Hindawi
Aquaculture Nutrition
Volume 2022, Article ID 9367587, 10 pages
https://doi.org/10.1155/2022/9367587

Review Article

A Review and Meta-analysis of the Effects of Replacing Fishmeal with Insect Meals on Growth of Tilapias and Sharptooth Catfish

Mmaditshaba Rapatsa and Ngonidzashe Moyo

Aquaculture Research Unit, School of Agricultural and Environmental Sciences, Faculty of Science and Agriculture, University of Limpopo (Turfloop Campus), Private Bag X1106, Sovenga 0727, South Africa

Correspondence should be addressed to Mmaditshaba Rapatsa; rapatsa.maditshaba13@gmail.com

Received 15 December 2021; Revised 2 February 2022; Accepted 22 February 2022; Published 10 March 2022

Academic Editor: Zhen-Yu Du

The high cost of fish feed has affected the culturing of tilapias and sharptooth catfish in Africa. However, Africa is well endowed with terrestrial insects that can potentially replace fishmeal in the diets of fish. In this paper, the nutritional index, availability, and cost of selected insect meals are compared. The SOLVER function in Excel was used to formulate least-cost diets of *Musca domestica*, *Gryllotalpa africana*, *Schistocerca gregaria*, *Macrotermes natalensis*, and *Gonimbrasia belina*. The crude protein levels of all the insects were above 50% and met the requirements of both fish species. The essential amino acid index (EAAI) was highest in *M. domestica* (3.2613). Except for *M. natalensis*, all the insect meals met the fat requirements for tilapias and sharptooth catfish. The most available insects were *S. gregaria* and *M. domestica*. Feed value was highest in fishmeal (15.62) followed by *M. domestica* (15.52). A meta-analysis of the effects of replacing fishmeal with insect meal on growth performance of tilapias and sharptooth catfish was also carried out. The effect summary for the specific growth rate was significant whereas the effect summary for the food conversion ratio was not significant. The relationship between fishmeal replacement levels and response ratio showed wide scatter. It was thus not possible to determine the optimum replacement level. *Musca domestica* is recommended in the replacement of fishmeal.

1. Introduction

Tilapias and sharptooth catfish are two of the most widely cultured fish species in Africa [1]. Both species are amenable to culture because they are hardy species that are tolerant of poor water quality and wide temperature ranges. Among tilapias, *Oreochromis mossambicus* is the most widely cultured tilapia in Southern Africa [2]. It has been reported to feed on aquatic and submerged terrestrial plants, benthic algae, phytoplankton, zooplankton, and organic detritus [3–5]. Evidently, *O. mossambicus* is euryphagous. Since *O. mossambicus* opportunistically feeds on insects in nature, it can be assumed that it is preadapted to utilizing insect-based diets. *Clarias gariepinus* (sharptooth catfish) is the most widely cultured clariid in Africa. It is known to be an omnivorous fish that feeds on a variety of food items such as fish, insects, phytoplankton, zooplankton, macrophytes, and detritus [6, 7]. Spatary et al. [8] identified more than 50 species of animals and plants from the intestines of one population of *C. gariepinus* in Lake Kinneret, Israel, and these included fish, insects, and zooplankton. Kadye and Booth [9] recorded that insects constituted 87% of the diet of *C. gariepinus* in Great Fish River in Eastern Cape, South Africa. It is clear from the literature that insects constitute an important food item in the diet of sharptooth catfish. It can also be assumed that sharptooth catfish is preadapted to utilizing insect-based diets.

Despite numerous efforts by governments in Southern Africa, warm water aquaculture has failed to attain a commercial status. In a recent review, Moyo and Rapatsa [10] identified the cost and quality of feed as one of the major constraints affecting aquaculture in Southern Africa. One way of reducing the cost of feed is through the replacement of fishmeal with locally available ingredients. In recent years, insects have been identified as an alternative protein source for the replacement of fishmeal, which is becoming increasingly expensive [11–13]. Consumers, particularly in developed countries, are reluctant to eat fish that have been fed on fishmeal because of sustainability concerns [14]. Insects have been described as good candidates to replace fishmeal because some insects have high protein content and good amino acid and fatty acid profile [11, 15]. There are many insects in Southern Africa that can probably potentially replace fishmeal, and yet, no practical diets have ever been formulated. In this paper, we seek to evaluate the potential of insect meals in Southern Africa. The insects that will be investigated are mopane worm (*Gonimbrasia belina*), locust (*Schistocerca gregaria*), house fly maggot (*Musca domestica*), termites (*Macrotermes natalensis*), and crickets (*Gryllotalpa africana*). These insects are widely distributed in Southern and Central Africa, and their proximate composition has been determined in some studies. Most studies [12, 16–18] on the replacement of fishmeal have concentrated on the nutritional value of the insect and have ignored the availability and the price of the insect. The concept of feed value has seldom been explored in studies that investigated the effect of insect meals as substitutes of fishmeal on various fish species. Feed value incorporates nutritional quality, price, and availability. In this study, we highlight the feed value of these commonly available insects in the diet of tilapias and sharptooth catfish.

The overall effect of replacing fishmeal with insect meal in the diets of tilapias and sharptooth catfish has not been evaluated. It is thus prudent to carry out meta-analysis. Hua [19] carried out a meta-analysis of the effects of replacing fishmeal with insect meals on different fish species. Thus, their study did not specifically focus on tilapias and the sharptooth catfish. Meta-analyses integrate information from different studies. Since tilapias and sharptooth catfish are important aquaculture species, it is important to integrate the different experimental observations through a quantitative method like meta-analysis. Therefore, the objectives in this study were to rank the insect feed ingredients in Southern Africa according to feed value, formulate least-cost insect diets for fish farmers, and undertake meta-analysis on the effects of replacing fishmeal with insect meals on growth performance of tilapias and sharptooth catfish.

