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Fishmeal Replacement by House cricket (*Acheta domesticus*) and Field cricket (*Gryllus bimaculatus*) Meals in Nile Tilapia (*Oreochromis niloticus*) Fingerling Feed

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Abstract

Insect meal is a candidate and promising ingredient to replace the unsustainable fishmeal (FM) in aquafeeds. However, previous studies showed that total replacement of FM with some insect meals was not successful for some stages of Nile tilapia. Therefore, this experiment aimed to evaluate the growth performance of Nile tilapia fingerlings, replacing the FM with house cricket meal (HCM) and field cricket meal (FCM). The FM of the control diet (100FM) was 100% replaced in the house cricket-included diet (100HCM) and field cricket-included diet (100FCM). All the fish were fed on the respective research diets for six weeks. The weight gain (WG), daily weight gain (DWG), and relative weight gain (RWG) of 100FM were significantly ($P<0.05$) higher than in 100HCM and 100FCM. However, the specific growth rate (SGR) of 100FM was not significantly different from 100FCM, while the SGR of 100HCM was significantly lower than both 100FM and 100FCM. The feed conversion ratio (FCR) of 100FM and 100FCM were statistically similar ($P<0.05$), and significantly lower than that of 100HCM. Survival was not significantly different among all the treatments. Results suggest that FCM has the potential as an alternative to FM in Nile tilapia fingerling feed.

Introduction

Exploring alternatives to FM is a trend and a topic broadly researched in recent studies. Nonetheless, FM is still the key and important ingredient in aquafeed formulations due to its high nutrient content (Ween et al., 2017; Hamid, 2020; Estevez et al., 2022), with highly digestible essential amino acids (EAAs) and fatty acids (Zinn et al., 2009). Therefore, FM is well-fit for aquafeeds from the nutritional point of view. However, from sustainable, environmental, and economic perspectives, FM is unsuitable for the long-term future of the industry.

The FM price will be soared (Nagappan et al., 2021) due to the high demand and the enhanced usage of human fish consumption as a healthy animal food (Soliman et al., 2017; Tacon et al., 2020). FAO (2020) has reported that 22.2 % of the global fisheries and aquaculture production in 2018 was utilized for non-food purposes; i.e., mainly for FM and fish oil production instead of direct human consumption. Similarly, predictions have been made that the total aquafeed demand will be raised by 75% from 2015 to 2025 (Hua et al., 2019). Therefore, it is necessary that sustainable solutions to replace FM are identified.

Insect meal has been developed as the best substitute ingredient to be included in animal feed (Abdel-Tawwab et al., 2020; Abdel-Latif et al., 2021) due to its high amino acid content, lipid profiles with high digestibility (Wang et al., 2005; Nogales-Merida et al., 2019) and high content of vitamins and minerals (Akinawa & Ketiku, 2000). Furthermore, insect farming has several advantages over traditional animal feed, including environmentally friendly breeding conditions, a short life cycle, lower production cost, lower carbon footprint, less competition for space or resource complement and high feed conversion efficiency (Henry et al., 2015; Huis & Oonincx, 2017; Taufek et al., 2017; Dickie et al., 2019; Lambert et al., 2022).

FM has been entirely replaced by insect meals in relation to a few fish species, such as guppy (Perera & Bhujel, 2022) and, African catfish (Taufek et al., 2017) in addition to tilapia. Though Nile tilapia has been frequently researched on the topic of FM replacement (Jabir et al., 2012; Sanchez-Muros et al., 2015; Freccia et al., 2016; Muin et al., 2017; Gbai et al., 2019; Tippayadara et al., 2021; Perera & Bhujel, 2021a; Perera & Bhujel, 2021b) only some stages of Nile tilapia (Gbai et al., 2019; Tippayadara et al., 2021;) have been completely replaced by FM. House cricket and field crickets are two edible cricket species on larger scales. The FM replacement potential of the above two cricket species has not been compared and researched in relation to the Nile tilapia fingerling stage. Therefore, this experiment was conducted to investigate the most suitable cricket species to replace FM.

