Potential of field crickets meal (Gryllus bimaculatus) in the diet of African catfish (Clarias gariepinus)

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ABSTRACT

This study was conducted to evaluate the effect of dietary replacement of fishmeal (FM) by using field crickets (CM) and on growth performance and feed utilization of African catfish fingerlings. Five isonitrogenous diets (28% crude protein) were used containing 0\% (control), 25\%, 50\%, 75\% or 100\% of FM substituted by CM. Triplicate group of fish ($n = 15$) were fed with their respective diets with initial mean body weight (BW) of $4.00 \pm 0.8$ g (mean $\pm$ SE) for 56 days. Fish fed with 100\% CM exhibited significantly lower food conversion ratio than the lower inclusion level. Values of specific growth rate and protein efficiency ratio increased gradually with increasing amount of CM inclusion level from 50\% to 100\%. All compounds of essential amino acids were present in experimental diets although methionine, lysine and tryptophan were comparatively less than the required amount of amino acid for African catfish. Whole-body crude protein composition was significantly higher in fish fed with diet 50\% to 100\% CM compared to initial fish. These results indicated that CM is capable of serving as an alternative protein replacement for FM in the diet of farmed African catfish up to 100\% without affecting body composition and feed utilization.

Introduction

The increasing world population has boosted the demand for protein sources, which has inevitably impacted the aquaculture industry to produce high-yielding fish with lower cost. Fish feed constitutes 80\% of operating cost in aquaculture where 2013. Simultaneously, as aquaculture industry has been considered as the fastest-growing animal-food sector (FAO 2014), studies on sustainable resources to expand this industry are essential. Besides aquaculture, (al. 2000), which led to its high cost of production due to the declining amount of wild-caught fish available in its production process.

The use of other sustainable sources as alternatives for FM in relation to the production of formulated feed has reduced the dependency on FM. High prices of FM and increasing demand of aquaculture production have led to the establishment of research in insect protein for aquaculture and livestock (Barroso et al. 2014; Henry et al. 2015). Insects meal such as grasshopper meal (\textit{Zonocerus variegatus}) (Alegbeleye et al. 2012), termites meal (\textit{Macrotermes} spp.) (Sogbesan and Ugwumba 2008), superworm meal (\textit{Zophobas Mario}) (Jabir et al. 2012), mealworm (\textit{Tenebrio molitor}) (Gasco et al. 2016) as well as molluscs such as garden snail (Sogbesan et al. 2006) and plants feedstuff (Muin et al. 2015) have been identified as successful alternatives for FM replacement.

Crickets have been commonly used as complimentary food source for ornamental fish, reptiles as well as in poultry industry. Previous studies have reported that field crickets gave a promising result as a soybean replacement in broiler diet (Ramos-Elorduy et al. 2002). Although these investigations reported interesting results in poultry industry, no attempt was made to explore the potential of crickets as formulated diet for fish. Nevertheless, there are some trials that have already been done using Orthoptera insects in fish feeding. According to Alegbeleye et al. (2012), 13\% dietary inclusion of variegated grasshopper could improve growth performances of catfish. However, total replacement of grasshopper meal from FM reduced the growth of African and walking catfish (Johri et al. 2011; Alegbeleye et al. 2012). Another insect that has been tested in fish is migratory locust (\textit{Locusta migratoria}), which could enhance the growth of tilapia with the inclusion level up to 25\% in their diet (Makkar et al. 2014). Since cricket can be found in abundance in the tropics, they are easily cultured and mass harvested in controlled environments with the benefit of low cost of production. Therefore, it can be a suitable candidate for alternative protein resources for animal diet.

The Malaysian production of catfish within the past decade has been rising exponentially as a result of market demand. However, projections by the Department of Fisheries, Malaysia (2014) estimated that the total production of African catfish,
Clarias in 2014 was approximately 46,000 tonnes, which is reduced by 0.08% from 2013. Nevertheless, it is still regarded as the most cultivated and popular freshwater fish. Thus, many researches have highlighted the study on different aspects of this particular fish in order to enhance its growth and increase its productivity.