2. Methods

2.1. Insect Feed Value. The nutritional value of *G. belina*, *M. domestica*, *S. gregaria*, *M. natalensis*, and *G. africana* was determined using data available from literature listed in Table 1. The proximate composition (crude protein, lipids, and ash) of each of the insects under study was recorded. The search engines used were Google Scholar, Science Direct, Scopus, Microsoft Academic, BASE, CORE, and Semantic Scholar. The essential amino acid index of the insect ingredients was calculated using the Penaflorida [20] formula below:

$$\mathrm{EAAI} = \sqrt[n]{\frac{\mathrm{aa1}}{\mathrm{AA1}} \times \frac{\mathrm{aa2}}{\mathrm{AA2}} \times \cdots \cdots \frac{\mathrm{aa}n}{\mathrm{AA}n}}, \quad (1)$$

where aa is the amount of amino acid in the insect ingredient, AA is the requirement of the same amino acid in fish tissue, and n is the total number of amino acids used in the calculation. Thus, the EAAI is a ratio between the concentration of amino acid in the ingredient and requirement of the fish for the amino acid.

The insect feed ingredients were ranked according to feed value. Feed value incorporates the nutritional composition of the insect ingredient, their availability, and cost. It was calculated using the formula below:

$$\text{Feed value index} = 2N_i + \mathrm{Av}_i + \frac{1}{C_i}, \quad (2)$$

where N_i is the nutritional index which was determined as follows:

$$N_i = 4P_i + F_i + \frac{\mathrm{CHO}_i}{5}, \quad (3)$$

where P_i is protein content in the ingredient/optimal protein requirement of the fish, F_i is fat content in the ingredient/optimal fat requirement of the fish, and CHO_i is carbohydrates in the ingredient/carbohydrate requirements of the fish. Av_i is the availability of the ingredient, and C_i is the cost of the ingredient.

The nutritional requirement of tilapias and catfish was obtained from literature and listed in Table 1.

Picker et al. (2014) was used to estimate insect availability (Av_i). Picker et al. [21] has maps showing geographical distributions in South Africa, and the availability of insects in Southern Africa was scored between 0 and 10 based on the maps in Picker et al. [21]. The scores of the distribution map were validated through interviews with insect traders who were also asked to score the abundance of insects on a scale of 0-10. The insect cost was determined from insect traders at a local insect market and expressed in US dollars.

2.2. Formulating Least-Cost Insect Diet for Fish Farmers in Southern Africa. Least-cost formulation of insect diets optimizing the combination of feed ingredients that supply the required nutrients at low cost was formulated. The insect-based diets were formulated in Excel which comes with a programming capability of SOLVER function that has linear programming functionality. The SOLVER function was used in least-cost diet formulation. The first step was to list the insect ingredients available in Southern Africa, their cost, and chemical composition (crude protein and metabolizable energy) as a database. In this study, we only incorporated three components, namely, crude protein, metabolizable energy, and cost. The main focus was on protein which is the most expensive component in fish feed and metabolizable energy which affects fish growth. The second step was to specify the diet quality (based on literature), and the feeds were balanced for protein and energy. Vitamin and mineral premix, oil, and binder were incorporated in the diets. The third step was to specify the formula in Excel for calculating the crude protein (CP), metabolizable energy (ME), and the cost of

Table 1: Proximate composition (%) of insects in Southern Africa and the nutritional requirements of tilapias and sharptooth catfish.

Components	*Gonimbrasia belina*[1]	*Schistocerca gregaria*[2]	*Musca domestica*[2]	*Macrotermes sp.*[3]	*Gryllotalpa africana*[2]	Fishmeal[1]	Tilapias[4]	Sharptooth catfish[5]
Crude protein	56.83	50.79	50.4	54.69	59.46	65.5	30	40-42
Lipids	12.92	13	18.9	2.90	15.19	12.0	5-6	9-12
Carbohydrates	12.14	13.46	4.37	36.71	21.81	1.8	—	—
Ash	10.40	2.42	6.25	3.70	4.66	18	—	—

[1]Rapatsa and Moyo [31]; [2]Tran et al. [34]; [3]Ntukuyoh et al. [35]; [4]Jauncey et al. [23]; [5]Hecht et al. [36].

the formulated feed. Finally, in the SOLVER function, the cost US$/kg was selected as the target cell and the optimum diet was produced.

2.3. Meta-analysis of the Effects of Insect Meal on the Growth of Tilapias and Sharptooth Catfish. Meta-analysis is a useful tool that was used to integrate results from different studies. A comprehensive search of literature on incorporation of insect meals in the diets of tilapias and sharptooth catfish in Southern Africa was undertaken. The papers were selected using a combination of the terms tilapia, African catfish, insect feed, growth performance, and fishmeal replacement. A focused search yielded 167 full papers, and the final papers (Table 2) used for meta-analysis were retained using the following criteria:

(i) Studies with a control (fishmeal)

(ii) Fish fed to satiation

(iii) Studies that used fish size between 2 and 70 g

(iv) Studies with experimental diets using insect meals and an alternative to fishmeal

(v) Studies with at least 3 replication

(vi) Studies that determined SGR and FCR or both indices could be calculated from the given data. The indices must be calculated using the formula, $\text{SGR} = 100 \times \ln Wt - \ln W0/t$ and $\text{FCR} = \text{feed consumed/weight gain}$

The mean effect size (Hedge's g) was determined for two responses (SGR and FCR). Mean effect size measures the strength of the relationship between the experimental group and the control group. This was done following the random effects approach in the R programme version 4.1.1. Comparisons of the different studies were done by calculating the response ratio [22]. The response ratio was calculated by dividing the growth parameters of the experimental group and the control group. This shows the proportionate change resulting from experimental manipulation.