Cricket meals are comparable to FM in terms of nutritional specifications such as amino acid profiles, fatty acid profiles, and proximate compositions (Jeong et al., 2021). The range values of the crude protein, lipid, fiber and ash percentages of the most edible cricket powders are 49-71%, 7-25%, 1-13%, and 3-10% respectively (Magara et al., 2021). Moreover, the ranges of the same parameters of high-quality FM are 60-72%, 4-20%, 0-0%, and 10-20%, respectively (Barlow, 1993; Miles & Chapman, 2021). Moreover, the ranges of the EAAs of cricket powders and FM are 0.27-7.90 g/100g protein (Magara et al., 2021) and 0.68-5.10 g/100g protein (Masagounder et al., 2016) respectively. Furthermore, house and field crickets are sustainable and more nutritious cricket species (Straub et al., 2019; Bawa et al., 2020).

Nile tilapia (*Oreochromis niloticus*) is the third major species in the world aquaculture in terms of production (FAO, 2020). Compared to the carnivorous fishes and shrimp species, the FM dependency in tilapia feed is less. Though the inclusion level has been reduced, FM is still favoured in Nile tilapia formulations (Nguyen, 2015; Sarker et al., 2020). Moreover, the FM has been completely replaced by maggot meal in the Nile tilapia fingerling diet (Ogunji et al., 2008; Gbai et al., 2019). In contrast, HCM could replace the FM in up to 60% of the Nile tilapia fingerling diet (Lee et al., 2017). However, previous research findings related to the replacement of FM by FCM in the Nile tilapia fingerling stage are insufficient. Similarly, FCM could be used to replace FM up to 50% in the hybrid red tilapia juvenile diet (Hanan et al., 2022). Hence, all the facts mentioned above were considered in, designing this experiment to replace FM with HCM and FCM in the Nile tilapia fingerling feed.

Materials and Methods

The experiment was conducted in the indoor aquarium of the division of Aquaculture and Aquatic Resources Management (AARM) of the Asian Institute of Technology, Thailand, from October to December 2021.

Experimental Setup

Nine glass aquaria (107.5 cm (length)×46.5 cm (width)×46.5 cm (height)) were prepared to stock Nile tilapia fingerling. Those tanks were filled with conditioned freshwater to 30.5 cm in depth. Each aquarium was provided with an internal filter. Each aquarium was supplied with compressed air by using a 385W HAILEA ACO-380 air compressor (Hailea Group Co. Ltd, Guangdong, China). Air temperature and light intensity were monitored and controlled at 28.6±0.7°C and 985±74 Lux, respectively. The photoperiod was set for 12 hours (light)/12 hours (dark) using fluorescent tube bulbs as a light source during the experimental period. Illumination was regulated by a SMART SENSOR AS803 digital lux meter (ARCO Electronics Ltd, Dong Guan City, China).

Procuring and Conditioning Nile Tilapia Fingerling for the Experiment

Randomly selected two hundred and twenty-five all-male Nile Tilapia (*Oreochromis niloticus*) fingerling (initial weight, 1.01±0.08 g/fish) were purchased from the AARM hatchery and acclimatized for a week. Those fish were stocked in the glass aquarium at a density of 164 /m^3 (25 fish per aquarium). The control feed containing 37.5±0.7 % crude protein was fed twice daily at 5% of the body weight (Perera and Bhujel, 2021a) during the above week. Water height was maintained at 30.5 cm, and water quality parameters were maintained as pH; 7.6±0.8, dissolved oxygen; 6.4±3.1 mg/l, ammonia; 0.137±0.052 mg/l, alkalinity; 82.2±8.7 and water temperature; 25.3±0.5°C.