Since there is a dearth of information on cricket meal (CM) as feed resources for local fish, this study aims to experimentally investigate the effect of varying levels of CM as FM replacement in African catfish diet on their growth performances, feed utilization, body composition and survival rate.

Materials and methods

Experimental diet

Adult live field crickets (Gryllus bimaculatus) used in the formulated diet were purchased from a local field crickets farm. It was then transported to the laboratory and refrigerated at −20°C before being dried in an oven at 60°C. The dried crickets were then grounded with a dry feed grinder and kept in a cold room (4°C) prior to the proximate analysis. All the raw materials for the ingredients, including FM, corn meal, rice bran, soybean, vitamins, mineral and dicalcium phosphate (DCP), were purchased from a local livestock feed center.

Formulation and chemical composition of all the experimental diets and feed ingredients are tabulated in Table 1. Five formulated diets were used in this experiment by using CM as alternative sources to FM. Various inclusion percentages of CM (0% (control), 25%, 50%, 75% and 100%) were formulated to yield an isonitrogenous content of 28% crude protein.

Table 1. Formulation and chemical composition of the experimental diets.

| Ingredients (g kg⁻¹) | Replacement (%) |
|----------------------|-----------------|
|                      | (0%) (25%) (50%) (75%) (100%) |
| Fishmeal (FM)        | 300.0 225.0 150.0 75.0 0.0 |
| Cricket meal (CM)    | 0 75.0 150.0 225.0 300.0 |
| Soybean meal (SB)    | 58.6 9.8 19.2 33.3 96.2 |
| Corn starch (C)      | 82.6 242.4 276.7 365.9 341.7 |
| Rice bran (RB)       | 543.8 432.8 389.1 285.8 247.1 |
| Vitamin premixa      | 2.0 2.0 2.0 2.0 2.0 |
| Mineral premixb      | 3.0 3.0 3.0 3.0 3.0 |
| DCP                  | 10.0 10.0 10.0 10.0 10.0 |
| Total                | 1000 1000 1000 1000 1000 |
| Nutrient level determined by as is basis (% dry matter basis) |
| Dry matter           | 94.36 94.42 94.06 93.26 93.14 |
| Crude protein        | 28.0 28.00 27.50 27.70 27.90 |
| Crude fat            | 8.43 8.51 9.71 9.42 9.45 |
| Crude ash            | 9.00 8.35 8.24 7.42 7.55 |
| Crude fibre          | 1.36 1.86 2.90 3.15 3.24 |
| Gross energy         | 18.42 18.44 18.48 18.39 18.35 |
| NFE⁴                 | 47.57 47.50 45.71 45.57 45.00 |

⁴The vitamin premix supplied the following per 100 g diet: Vitamin A, 500 IU; Vitamin D₃, 100 IU; Vitamin E, 0.75 mg; Vitamin K, 0.02 mg; Vitamin B₁, 1.0 mg; Vitamin B₂, 0.5 mg; Vitamin B₃, 0.3 mg; Vitamin B₆, 0.2 mg; Vitamin B₁₂, 0.001 mg; Vitamin C, 0.1 mg; Niacin, 0.2 mg; Folic acid, 0.1 mg; Biotin, 0.235 mg; Panthothenic acid, 1.0 mg; Inositol, 2.5 mg.

The mineral premix supplied the following per kg diet: Selenium, 0.2 mg; Iron, 8 mg; Manganese, 1.0 mg; Zinc, 8.0 mg; Copper, 0.15 mg; Potassium Chloride, 0.4 mg; Magnesium Oxide, 0.6 mg; Sodium Bicarbonate, 1.5 mg; Iodine, 1.0 mg; Cobalt, 0.25 mg.

Gross energy was calculated as 23.9, 39.8 and 17.6 kJ/g for protein, fat and NFE, respectively.

Winfeed 2.8 version software was used to establish the formulated feed. All dry ingredients were grounded in a hammer mill (Disk Mill, FFC 454). Vitamins, minerals and DCP were mixed thoroughly with the dry ingredients and water was added to the mixture prior to being pelleted into sizes of 1 mm diameter using a mini pelleting machine (KCM, Y132M-4). The wet pellets were then dried in an oven at 70°C for 24 hours and later stored in a cold room (4°C) until used for feeding.

