studies were consistent with the majority of former research on fish. Even though it was not different statistically, survival in G-50 was lower than in other groups. However, 100% replacement of FM decreased growth performance, the G-100 did not decrease below the performance of control.

The fatty acid composition of experimental feeds is presented in Table 3. The diets including IEM had higher SFA content with higher palmitic acid levels. There were no negative effects on growth performance due to the high load of SFA. Similar results were reported for Atlantic salmon [19]. IEM inclusion of 50% resulted in the highest MUFA and oleic acid content, but PUFA content was better in G-0 and 100% IEM diets. The control group also had a better ω3/ω6 ratio. When compared to the diets including close rates of black soldier fly prepupae, yellow mealworm, or silkworm pupae meal in previous studies [20,32,33], IEM seemed to reveal higher levels of linoleic and docosahexaenoic acid content. Total monounsaturated fatty acids and polyunsaturated fatty acids were found to be higher than in the G-0 diet and also many experimental feeds including black BSF prepupae or yellow mealworm meals in the literature.

The whole-body fatty acid composition of carp fed with IEM diets indicated a significant difference between experimental groups (Table 4).

Zhou et al. [28] reported significantly increased saturated fatty acid in the whole body, muscle, and hepatopancreas of Jian carp, whereas unsaturated fatty acids significantly decreased with the increasing replacement of fish meal with black soldier fly larvae meal. In the present study, controversially total saturated fatty acid was decreased while total unsaturated fatty acid increased. It could be considered that this observed contrast appeared because insects from different families were studied and eggs were used instead of larvae in our study.

The fatty acid composition of fish has highly dependent on the diet. The major reason for reluctance against insect meal is the lack of some amino acids and fatty acids with the fish meal rich in content. Current studies have focused on a very limited number of species, but there are about one million described insect species, and the nutritive profile of insect meals is possible to be balanced with multiple combinations of different species in different life stages. Insects are found to be richer in palmitic acid, oleic acid, linoleic acid, and linolenic acid rather than fish oil but poor in docosahexaenoic acid.

Since fish are unable to synthesize PUFA, freshwater species tend to receive n-3 and n-6 by their diets [34]. Dietary lipid sources can influence fillet lipid composition as well as growth performance. Meriç and Demir [35] have reported a significant difference in fatty acid composition of carp fed with sunflower feed over 15% dietary inclusion, but Ljubojevic et al. [36] have revealed no difference from dietary oil replacement in carp. However dietary lipid profile is not the only main characteristic affecting the proximate composition of fish.

In conclusion, the results of this study revealed that IEM was possible to be replaced with dietary FM in the diets of common carp. With the increasing price and shortage of fish meal, IEM could be an alternative and sustainable feedstuff and a major expense could be saved in aquaculture, but further studies have been needed to be carried out.

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