Experimental Diets

Three iso-protein (37.54±0.15% crude protein) and iso-caloric (19.32±0.24 kJ GE/g) test diets were prepared as outlined in Table 1. The crude protein content of the FM was replaced by HCM and FCM at 100% (100HCM and 100FCM, respectively). The HCM and FCM were purchased from Cricket Fit Limited, Thailand. The rest of the ingredients were purchased from Weeramas

Karnkaset Company, Thailand.

Research feeds were prepared, mixing the ingredients according to Table 1 formulas. Warm distilled water was included in the mixture to form a duff. It was passed through a VENZ SP 1/2 mincer (VENZ Co. Ltd, Bangkok, Thailand), and 1.5-2.0 mm diameter pellets were obtained. After transferring to the trays, the feeds were dried at 60°C for 24 hours in a memmert UF 110 electric oven (memmert GmbH+ Co., Schwabach FRG, Germany). Finally, drying constantly, cooled feeds were transferred to sealed bags and stored in a refrigerator (4-10°C).

Chemical Composition of the Ingredients and Diets

Proximate Analysis of the Ingredients and the Feeds

The standard protocol of AOAC (1990) was followed to test the moisture, ash, fiber, crude protein, and crude lipid of the ingredients and feeds. Moisture content was tested by Air Oven Method utilizing memmert UF 110 oven (memmert GmbH+ Co., Schwabach FRG, Germany). Ash content was determined by incineration in a Lab Tech LEF-115S-1 muffle furnace (DAIHAN LABTECH Co. Ltd, Namyangju City, Korea). The crude fiber was tested following Weende Method operating FOSS Fibertec 1020 apparatus (FOSS Scino (Suzhou) Co. Ltd, Suzhou, China). The crude protein was estimated according to the Micro-Kjeldahl Method operating FOSS Kjeltec 8100 apparatus (FOSS Analytical AB, Hoganas, Sweden). As recommended by Ritvanen et al. (2020), 5.0 was used as the nitrogen-to-protein conversion factor for both cricket meals. The crude lipid was determined by Soxhlet Method using FOSS Soxtec 2043 apparatus (FOSS Scino (Suzhou) Co. Ltd, Suzhou, China). The Gross energy of the research diets was tested using LECO AC 500 Isoperibol Calorimeter (LECO, Michigan, USA).

Amino Acid Profiles of FM, and Cricket Meals

FM and cricket meal samples were analyzed using biochrom 30^{+} amino acid analyzer (Biochrom Ltd, Cambridge, United Kingdom) to test the amino acid profiles following the standard protocol of AOAC (2005).

Rearing and Feeding

The fingerlings of *O. niloticus* were conditioned for one week, as mentioned in 2.1. The body weights of the randomly selected ten fish in each treatment were measured and recorded on the first day of the experiment, using OHAUS PIONEER PA 214C chemical balance (OHAUS Corporation, Parsippany, USA). The fish were hand-fed at 5% of the body weight twice daily at 09.00 and 15.00 hours. The body weights of the randomly selected ten fish in each treatment were measured every week, and feed budgets were adjusted. Unused feed particles were collected by siphoning after 15 minutes of feeding and dried in the above-mentioned oven at 55°C. Finally, the body weights of all fish in each treatment were measured after 42 days using the same

Table 1. Feed formulas and nutritional information of the test diets (%, dry weight basis)

Ingredients	100FM	100HCM	100FCM
Fish meal	30.00	0.00	0.00
House cricket meal	0	36.42	0.00
Field cricket meal	0.00	0.00	30.40
Soybean meal	47.00	47.78	47.00
Rice polish	11.20	4.50	10.80
Corn flour	5.00	5.00	5.00
Fish oil	2.00	1.50	2.00
Vitamin-mineral[1]	2.00	2.00	2.00
Vitamin C	0.20	0.20	0.20
CMC[2]	2.00	2.00	2.00
Dicalcium phosphate	0.50	0.50	0.50
Probiotic (BIOVET-YC)[3]	0.10	0.10	0.10
Crude protein (%)	37.71	37.24	37.66
Crude lipid (%)	6.41	7.75	8.29
Moisture (%)	8.42	9.47	8.35
Ash (%)	11.84	7.56	6.91
Fiber (%)	2.76	7.45	8.22
NFE (%)	32.86	30.53	30.57
Energy (kJ/g)	18.94	19.26	19.76