Experimental fish and set-up

African catfish were purchased from local farmers and transported to the Freshwater Aquarium Laboratory located in the Institute of Biological Sciences, Faculty of Science, University of Malaya. Two hundred and ± 0.8 g. All the fishes were acclimatized to natural environment condition for two weeks prior to the feeding trials and fed with commercial diet twice per day at 0900 h and 1500 h during the acclimatization and throughout the experiment and uneaten feed was collected after feeding. Water quality was monitored regularly and any mortality was recorded. Fifteen plastic (15) tanks (3 × 2 × 1') with a capacity of 100 litres of water with closed re-circulation system were used in these feeding activities. The tanks were equipped with top filter pump at a flow rate of 20 L min⁻¹ and aeration with air–stone diffuser was provided in each tank for circulation of dissolved oxygen. Tap dechlorinated water were used and 20–30% of water were changed once in two days to maintain water quality.

The feed were given at a rate of 10% of their BW ratio at the beginning of the feeding trial. The level was adjusted according to the BW after weighing them once in two weeks and the final feeding rate was at 5% of their BW ratio. The feeding trials were conducted over 56 days. At the end of the experiment, all fishes were weighed, sacrificed for body composition and frozen at −20°C for further analysis.

The water quality for all tanks was tested according to the method by APHA (1992). Water temperature was maintained at 28–29°C, pH at 6.0–6.8 and dissolved oxygen (DO) above 4.5 mg L⁻¹. Ammonia and nitrate were determined weekly using a spectrophotometer while water temperature, pH and DO were monitored daily.

Proximate and chemical analysis

The experimental diets, ingredients and body composition were analysed for proximate composition according to the method of Association of Official Analytical Chemist (2003). Kjeldahl method was used to analyse crude protein after acid digestion (FOSS Tecator Digestor Auto). Moisture and dry matter were measured by drying in oven at 105°C to constant weight. Ash was determined by combustion in muffle furnace (Nabertherm) at 600°C. Soxhlet method with petroleum ether extraction (FOSS Soxtec 2055) was used to measure crude lipid content.

Amino acid analysis

Amino acid profiles were determine using the High Performance liquid Chromatography (JASCO CO-2065 Plus, Intelligent
Column Oven) and the contents were determined by comparison peak retention times to a known standard by using the Pico-Tag method by Heinirkskon and Meredith (1984). Tryptophan was determined after alkaline hydrolysis according to Nielsen and Hurrell (1985).

**Analysis of experimental data**

From the experimental data obtained, daily feed intake (DFI), specific growth rate (SGR), food conversion ratio (FCR), body weight gain (BWG), protein efficiency ratio (PER) and survival rate (SR) were calculated as follows. All calculations were measured according to triplicate tanks treatments.

(1) DFI = Daily food supplied per treatment (g)/number of fish per treatment
(2) BWG = final weight (g) – initial weight (g)
(3) FCR = total food supplied (g, dry basis)/live weight gain (g)
(4) SGR = (ln final weight of fish – ln initial weight of fish / number of feeding days)*100
(5) PER = live weight gain (g) / total protein fed (g, dry basis)
(6) SR (%) = (final number of fish / initial number of fish) × 100

**Statistical analysis**

All data were subjected to one-way analysis of variance (ANOVA) using SPSS version 21.0 (SPSS Inc., Chicago IL, USA). The differences between means were compared by Duncan’s post hoc test at 5% (P < .05) probability level. Data are presented as mean ± standard error (SE).