3. Results and Discussion

3.1. Nutritional Quality of Insect Meals. The crude protein levels in the selected insects varied between 50.4 and 59.46% (Table 1). *Gryllotalpa africana* has the highest crude protein level. Although fish do not have a quantitative protein requirement per se, it is generally understood that *O. mossambicus* requires between 30 and 35% protein [23] and *C. gariepinus* requires between 40 and 42% protein [24]. Evidently, all the selected insects in this study meet the protein requirement of both fish species. However, the crude protein levels of all the insects are below that of fishmeal.

Lipid levels varied between 2.9 and 18.9% (Table 1). *M. domestica* has the highest fat level. *Macrotermes* species has a very low lipid level. The crude fat requirements of *O. mossambicus* and *C. gariepinus* were estimated to be 5-6% and 9-12%, respectively (Table 1) Lipid levels greater than 20% impair the immunity of fish [25]. There is thus no need to defatten any of the selected insects. However, Fasakin et al. [26] reported that defatting enabled the researchers to increase dietary inclusion levels of *M. domestica* in *C. gariepinus* without compromising the growth of the fish.

Carbohydrate levels varied between 4.37 and 36.71% (Table 1). *Macrotermes* sp. has the highest carbohydrate level. Both *O. mossambicus* and *C. gariepinus* do not have quantitative requirements for carbohydrates. Although carbohydrates are a cheap source of energy for fish, high levels of carbohydrates reduce digestibility because some carbohydrates have antinutritional elements which may affect the growth performance of the fish [13, 27].

The EAAI ranged between 0.5135 and 3.2613 and was highest in *M. domestica* and lowest in *M. natalensis* (Table 3). *Musca domestica* is high in methionine and lysine. It has a methionine level of 2.2 and a cysteine level of 0.7, and both are way above the levels found in fishmeal (Table 3). Lysine levels in *Musca domestica* are higher than fishmeal. Lysine is one of the limiting amino acids in fish. Lysine, methionine, tryptophan, and arginine are the most common limiting amino acids in fish. Methionine, lysine, and tryptophan levels in *M. domestica* are above the requirements for both *O. mossambicus* and *C. gariepinus* (Table 3). Methionine, lysine, and cysteine levels in *M. natalensis* are way below those of fishmeal (Table 3) and do not meet the amino acid requirements for both *O. mossambicus* and *C. gariepinus*.

Linolenic (C18:3(n-3)) fatty acids were highest in *S. gregaria* and lowest in *M. natalensis* (Table 4). Linoleic (C18:2(n-6)) fatty acids were highest in *G. africana* and lowest in *G. belina* (Table 4). The quantitative omega 3 and omega 6 requirements for both *O. mossambicus* and *C. gariepinus* are not known. However, it is generally estimated that both omega 3 and omega 6 must constitute between 1 and 2% of the fish diet. Both omega 3 and omega 6 are limiting fatty acids. *Musca domestica* and *G. africana* had high

Table 2: Source of data for meta-analysis.

Author	Fish species	Fish size (g)	Insect species	Replacement level of fishmeal (%)	SGR	FCR
Fawole et al. [37]	*Clarias gariepinus*	4	*Hermetia illucens*	0, 25, 50, 75	2.19, 2.32, 2.66, 2.39	1.86, 1.78, 1.48, 1.65
Adeoye et al. [16]	*Clarias gariepinus*	2.67	*Hermetia illucens*	0, 25, 50, 100	5.48, 4.55, 4.83, 2.39	1.22, 1.41, 1.29, 2.96
Tippayadra et al. [38]	*Oreochromis niloticus*	14.77	*Hermetia illucens*	0, 10, 40, 60, 80, 100	1.32, 1.29, 1.39, 1.41, 1.38, 1.33, 1.30	2.22, 2.15, 2.14, 2.16, 2.16, 2.23
Wang et al. [39]	*Oreochromis niloticus*	68.85	*Musca domestica*	0, 25, 50, 75, 100	1.53, 1.54, 1.54, 1.64, 1.12	1.36, 1.45, 1.45, 1.32, 1.86
Rapatsa and Moyo [31]	*Oreochromis mossambicus*	40	*Imbrasia belina*	0, 10, 20, 40, 80	3.49, 2.86, 2.96, 2.98, 3.16	1.29, 1.53, 1.52, 1.31, 1.25
Rapatsa and Moyo [13]	*Clarias gariepinus*	67.4	*Imbrasia belina*	0, 10, 20, 40, 80	1.85, 1.68, 1.55, 1.45, 1.43	1.22, 1.26, 1.32, 1.34, 1.40
Ng et al. [40]	*Clarias gariepinus*	5.1	*Tenebrio molitor*	0, 20, 40, 60, 80, 100	3.6, 3.8, 3.4, 3.0, 3.3, 2.6	3.27, 3.31, 2.97, 2.55, 2.81, 2.23
Taufek et al. [41]	*Clarias gariepinus*	13.2	*Gryllotalpa bimaculatus*	0, 75, 100	1.93, 2.63, 2.76	1.58, 1.24, 1.17
Devic et al. [18]	*Oreochromis niloticus*	5.7	*Hermetia illucens*	0, 25, 50, 70	3.3, 3.7, 3.2, 3.1	2.2, 2.1, 2.0, 2.1
Gana et al. [42]	*Clarias gariepinus* x *Heterobranchus longifilis*	2.56	*Hermetia illucens*	0, 20, 40, 60, 80, 100	3.81, 4.21, 3.50, 3.42, 3.24, 3.13	2.34, 2.47, 3.04, 2.86, 2.78, 3.11

Table 3: Essential amino acid (g/100 g) profile of insects in Southern Africa and the amino acid requirements of tilapias and sharptooth catfish.