[1]Composition of Vitamin-mineral mixture per 1 kg- Vitamin A-1,000,000 IU, Vitamin D3- 100,000 IU, Vitamin E- 10,000 IU, Vitamin C- 10,000 mg, Vitamin K- 800 mg, Vitamin B1- 1500 mg, Vitamin B2- 1200 mg, Vitamin B6- 750 mg, Vitamin B12- 20 mg, Pantothenic Acid- 3000 mg, Niacin- 2150 mg, Folic Acid- 300 mg, Inositol -25,000 mg, Biotin- 25 mg, Selenium- 30 mg, Iron- 20,000 mg, Zinc- 32,000 mg, Copper- 2,000 mg, Cobalt- 150 mg, Iodine- 325 mg, Magnesium- 6,000 mg, Potassium- 100 mg, Sodium- 5.9 mg, Manganese- 1500 mg

[2]CMC; Carboxyl methyl cellulose

[3]Composition of BIOVET-YC (Probiotic) per 1 Kg – *Saccharomyces cerevisiae* (SC-47)- 300,000 million CFU, *Saccharomyces boulardii*- 50,000 million CFU, *Lactobacillus acidophilus*- 45,000 million CFU, *Propionibacterium freudenreichil*- 50,000 million CFU, Seaweed Powder- 100g

balance. Growth performance and the related parameters during the experiment period were calculated based on the following equations.

$$\text{Survival Rate} = (\text{Final fish number}/\text{Initial fish number}) \times 100$$

$$\text{Weight Gain (WG)} = \text{Final weight (g)} - \text{Initial weight (g)}$$

$$\text{Daily Weight Gain (DWG)} = \text{Weight gain (g)} / \text{Number of days}$$

$$\text{Relative Weight Gain (RWG)} = \text{Weight gain (g)} / \text{Initial weight (g)} \times 100$$

$$\text{Specific Growth Rate (SGR)} = (\text{Ln weight (final)} - \text{Ln weight (initial)}) / \text{number of days} \times 100$$

$$\text{Feed Conversion Ratio (FCR)} = \text{Total feed consumed} / \text{Total weight of fish produced}$$

where:

Total weight of fish produced= final weight of the fish- initial weight of the fish

Water Quality Management

Two-thirds of the water volume was changed from each aquarium every week. The excreta were siphoned out daily, followed by refilling the tank up to 30.5 cm level. Total ammonia was tested weekly according to the standard methods of APHA (1998). Dissolved oxygen was measured daily using LAQUA DO 220 DO meter (HORIBA Advanced Techno Co. Ltd, Kyoto, Japan). The pH and water temperature were measured daily using EUTECH pH 150 pH meter (Thermo Fisher Scientific Eutech Industries Pte Ltd, Singapore). Water quality parameters were maintained among the optimum ranges as water temperature 25.7±2.3°C, pH 7.8±0.9, dissolved oxygen 6.3±2.8 mg/l total ammoniacal nitrogen 0.136±0.048 mg/l, and total alkalinity 81.9±9.

Statistical Analysis

All the measurements were repeated in triplicate. Data were processed and compiled using MS Excel. Treatments were compared using one-way ANOVA followed by Tukey's post hoc test after confirming the normality of the data and homogeneity of the variance by the Levene's test. In addition, linear and quadratic regression analyses were done to derive the relationship between the growth of the nursery stage of the fish with the experimental days. Statistical analysis was completed using SPSS software version 22.0. All the means were expressed as the mean ± standard error at $P<0.05$ significance level.