**Results**

The inclusion level of CM (0%, 25%, 50%, 75% and 100%) in the diets with isonitrogenous crude protein (28%) and chemical composition of the experimental diets are shown in Table 1. The FM and CM were formulated according to the percentage inclusion level of the diets. However, soybean, rice bran and corn meal were changed and evaluated to make sure the overall composition were the same amongst all the diets. The results of the present study clearly indicate that growth performances of African catfish fingerlings were affected by different experimental diets of CM. Daily water temperature, pH and DO for every tank were observed and maintained to the standard requirement. Variations in the levels of total ammonia and nitrate in all tanks were between 0.33 and 0.81 mg ml⁻¹, and 0.79 and 1.91 mg ml⁻¹, respectively, throughout the experimental period. Generally, there were no significant difference between treatments and remained in the suitable range for African catfish growth, indicating that the experimental diets did not affect water quality of the fish.

The amino acid profiles for FM and CM are shown in Table 3. Ten amino acids (methionine, arginine, threonine, tryptophan, histidine, isoleucine, lysine, leucine, valine and phenylalanine) are not synthesized in fish, therefore need to be supplied in their feeding materials according to NRC (1993). Compared to FM, the CM is relatively rich in limiting amino acid; methionine, lysine and cysteine as well as greater in histidine and tyrosine. On the other hand, FM is comparatively higher in threonine, valine, isoleucine and leucine.

All compounds of essential amino acids (EAA) were present in experimental diets (Table 3). The values of amino acid in the diets containing CM were equal to or slightly higher than control (0%), which can be considered negligible. All EAA tested in this study were compared with the EAA requirement for catfish as reported by Jimoh et al. (2014) and Fagbenro and Nwanna (1999). Methionine, lysine and tryptophan were comparatively less than the required amount of amino acid for African catfish.

During the 56 days of feeding trial, all experimental diets were well accepted by African catfish fingerlings. The effect of growth performance and survival of the fish fed with the experimental diets are presented in Table 4. Growth performance and feed utilization of fish fed with 100% CM were significantly improved compared to the lower percentage of CM replacement. Reduced weight gain was observed in group fed with 25% CM although it does not differ significantly with 0% and 50% CM. Lower weight gain was observed in fish fed with diet 0% until 75%, which suggested that diet with increased replacement of FM by crickets meal from 50% up to 100% enhances the growth performances, feed efficiency and survival rate of African catfish fingerlings.

FCR was significantly lower in 100% CM inclusion level (average: 2.20) when compared to the lowest inclusion level. Similarly, this result is confirmed by a significant increase of PER and SGR of fish fed 100% CM (average: 1.69 and 2.32, respectively) than those fed with 0–50% CM. Values of SGR and PER increased gradually with increasing amount of CM inclusion level from 50% up to 100%. In general, these growth parameters are positively parallel with increasing CM level from 50% upwards, which suggests that African catfish could well utilize CM as protein sources in their diet.

Full replacement of CM up to 100% of FM clearly affected the whole-body composition of African catfish. The crude protein for initial fish were significantly different with the final body composition of experimental fishes fed with diet 50%, 75% and 100% CM inclusion level but did not differ significantly with diet 0% and 25% CM inclusion level (Table 5). The present findings also suggest that crude protein body

| Component           | FM     | CM     | RB     | SB     | C      |
|---------------------|--------|--------|--------|--------|--------|
| Dry matter (g 100g⁻¹) | 85.59  | 95.18  | 92.61  | 80.01  | 88.79  |
| Crude protein (g 100g⁻¹) | 53.61  | 57.02  | 16.44  | 39.34  | 8.91   |
| Crude lipid (g 100g⁻¹) | 2.69   | 13.90  | 10.84  | 2.23   | 3.05   |
| Crude ash (g 100g⁻¹)  | 19.30  | 4.83   | 11.27  | 7.25   | 2.28   |
| Crude fibre (%)       | 4.64   | 9.21   | 3.84   | 2.80   | 4.47   |

**Table 2.** Chemical composition of FM, CM, soybean (SB) and corn (C) meal used in the trial diet.
composition of fish fed with 50–100% CM exhibits significantly higher level than 0% and 25% CM inclusion level.

On the other hand, crude lipid body composition did not differ significantly between initial group, 0%, 25% and 50% CM while fish fed with 75% and 100% CM demonstrated significantly lower values than the other treatments. Crude ash was found to be highly significantly different in final body of fish fed diet above 50% CM level when compared to the initial. Highest level was observed in the group that received 100% CM level.