	Gonimbrasia belina[1]	*Schistocerca gregaria*[2]	*Musca domestica*[2]	*Macrotermes natalensis*[3]	*Gryllotalpa africana*[2]	Fishmeal[1]	Tilapias[4]	Sharptooth catfish[5]
Arginine	3.2	—	—	0.67	—	4.2	2.28	1.20
Cysteine	—	0.8	0.7	—	0.8	0.34	—	—
Histidine	1.65	3.0	2.4	0.67	2.3	1.4	1.05	0.42
Isoleucine	2.22	4.0	3.2	0.47	4.4	2.6	2.01	0.73
Leucine	3.50	5.8	5.4	0.9	9.8	4.5	3.40	0.98
Lysine	3.58	4.7	6.1	0.7	5.4	4.8	3.78	1.43
Methionine	0.89	1.4	2.2	0.2	1.4	1.5	0.9	0.64
Phenylalanine	2.51	3.4	4.6	1.09	3.0	2.9	2.50	1.40
Threonine	2.73	3.5	3.5	0.56	3.6	2.5	2.93	0.50
Tryptophan	0.68	0.8	1.5	0.06	0.6	3.4	0.43	0.14
Tyrosine	3.57	3.3	4.7	—	5.2	4.6	1.80	—
Valine	3.14	5.1	4.0	0.61	5.1	3.1	—	0.84
Essential amino acid index (EAAI)	2.2637	2.9503	3.2613	0.5135	3.1050	2.6818		

[1]Rapatsa and Moyo [31]; [2]Tran et al. [34]; [3]Igwe et al. [43]; [4]Jauncey et al. [23]; [5]Hecht et al. [36].

levels of omega 6 in comparison to omega 3, and this resulted in a high n-6/n-3 ratio. These high ratios can affect the stress response of fish [28].

Among the insect ingredients, the nutritional index was highest in *G. africana* and lowest in *M. natalensis* (Table 5). Availability was highest in *S. gregaria* and lowest in *G. belina*. The most expensive insect ingredient is *G. belina* whose price is similar to that of fishmeal (Table 5). Feed value was highest in *M. domestica* and lowest in *M. natalensis*. *G. africana* and *M. domestica* feed values were comparable to that of fishmeal. *Musca domestica* along with black soldier fly and yellow mealworm are regarded as the most promising insect ingredients in fish diets [29]. *Musca domestica* is ranked one of the top potential insect ingredients in terms of feed value. The amino acid profile of *M. domestica* is better than that of fishmeal. It is also available at minimum cost. Despite its high potential in the replacement of fishmeal, *M. domestica* larvae is regarded as a

Table 4: Fatty acid (%) profile of insects in Southern Africa.

FA	*Gonimbrasia belina*[1]	*Schistocerca gregaria*[2]	*Musca domestica*[2]	*Macrotermes natalensis*[3]	*Gryllotalpa africana*[2]
Lauric acid C12:0	<0.1	0.32	—	0.18	—
Myristic acid C14:0	<0.1	2.55	5.5	1.16	0.7
Palmitic acid C16:0	3.2	26.88	31.1	38.35	23.4
Oleic acid C18:1(n-9)	1.6	31.66	24.8	41.74	23.8
Linoleic acid C18:2(n-6)	3.7	24.67	19.8	5.03	38.0
α-Linolenic acid C18:3(n-3)	1.6	10.14	2.0	0.87	1.2
Stearic acid C18:0	1.7	3.81	3.4	9.53	9.8

[1]Rapatsa and Moyo [31]; [2]Tran et al. [34]; [3]Igwe et al. [43].

Table 5: Feed value of insects in Southern Africa.

Insects	Nutritional index	Availability	Cost ($/kg)	Feed value
Fishmeal	7.2606	0.8	1.49	15.692
Musca domestica	6.3616	0.8	0.50	15.520
Gryllotalpa africana	7.0778	0.2	0.50	15.027
Schistocerca gregaria	6.0089	0.9	0.50	14.917
Gonimbrasia belina	6.5747	0.3	1.49	14.121
Macrotermes natalensis	5.7741	0.5	0.50	12.719

nuisance and undesirable entity since it is associated with rotting material. Very few studies have looked at organoleptic parameters of fish that have been fed with *Musca domestica* [17]. Furthermore, consumer acceptance has also been ignored in most studies. There is thus a need to carry out a consumer survey before any commercial uptake of *M. domestica* larvae to replace fishmeal in fish diets is implemented. *G. africana* is also a good candidate in the replacement of fishmeal. Among the insect ingredients, it had the highest nutritional index, but the main challenge is its availability. *Gryllotalpa africana* is nocturnal and spends most of its time underground, and thus, they may be difficult to harvest. Currently, we are not aware of any efforts to farm *G. africana*. Although some species are widely cultivated in Asia, no such cultivation is taking place in Southern Africa. It is suggested that preliminary trial on the culturing of *G. africana* be instituted because of its high potential in the replacement of fishmeal.

Macrotermes natalensis was the least performing insect ingredient. Thus, its inclusion in the replacement of fishmeal is not recommended in the diets of both *O. mossambicus* and *C. gariepinus*. No studies have been undertaken to evaluate the replacement of fishmeal with *M. natalensis*. *Macrotermes natalensis* are also subject to seasonal availability. Unlike most of the insects discussed so far, rearing of termites is very difficult and is not recommended [30]. Furthermore, termites exhibit high emissions of methane.