Results

Proximate Composition of FM, HCM, and FCM

The proximate composition of FM, HCM, and FCM is significantly different from each other, as shown in Table 2. However, the crude protein percentage is significantly lower in HCM than in FM and FCM. Moreover, lipid content in HCM is significantly higher than that of FCM and FM, while the lipid content of the FCM is significantly higher than FM. Furthermore, the fiber contents of FCM and HCM are significantly higher than FM.

Amino Acid Profiles of FM, HCM, and FCM

Table 3 shows the differences in the EAAs profiles between the FM and cricket meals. Lysine and methionine contents of HCM are significantly lower than that of FM. However, methionine content of FCM is lower than that of FM while lysine contents of FCM and FM are statistically similar. Furthermore, valine, leucine, and arginine amounts of FCM are significantly higher than HCM. Arginine, leucine, threonine, and valine contents are significantly higher in the FCM than that of the HCM. Therefore, FCM is richer in EAAs compared to HCM.

Fish Growth Performance

During the experimental period, all experimental diets were well ingested by the fish. Results confirmed that the growth performance of 100FM is significantly higher than that of 100HCM and 100FCM in terms of final weight, WG, DWG, and RWG. The SGR of 100FM and 100FCM are statistically similar to each other and significantly higher than the SGR of 100HCM.

Table 2. Proximate composition of the FM, HCM, and FCM (%, dry weight basis)

Parameter	FM	HCM	FCM
Dry matter content	90.6^{a}	92.8^{c}	91.3^{b}
Protein	58.7^{b}	48.4^{a}	58.0^{b}
Lipid	6.1^{a}	12.4^{c}	8.2^{b}
Moisture	9.4^{c}	7.2^{a}	8.7^{b}
Ash	23.8^{c}	6.3^{b}	4.8^{a}
Fiber	0.6^{a}	7.7^{b}	9.2^{c}
NFE	1.4^{a}	18.0^{c}	11.1^{b}
Energy (KJ/g)	19.66^{a}	26.51^{c}	24.40^{b}

Meanwhile, the FCR of 100FM and 100FCM are statistically similar to each other and lower than the FCR of 100HCM. On the other hand, the survival rates of the fingerling in all treatments were equal, ranging from 93.33-97.33% (Table 4).

The growth pattern of all the treatments showed polynomial relationship during the experiment period. The weekly growth curve (Figure 1) clearly showed that the fry fed with the 100FM diet grew significantly higher than the other groups.

Table 2. Comparison of amino acid profiles of FM, HCM, and FCM used in the experimental diets (g/100g, dry weight basis)

Amino Acid	FM	HCM	FCM
Arginine	3.58±0.04^{a}	3.89±0.06^{a}	4.64±0.05^{b}
Histidine	0.65±0.03^{a}	0.67±0.05^{ab}	0.93±0.02^{b}
Isoleucine	1.84±0.17^{a}	2.00±0.07^{ab}	2.47±0.10^{b}
Leucine	3.71±0.64^{a}	3.89±0.17^{a}	4.85±0.05^{b}
Lysine	4.39±0.01^{b}	3.64±0.04^{a}	4.29±0.15^{ab}
Methionine	1.59±0.09^{b}	0.97±0.01^{a}	1.18±0.05^{a}
Threonine	2.25±0.06^{ab}	2.15±0.08^{a}	2.67±0.06^{b}
Valine	2.41±0.05^{a}	2.76±0.03^{a}	3.55±0.07^{b}
Alanine	3.05±0.02^{a}	3.82±0.01^{b}	4.92±0.03^{c}
Aspartic Acid	4.80±0.01^{a}	4.81±0.08^{a}	5.52±0.07^{b}
Cystine	1.00±0.00^{ab}	1.17±0.06^{b}	0.90±0.00^{a}
Glutamic acid	7.49±0.12^{b}	6.20±0.06^{a}	8.02±0.12^{b}
Glycine	3.93±0.01^{b}	2.89±0.10^{a}	3.58±0.06^{b}
Proline	2.80±0.07^{a}	3.45±0.04^{b}	4.30±0.01^{c}
Serine	2.16±0.04^{a}	2.63±0.40^{a}	2.88±0.07^{a}

Notes: All values are Mean ± SE, calculated from three replicates. ^{a,b}Means with different letters are significantly different (P<0.05) from each other Phenylalanine, Tryptophan, and Tyrosine were not detected.