An economic evaluation of all five diets presented in Table 6 demonstrated that the cost of the diets increased with elevating amount of CM up to RM 13.84 kg**−1** for total replacement of CM while the lowest price is the control diet (0% CM inclusion) with only RM 3.26 kg**−1**. The cost for CM per kg is almost 10-fold higher than for FM, which then resulted in a higher quality of FM reported by Lall and Anderson (2005). Thus, it is the possibilities for decreasing growth performance of fish fed with 100% FM as FCR level (3.50) was the highest among all treatments.

Higher level of arginine, leucine and phenylalanine were recorded in *G. bimaculatus* tested in this study in comparison to *G. testaceus* as reported by Wang et al. (2005). In addition, in studies by Finke (2002) on house cricket (A. domesticus), amino acid profile shows comparable result as *G. bimaculatus* but somewhat a higher level of leucine appeared in *A. domesticus*.

Lysine and methionine are the most limiting amino acids in fish feed; thus, many commercial diets include lysine and methionine supplementation to satisfy the amino acid requirement for their fish feed (Nunes et al. 2014). Similarly, in this case, all experimental diets are deficient in lysine, methionine, phenylalanine and tryptophan. However, according to Lovell (1989), non-essential amino acid such as cysteine can replace about 20% of cysteine in fish feed; thus, it may be possible to replace cysteine with other non-essential amino acids in these experimental diets.

**Table 3.** EAA composition of practical diets used in this study (g 100g**−1** crude protein).

| AEA       | Fishmeal | Cricket meal (G. bimaculatus) | Replacement (%) |
|-----------|----------|-------------------------------|-----------------|
|           | (0%)     | (25%)                         | (50%)           | (75%) | (100%) |
| Histidine | 1.14 ± 0.02* | 2.20 ± 0.01  | 1.62 ± 0.01*   | 1.63 ± 0.03* | 1.93 ± 0.11** | 2.19 ± 0.04b | 2.18 ± 0.03b |
| Arginine  | 6.64 ± 0.01* | 6.20 ± 0.03  | 5.66 ± 0.13*   | 5.66 ± 0.06* | 6.13 ± 0.12b | 6.23 ± 0.03b | 5.56 ± 0.05a |
| Threonine | 4.35 ± 0.13* | 3.88 ± 0.11  | 4.03 ± 0.27b   | 3.66 ± 0.02* | 3.61 ± 0.03* | 3.54 ± 0.02a | 3.09 ± 0.19a |
| Valine    | 5.91 ± 0.02* | 4.24 ± 0.05  | 4.91 ± 0.11a   | 5.21 ± 0.03b | 5.20 ± 0.03b | 5.26 ± 0.05b | 5.02 ± 0.03b |
| Methionine| 1.83 ± 0.01* | 2.02 ± 0.04  | 1.16 ± 0.02b   | 1.18 ± 0.17b | 1.35 ± 0.26b | 1.45 ± 0.02b | 1.45 ± 0.02b |
| Isoleucine| 4.32 ± 0.04  | 3.75 ± 0.01  | 3.67 ± 0.09a   | 3.64 ± 0.03a | 3.74 ± 0.02a | 3.87 ± 0.02a | 3.55 ± 0.10a |
| Leucine   | 7.27 ± 0.11  | 6.70 ± 0.07  | 6.15 ± 0.15b   | 6.30 ± 0.04* | 6.61 ± 0.04b | 6.75 ± 0.03b | 6.45 ± 0.06b |
| Phenylalanine| 4.40 ± 0.01  | 4.00 ± 0.02  | 5.58 ± 0.39c   | 4.84 ± 0.67b | 4.42 ± 0.02b | 3.81 ± 0.11a | 3.83 ± 0.04a |
| Lysine    | 3.09 ± 0.10  | 5.14 ± 0.04  | 2.46 ± 0.13a   | 2.33 ± 0.06a | 3.08 ± 0.06c | 3.50 ± 0.08c | 3.23 ± 0.02b |
| Tryptophan| 0.60 ± 0.15  | 0.85 ± 0.12  | 0.73 ± 0.02a   | 0.76 ± 0.03c | 0.84 ± 0.05c | 0.89 ± 0.01c | 0.94 ± 0.001c |
| Cystine*  | 3.01 ± 0.02  | 2.02 ± 0.01  | 4.40 ± 0.52b   | 4.89 ± 0.50b | 7.02 ± 0.31b | 6.93 ± 0.03b | 6.38 ± 0.03b |
| Tyrosine* | 3.15 ± 0.03  | 7.63 ± 0.02  | 2.63 ± 0.06*   | 3.01 ± 0.03a | 3.51 ± 0.04b | 4.30 ± 0.16b | 3.94 ± 0.03b |