G. belina had a high nutritional index but low feed value because it is expensive. The effect of replacing fishmeal with mopane worm meal in the diets of fish is poorly documented in Southern Africa. Rapatsa and Moyo [13, 31] used mopane worm meal to replace fishmeal in the diets of *Oreochromis mossambicus* and *Clarias gariepinus*. Another study was undertaken by Mwimanzi and Musuka [32] where they replaced fishmeal with mopane worm meal in the diet of *Oreochromis macrochir*. These are the only three studies where mopane worm meal has been used to replace fishmeal. Concerted efforts are currently underway in Southern Africa to breed *G. belina*. They have been successfully bred in Botswana and Zimbabwe.

3.2. Formulating Least-Cost Insect Diets. In this study, all insect ingredients were incorporated into the fish diet to achieve 35% crude protein and 12 MJ/kg dry matter metabolizable energy (Table 6). The choice of 35% crude protein and 12 MJ/kg metabolizable energy was based on proximate analysis of commonly used pellets in Southern Africa. The SOLVER function managed to converge to a solution because of the high quality of the insect ingredients. In terms of inclusion, the insect meals were ranked as *G. africana*>*G. belina*>*S. gregaria*>*M. natalensis*>*M. domestica*. However, in terms of cost, the insect ingredients are ranked as follows: *G. belina*>*G. africana*>*S. gregaria*>*M. domestica*>*M. natalensis* (Table 6). *G. africana* has the highest protein content of all the insect ingredients in this study, and the cost reduction is 23% on *G. africana* inclusion compared to the control diet. *Gonimbrasia belina* is ranked second in terms of inclusion level (Table 6). The cost reduction on inclusion of *G. belina* is 6% in comparison to the control. *Schistocerca gregaria* ranked third in terms of the inclusion level (Table 6). The cost reduction compared to the control is 24%. *M. natalensis* is ranked fourth in terms of inclusion level (Table 6), and its cost reduction is 31% compared to the control. Despite its high cost reduction, *M. natalensis* had the lowest nutritional index. *Musca domestica* is ranked last in terms of inclusion level (Table 6), and the cost reduction as compared to the control is 28%. Evidently, *M. domestica* has a high cost reduction and is thus recommended in the replacement of fishmeal. All the insect meals resulted in cost reduction; this clearly shows

Table 6: Software predicted nutritional composition (% DM) and cost ($/kg) of formulated feeds.

Component	Control (FM)	% insect inclusion *Gonimbrasia belina*	*Schistocerca gregaria*	*Musca domestica*	*Macrotermes natalensis*	*Gryllotalpa africana*
Maize	25.14	2.50	11.00	10.00	10.00	22.42
Fishmeal	41.62	20.00	20.38	18.11	18.59	23.08
Insect	0	19.74	15.00	15.00	15.00	21.24
Cotton seed meal	14.58	28.70	48.93	48.26	44.02	13.16
Maize bran	13.66	4.06	6.68	3.62	7.39	15.09
Oil	1	1	1	1	1	1
Vitamin & mineral premix	2	2	2	2	2	2
Binder	2	2	2	2	2	2
Total	100	100	100	100	100	100
CP	35	35	35	35	35	35
ME (MJ/kg)	12	12	12	12	12	12
Cost ($/kg)	0.7901	0.7429	0.5993	0.5700	0.5466	0.6087

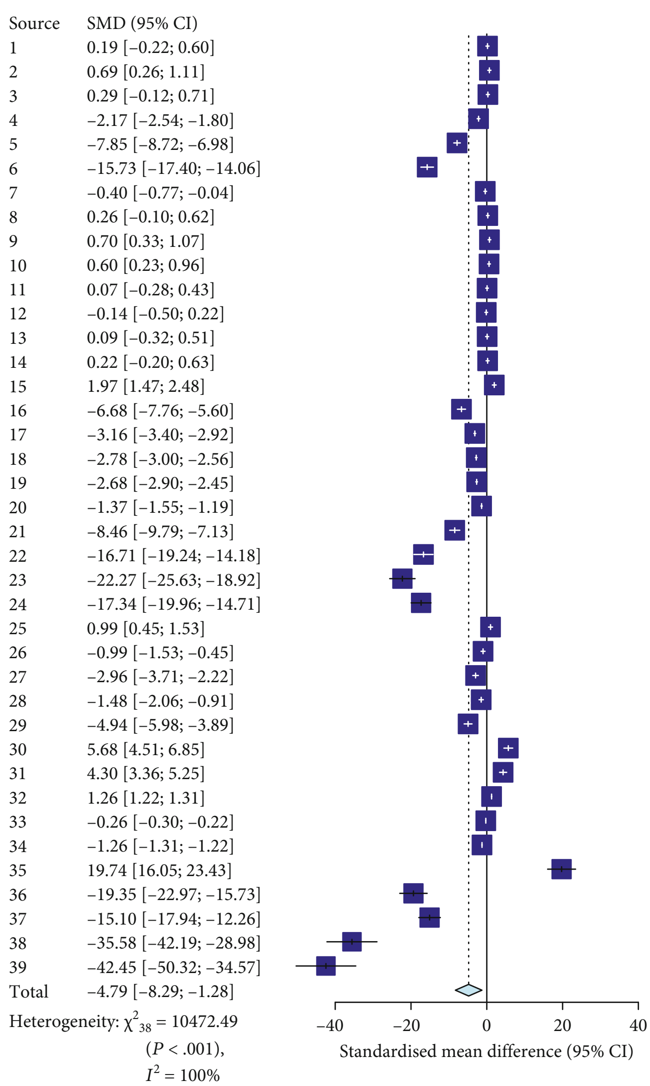

Figure 1: SGR forest plot of effect sizes of insect meals as a replacement of fishmeal in tilapias and sharptooth catfish.