Table 4. Growth performance of Nile tilapia (*Oreochromis niloticus*) fingerling during the research period

Parameter	100FM	100HCM	100FCM
Initial weight (g/fish)	1.44±0.02^{a}	1.34±0.04^{a}	1.31±0.02^{a}
Final weight (g/fish)	12.04±0.14^{a}	7.66±0.12^{c}	9.38±0.27^{b}
Weight gain (g/fish)	10.60±0.07^{a}	6.32±0.12^{c}	8.08±0.23^{b}
DWG (g/day)	0.30±0.00^{a}	0.18±0.00^{c}	0.23±0.01^{b}
RWG	737.42±31.49^{a}	474.24±19.31^{c}	618.34±3.84^{b}
SGR	6.06±0.10^{a}	4.8±0.24^{b}	5.64±0.01^{a}
Survival Rate (%)	97.33±0.67^{a}	93.33±0.33^{a}	93.33±0.33^{a}
FCR	1.37±0.01^{a}	1.79±0.03^{b}	1.30±0.04^{a}

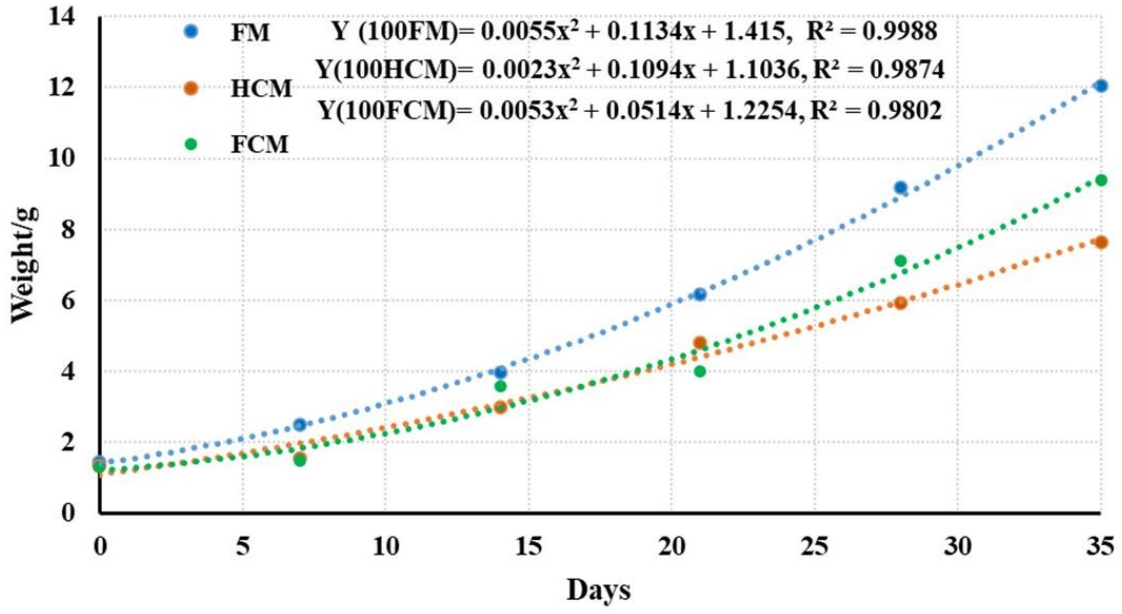

Figure 1. Growth curve of *O. niloticus* fingerling during the experiment period.