Notes: Values are means of duplicates samples. Mean values in the same row with different superscript letters are significantly different (P < 0.05).

1Non-essential amino acid.

On the other hand, crude lipid body composition did not differ significantly between initial group, 0%, 25% and 50% CM while fish fed with 75% and 100% CM demonstrated significantly lower values than the other treatments. Crude ash was found to be highly significantly different in final body of fish fed diet above 50% CM level when compared to the initial. Highest level was observed in the group that received 100% CM level.

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60% of methionine requirement while tyrosine can spare up to 50% of phenylalanine in catfish diet. The deficiencies of lysine and tryptophan could be increased up to the optimum requirement by increasing crude protein level in the diet.

Li et al. (2006) have proposed that crude protein level as low as 26% is still accepted for growing catfish. Crude protein of 28% provide good growth at stocking density of less than 10,000 fishes per acre per day with 1000 fish grown up to 100 pounds (Li et al. 2003). However in this study, it is observed that FCR levels were extremely high in all experimental diets. Numerous studies to date have made an assumption that chitin is responsible for growth retardation of fish that consume insects (Goodman 1989; Alegebeleye et al. 2012). In contrast, Taufek et al. (2016) indicated that chitin in CM does not affect digestibility of fish as it showed higher nutrient digestibility than FM. In fact, according to Finke (2007), most of nitrogen recovered from insect meal came from amino acid but only a small amount is related to chitin. Hence, growth reduction is more likely occurred due to insufficient amino acid rather than to the presence of chitin. Therefore, in this study, insufficient crude protein level for the practical diet formulation in African catfish fingerlings might be the reason for the lower growth response. Further studies on higher crude protein level will be beneficial to generate lower FCR value and consequently increase growth rate.

Other insects that have been tested in catfish diet have shown poor growth in total replacement for FM. Previous studies by Roncarati et al. (2015) highlighted that the inclusion of mealworm (*Tenebrio molitor*) (50.8% crude protein) in common catfish could enhance their growth, although FM fish (51.6% crude protein) showed significantly higher weight gain than mealworm group. As for survival, the control diet (0%), 75% and 100% CM inclusion level showed the highest rate (average: 93.3%) compared to 25% and 50% CM (average: 86.7) although the differences observed were insignificant.

Body composition was affected by many factors, including growth, ingredient used in the diets and water temperature. Apart from that, feed rate could also affect body composition of fish (Ahmed 2007; Kim et al. 2012). The results showed that gross body composition of fish fed with 50–100% CM inclusion level showed significantly higher crude protein content than those fed with lower inclusion of CM. However, fat content was inversely affected by growth performance and protein content as higher lipid body composition were observed in fish fed with 0–50% CM. The findings are consistent with past findings by Babalola and Apata (2006), which reported that reduced growth performance of African catfish fingerlings could increase lipid deposition. Hence, it could be deduced that changes in lipid content could be linked to muscular deposition rate, fish weight and/or growth performance (Abdel-Tawwab et al. 2010). Similar results were also obtained in Nile tilapia by Al Hafedh (1999), Khattab et al. (2000) and Abdel-Tawwab et al. 2010). Increasing body lipid deposition must be carefully considered as it could affect carcass quality, storage characteristics and flavour (Hillestad and Johnsen 1994).