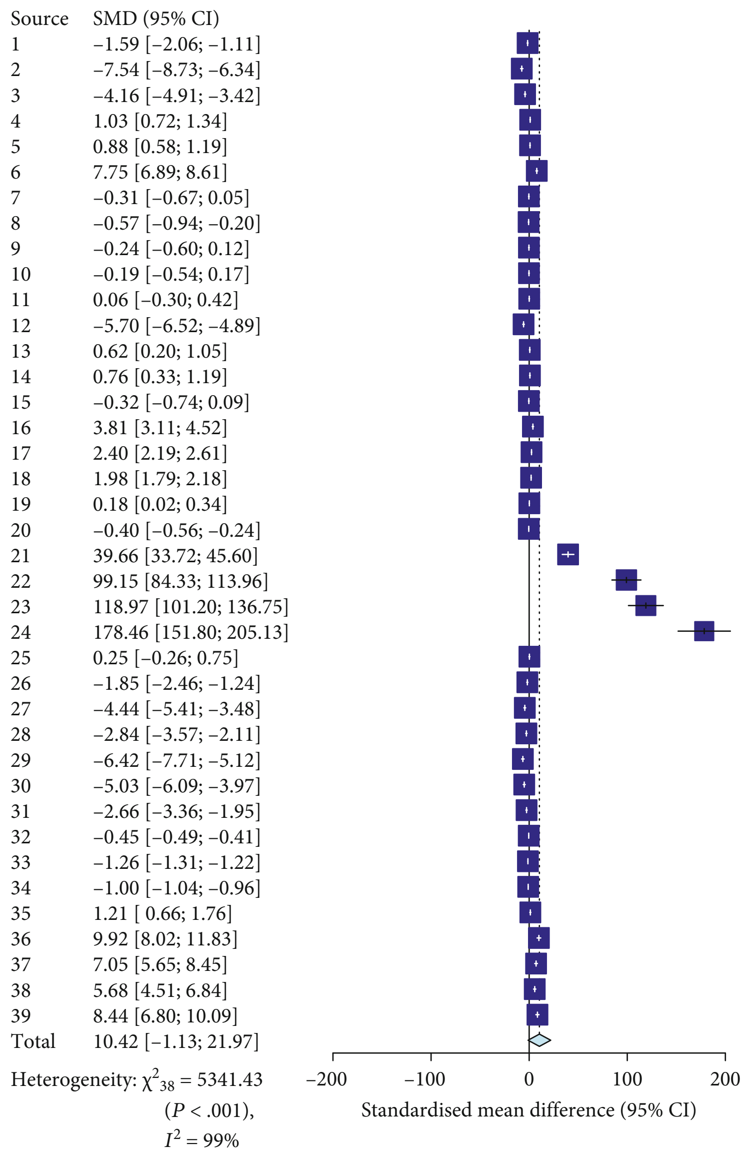

Figure 2: FCR forest plot of effect sizes of insect meals as a replacement of fishmeal in tilapias and sharptooth catfish.

that from an economic perspective, replacement of fishmeal with insect meals may be a viable alternative.

Fish farmers in Southern Africa have to contend with expensive and sometimes poor quality feed [10]. Insects are readily available at most of the fish farms, albeit seasonally. Fish farmers must be encouraged to make their own feed at the farms using the SOLVER function in Excel. A basic knowledge of Excel is all that is required, and most fish farmers in Southern Africa have computers. In cases where fish farmers do not have computers, government through extension officers must provide hardware, software, and training. There is a need to test our formulated diets in both tilapias and sharptooth catfish. One of the challenges that may arise from our formulated feed is the high amounts of cotton seed meal used in formulating the diets. It has been reported that high amounts of cotton seed meal (more than 25%) may reduce feed intake and thus affect the growth of the fish [33].

3.3. Meta-analysis of the Effects of Insect Meal on the Growth of Tilapias and Sharptooth Catfish. Figures 1 and 2 depict the forest plots of the treatment effects of insect meals used in the replacement of fishmeal in the diets of tilapias and sharptooth catfish. The overall effect size of the comparisons between fishmeal replacement levels in the diet and a control condition was -4.79 (99%CI -8.29; -1.28) for SGR (Figure 1) and 10.42 (99% CI -1.13; 21.97) for FCR (Figure 2). The meta-analysis showed a mean effect size that was significantly different for SGR. The level of heterogeneity for SGR was $I^2 = 100\% (P < 0.01)$ and $I^2 = 99\% (P < 0.01)$ for FCR. Thus, overall, the meta-analysis shows that insect meals have a significant effect on the SGR of tilapias and sharptooth catfish since the diamond does not cross or touch the centre line. This again highlights the potential positive impact of insect meals on the growth of tilapias and sharptooth catfish. Hua [19] carried out a comprehensive meta-analysis study of replacing fishmeal with insect meals

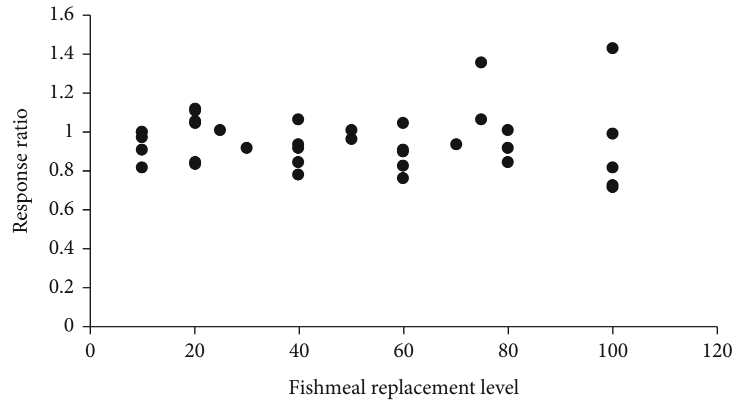

FIGURE 3: SGR response ratio of tilapias and sharptooth catfish fed on insect meals.