Discussion

Insects and mealworms potentially serve as high-quality protein sources to replace FM (Abdel-Tawwab et al., 2020; Shafique et al., 2021). The findings of the experiment confirmed that the SGR and FCR of diets containing 100FM and 100FCM were statistically similar to each other and better than that of 100HCM. Additionally, 100FCM has great potential replacement FM as it significantly increases the final weight of fish, WG, DWG, and FCR compared to the diet containing 100HCM. Hence the increased growth observed in the current study can be attributed to the multiple roles of FCM as reported for fish survival, growth performance, and nutrient utilization. However, current results showed that the FM could not be entirely replaced by both cricket meals in the used diet formulations for Nile tilapia fingerlings. Previous research has also shown that FCM can replace up to 80% of FM in the Nile tilapia fry diet (Perera & Bhujel, 2021a) and red tilapia juvenile diet (Hanan et al., 2022) without any adverse effects on growth, survival, and feed utilization, apparent digestibility, and feed conversion efficiencies.

Previous studies have confirmed that FM can be partially replaced by various insect meals, including maggot meal (Ogunji et al., 2007, 2008; Tran et al., 2015; Gbai et al. 2019), mealworm meal (Sanchez-Muros et al., 2015; Fontes et al., 2019), and super worm meal (Jabir & Vikineswary, 2012) in tilapia feed. The above results revealed that FM replacement percentage by insect meals depends on the stage of the fish and the insect meal species. Therefore, the total replacement of FM with insect meals seems complicated for the fry and nursery stages. However, the potential for completely replacing for FM with insect meal is relatively higher for fingerling and juvenile-stage fish. Additionally, the complete replacement of FM with black soldier fly larvae meal in *O. niloticus* has been successful (Tippayadara et al., 2021) as has the replacement of FM with FCM in African catfish (Taufek et al., 2017).

The red hybrid tilapia fingerling achieved a negative growth rate (-3.8±0.1g) when it was solely fed by HCM (Lee et al., 2017). On the contrary to the above results, 100HCM recorded a positive weight gain (6.32±0.12g) in this experiment though FM could not be totally replaced by HCM. Lee et al., (2017) have mentioned that the inclusion of HCM in high levels (>60%) adversely affects liver functions and growth reduction. Therefore, hazardous compounds in HCM should be identified in future research. There is no previous data are available on the replacement of FM with *G. bimaculatus* in the tilapia fingerling diet. However, results comparable to the commercial feed were achieved when *G. assimilis* meal was included in the tilapia fingerling feed (Alfaro et al., 2019). Furthermore, FM was completely replaced by maggot meal in the tilapia fingerling diet (0.75±1.93g) with SGR value of (4.01±0.09g) (Gbai et al., 2019). In contrast, higher SGR value were recorded for 100HCM (4.80±0.24g) and 100FCM (5.64±0.01g) in this experiment. It can be assumed that better formulations could result in higher performance. Therefore, the cumulative effects of the other ingredients could be utilized properly to compensate for the negative results of the insect meal-included diets in future experiments.

Amino acid profiles of the ingredients are more important in the feed formulations than crude protein content (Houlihan et al., 2001). EAAs of FM and FCM were comparable to estimated requirements for Nile tilapia (Table 3), which are close to earlier reports (Houlihan et al., 2001; Wang et al., 2005; Taufek et al., 2017; Perera & Bhujel, 2022; Hanan et al., 2022). Lysine content in FCM is comparable to FM, and some EAAs are available in higher concentrations than HCM. However, methionine content is poor in both cricket meals, and it causes poor growth and feed efficiency (NRC, 2011). The lower availability of crucial EAAs could be a significant reason for the poor growth performance in fish fed with cricket meals. As a result, the fish fed with FCM achieved higher growth compared to those fed with HCM. Moreover, the high crude protein, lipid, and energy in the proximate composition of FCM confirmed its high-performance capacity. However, it was noted that the ash content was significantly higher in FM compared to both cricket meals. Based on these results, it is recommended that FCM is a better option than HCM in terms of nutrient composition.