In tropical areas, crickets can be produced in large amounts and relatively within a short period of time. Since CM in this study was acquired from local supplier and the amount of local farmers producing them is limited, the price was still fairly expensive compared to FM. Based on Table 6, the price for full replacement of CM is four times costlier than the FM diet. This fact is attributable to lower demand of cricket supplies in Malaysia, hence expensive cost to produce CM. Further upsaling the insect production on an economically feasible basis could minimize the price of CM. Besides, further studies on automation and logistics could reduce labour cost and consequently produce cheaper CM without compromising the quality (Makkar et al. 2014).

The study of insects as substitutes for FM has been growing over the years to find sustainable resources to replace a very volatile and expensive FM. However, unlike other insects such as maggot meal, flies and silkworm, the information about crickets as protein sources for fish feed is very limited compared to poultry feed. Field crickets, *G. bimaculatus* as an animal protein source is a very good candidate since they contain sufficient amount of EAA for fish requirement. Besides, this species can be harvested in a considerable amount with mass rearing, under controlled condition.

### Conclusion

In conclusion, the use of a practical diet containing 100% CM is appropriate for growth and nutrition utilization of African catfish fingerlings. With a review to reduce feed cost for the aquaculture and other livestock industry, further research on CM as alternatives protein source should continue to be carried out since it holds great potential. The physiological and biochemical aspects of the fish when consuming CM are also important factors that need to be consider in future studies.

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### Table 5. Initial and final body composition of fish fed with the experiment diets (% dry matter basis).

| Components     | Initial (%) | (0%)  | (25%)  | (50%)  | (75%)  | (100%) |
|----------------|-------------|-------|--------|--------|--------|--------|
| Crude protein  | 46.18 ± 0.51 | 46.34 ± 0.11 | 46.87 ± 1.00 | 47.53 ± 2.08 | 48.88 ± 1.50 | 48.33 ± 0.62 |
| Crude lipid    | 16.38 ± 2.26 | 16.82 ± 0.84 | 16.99 ± 2.24 | 16.92 ± 1.07 | 14.71 ± 0.91 | 13.90 ± 1.56 |
| Crude ash      | 16.64 ± 0.03 | 17.69 ± 0.49 | 19.24 ± 1.26 | 20.36 ± 0.52 | 22.78 ± 0.91 | 25.29 ± 1.11 |
| Dry matter     | 91.37 ± 1.00 | 92.00 ± 1.76 | 95.46 ± 0.57 | 94.63 ± 2.15 | 97.69 ± 0.31 | 97.61 ± 0.24 |

Notes: Values are the mean ± SEM of triplicate groups of 15 fish per tank. Mean values in the same row with different superscript letters are significantly different (*P* < .05).

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### Table 6. Cost for all experimental diets and raw ingredients.

| Ingredients       | Diet 0% | Diet 25% | Diet 50% | Diet 75% | Diet 100% |
|-------------------|---------|----------|----------|----------|-----------|
| Fishmeal          | 4.00    | 1.20     | 0.90     | 0.60     | 0.30      | 0         |
| Cricket meal      | 39.00   | 0.00     | 2.93     | 5.85     | 8.78      | 11.7      |
| Soybean meal      | 2.80    | 0.16     | 0.03     | 0.08     | 0.10      | 0.29      |
| Corn meal         | 3.20    | 1.04     | 0.43     | 0.44     | 0.50      | 1.03      |
| Rice bran         | 1.80    | 0.54     | 1.07     | 1.04     | 0.97      | 0.50      |
| Vitamins          | 80.00   | 0.16     | 0.16     | 0.16     | 0.16      | 0.16      |
| Minerals          | 28.00   | 0.01     | 0.08     | 0.08     | 0.08      | 0.08      |
| DCP               | 8.00    | 0.08     | 0.08     | 0.08     | 0.08      | 0.08      |
| Total             | 151.50  | 3.26     | 5.68     | 8.31     | 10.97     | 13.84     |

Cost for all experimental diets and raw ingredients.
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Disclosure statement

No potential conflict of interest was reported by the authors.

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