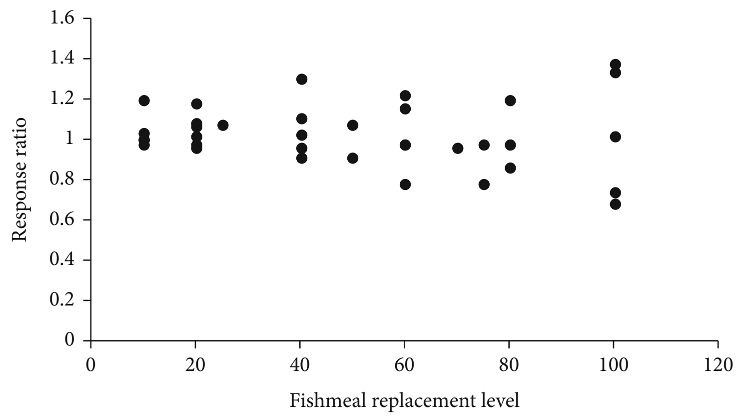

FIGURE 4: FCR response ratio of tilapias and sharptooth catfish fed on insect meals.

on growth performance of different fish species. The results of our focused meta-analysis are in agreement with Hua [19]'s overall finding that insect meals are a promising novel ingredient in the replacement of fishmeal. The overall effect size on FCR showed that there was no significant difference between the treatment and the control (Figure 2). This again shows that insect meals may be a viable alternative to fishmeal. Although meta-analysis is a useful tool in assessing the overall effect of insect meals on fish growth, the selection criteria may compromise the results because some insects may be totally excluded from the analysis. This problem is largely due to the limited number of studies undertaken for some of the insects.

The response of tilapias and sharptooth catfish to the replacement of fishmeal showed a wide scatter (Figures 3 and 4). Response ratios of less than one indicate that the insect meal is inferior to fishmeal [19]. For SGR, 38% of the studies recorded response ratios above one, while 50% of the studies recorded response ratios above one for FCR. These results are consistent with Rapatsa and Moyo [13, 31] who evaluated the utilization of mopane worm by *O. mossambicus* and *C. gariepinus*. They reported that *C. gariepinus* growth was negatively affected by inclusion levels of mopane worm as low as 20%. On the other hand, tilapias were not negatively affected by mopane worm inclusion levels as high as 60%. Factors causing inconsistencies among researchers on the use of insect meal in the diet of *O. mossambicus* and *C. gariepinus* may be due to variations in diet formulation, different fish sizes, and culture systems.

4. Conclusion and Recommendations

All the insect ingredients met the protein requirements for both *O. mossambicus* and *C. gariepinus*. Except for *M. natalensis*, all the other insect ingredients met the fat requirements for *O. mossambicus* and *C. gariepinus*. The amino acid profile for *M. natalensis* was also poor and did not meet the lysine, methionine, and tryptophan requirements for both fish species. The highest EAAI was recorded in *M. domestica*. *M. natalensis* had the lowest EAAI index. Use of *M. natalensis* is therefore not recommended in the replacement of fishmeal in both *O. mossambicus* and *C. gariepinus*. The most promising potential ingredients are *M. domestica* and *G. africana*. The meta-analysis also showed that overall, insect meals have a positive effect on SGR and FCR of tilapias and sharptooth catfish. It is recognised that each of these insects have limitations, and we recommend that future studies look at the possibility of mixing different insect meals in feed formulation.

Data Availability

Availability of data and material is on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] FAO, *African regional aquaculture review*, CIFA occasional paper 24, Food and Agriculture Organisation of the United Nations, Accra, Ghana, 2000.

[2] FAO, *Oreochromis mossambicus Peterss, 1852*, Fisheries and Aquaculture Division, Rome, 2021, https://www.fao.org/fishery/en/aqspecies/2408.

[3] S. H. Bowen, "Digestion and assimilation of periphytic detrital aggregate by Tilapia mossambica," *Transactions of the American Fisheries Society*, vol. 110, no. 2, pp. 239–245, 1981.

[4] S. S. De Silva, M. K. Perera, and P. Maitipe, "The composition, nutritional status and digestibility of the diets of *Sarotherodon mossambicus* from nine man-made lakes in Sri Lanka," *Environmental Biology of Fishes*, vol. 11, no. 3, pp. 205–219, 1984.

[5] H. C. Kim, J. H. Lee, K. H. Yang, and H. S. Yu, "Biological control of Anopheles sinensis with native fish predators (Aplocheilus and Aphyocypris) and herbivorous fish, tilapia in natural rice fields in Korea," *Korean Journal of Entomology*, vol. 32, no. 4, pp. 247–250, 2002.

[6] M. N. Bruton, "The breeding biology and early development of *Clarias gariepinus* (Pisces: clariidae) in Lake Sibaya, South Africa, with a review of breeding in species of the subgenus *Clarias (Clarias)*," *The Transactions of the Zoological Society of London*, vol. 35, no. 1, pp. 1–45, 1979.

[7] P. H. Skelton, *A complete guide to the freshwater fishes of southern Africa*, Struik Publishers, Cape Town, South Africa, 2001.

[8] P. Spatary, W. J. A. R. Viveen, and M. Gophen, "Food composition of *Clarias gariepinus* (= *C.* lazera) (Cypriniformes, Clariidae) in Lake Kinneret (Israel)," *Hydrobiologia*, vol. 144, no. 1, pp. 77–82, 1987.