The crude protein content of the HCM (48%) is significantly lower than FM (58.7%) and FCM (58%). Therefore, HCM-fed fish needs more insect meals to satisfy the dietary amino acid requirement. It could be assumed that the high feed intake causes high FCR.

The digestive system of teleost fish, such as tilapia, has not been well developed at the onset of exogenous feeding, while the enzyme activity of these fishes during the initial phase is also poor (Lahnsteiner, 2017). Moreover, the digestibility of the complex protein increases with age and size, and there are some issues with digesting the complex proteins for larval fish (Hamre et al., 2013). Therefore, the nursery feed for the nursery fish should be supplied with highly digestible ingredients as the digestibility of FM is high in tilapia feeds (Fontainhas-Fernandes et al., 1999; Maina et al., 2002; Khanom et al., 2017).

Insects are supposed to be a source of chitin (Abidin et al., 2020). Chitin in insects is neither degraded nor absorbed in the small intestine, negatively affecting protein estimation and digestibility (Rodriguez-Rodriguez et al., 2022). In contrast, the presence of chitinolytic enzyme has been found in the gastrointestinal tract and serum of Nile tilapia (Molinari et al., 2007). Therefore, it is necessary to determine the specific effects of chitin related to different fish species. The digestibility of the larvae stage of the black soldier fly was 89.7%, and it sharply decreased to 50% for the prepupae stage (Rodriguez-Rodriguez et al., 2022). Consequently, deposition of the chitin in the prepupae could be assumed as the reason for the low digestibility.

Therefore, it is worth identifying the optimum harvesting stage of the insects to enhance the digestibility of the applicable insect meal.

Furthermore, processing, method, slaughter method, and cooking techniques also affect digestibility (Rodriguez-Rodriguez et al., 2022), and the optimum technical know-how of insect meal preparation should be studied. The growth parameters, apparent digestibility, stress tolerance, and survival have been significantly increased in the *O. niloticus* diets while increasing the L-ascorbic acid supplementation level (Perera & Bhujel, 2021b). Accordingly, feed additives can potentially increase the parameters mentioned above and, generally, the nutritional value of insect meals. Therefore, insect meal could be a valuable animal protein source for FM, when the optimum additives are identified and applied.

Results of the present study on the use of FCM have demonstrated that it is a potential source of animal protein that contains high levels of nutrients comparable to FM. However, insect meal is not supposed to be an economical and practical animal protein source due to its higher market value than FM (Morales-Ramos et al., 2020). Moreover, consumers are unwilling to pay high prices for the insect meal included products (Popoff et al., 2017). The inclusion of insect meals has led to increasing the production cost of seabass feeds. (Pulina et al., 2018). However, when black soldier fly larvae meal was included in tilapia feeds, replacing the FM, it was cost-equivalent up to 100% (Wachira et al., 2021). The inclusion of maggot meal can reduce the Nile tilapia feed production cost (Gbai et al., 2019). Therefore, economical, and optimum insect meals should be identified, and at the same time, techniques should be identified to reduce the production cost.

Conclusion

Field cricket (*Gryllus bimaculatus*) meal has the potential as a substitute for fishmeal in the diet of *O. niloticus* fingerlings. The results of the study indicate that the growth performance and feed utilization of the fingerlings are improved with FCM compared to the HCM. These findings suggest that FCM may be a suitable alternative animal protein source for FM in aquafeeds. However, further research is necessary to identify the methods to enhance the nutrient availability of insect meals in aquafeeds.

Ethical Statement

No fish were sacrificed in this experiment. All recommended guidelines for the care and use of fish were followed. Optimum water quality, feeding and environmental conditions were provided to fish, and those conditions were monitored routinely.

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Author Contribution

G.S.C.P: Conceptualization, Methodology, Data curation, Formal analyzing, and Writing-original draft; **A.D.P**: Writing- review, and editing; **CP:** Formal analysis; **SP**: Laboratory testing, and analyzing.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper**.**

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