[9] W. T. Kadye and A. J. Booth, "Integrating stomach content and stable isotope analyses to elucidate the feeding habits of non-native sharptooth catfish *Clarias gariepinus*," *Biological Invasions*, vol. 14, no. 4, pp. 779–795, 2012.

[10] N. A. G. Moyo and M. M. Rapatsa, "A review of the factors affecting tilapia aquaculture production in southern Africa," *Aquaculture*, vol. 535, 2021.

[11] M. Henry, L. Gasco, G. Piccolo, and E. Fountoulaki, "Review on the use of insects in the diet of farmed fish: past and future," *Animal Feed Science and Technology*, vol. 203, pp. 1–22, 2015.

[12] K. Katya, M. Z. S. Borsra, D. Ganesan et al., "Efficacy of insect larval meal to replace fish meal in juvenile barramundi, Lates calcarifer reared in freshwater," *International Aquatic Research*, vol. 9, no. 4, pp. 303–312, 2017.

[13] M. M. Rapatsa and N. A. G. Moyo, "Enzyme activity and histological analysis of *Clarias gariepinus* fed on *Imbrasia belina* meal used for partial replacement of fishmeal," *Fish Physiology and Biochemistry*, vol. 45, no. 4, pp. 1309–1320, 2019.

[14] A. van Huis and D. G. A. B. Oonincx, "The environmental sustainability of insects as food and feed. A review," *Agronomy for Sustainable Development*, vol. 37, no. 5, p. 43, 2017.

[15] A. van Huis, "Potential of insects as food and feed in assuring food security," *Annual Review of Entomology*, vol. 58, no. 1, pp. 563–583, 2013.

[16] A. A. Adeoye, Y. Akegbejo-Samsons, F. J. Fawole, and S. J. Davies, "Preliminary assessment of black soldier fly (Hermetia illucens) larval meal in the diet of African catfish (Clarias gariepinus): impact on growth, body index, and hematological parameters," *Journal of the World Aquaculture Society*, vol. 51, no. 4, pp. 1024–1033, 2020.

[17] A. O. Aniebo, C. A. Odukwe, C. I. Ebenebe, P. K. Ajuogu, O. J. Owen, and P. N. Onu, "Effect of housefly larvae (*Musca domestica*) meal on the carcass and sensory qualities of the mud catfish, (*Clarias gariepinus*)," *Advances in Food and Energy Security*, vol. 1, pp. 24–28, 2011.

[18] E. Devic, W. Leschen, F. Murray, and D. C. Little, "Growth performance, feed utilization and body composition of advanced nursing Nile tilapia (*Oreochromis niloticus*) fed diets containing black soldier Fly (*Hermetia illucens*) larvae meal," *Aquaculture Nutrition*, vol. 24, no. 1, pp. 416–423, 2018.

[19] K. Hua, "A meta-analysis of the effects of replacing fish meals with insect meals on growth performance of fish," *Aquaculture*, vol. 530, 2021.

[20] V. D. Penaflorida, "An evaluation of indigenous protein sources as potential component in the diet formulation for tiger prawn, *Penaeus monodon*, using essential amino acid index (EAAI)," *Aquaculture*, vol. 83, no. 3-4, pp. 319–330, 1989.

[21] M. Picker, C. Griffiths, and A. Weaving, *Field Guide to Insects of South Africa*, Struik Nature, Cape Town, South Africa, 2004.

[22] M. Borenstein, L. V. Hedges, J. P. Higgins, and H. R. Rothstein, *Introduction to Meta-Analysis*, Wiley, Chichester, UK, 2009.

[23] K. Jauncey, A. G. J. Tacon, and J. Jackson, "The quantitative essential amino acids of Oreochromis (Saretherodon) mossambicus," in *International Sysposium on Tilapia in Aquaculture*, L. Fishelson and Z. Yaron, Eds., pp. 328–337, Tel Aviv University, Israel, 1983.

[24] J. H. Van Weerd, "Nutrition and growth inClariasspecies - a review," *Aquatic Living Resources*, vol. 8, no. 4, pp. 395–401, 1995.

[25] M. Henry and E. Fountoulaki, "Optimal dietary protein/lipid ratio for improved immune status of a newly cultivated Mediterranean fish species, the shi drum *Umbrina cirrosa*, L.," *Fish & Shellfish Immunology*, vol. 37, no. 2, pp. 215–219, 2014.

[26] E. A. Fasakin, A. M. Balogun, and O. O. Ajayi, "Evaluation of full-fat and defatted maggot meals in the feeding of clariid catfishClarias gariepinusfingerlings," *Aquaculture Research*, vol. 34, no. 9, pp. 733–738, 2003.

[27] S. N. Hlophe and N. A. G. Moyo, "A comparative study on the use of Pennisetum clandestinum and Moringa oleifera as protein sources in the diet of the herbivorous tilapia rendalli," *Aquaculture International*, vol. 22, no. 4, pp. 1245–1262, 2014.

[28] B. K. Hundal, S. N. Liland, G. Rosenlund, M. Bou, I. Stubhaug, and N. H. Sissener, "Increasing dietary *n*-6 fatty acids while keeping *n*-3 fatty acids stable decreases EPA in polar lipids of farmed Atlantic salmon (*Salmo salar*)," *British Journal of Nutrition*, vol. 125, no. 1, pp. 10–25, 2021.

[29] G. Sogari, M. Amato, I. Biasato, S. Chiesa, and L. Gasco, "The potential role of insects as feed: a multi-perspective review," *Animals*, vol. 9, no. 4, p. 119, 2019.

[30] J. H. P. Hackstein and C. K. Stumm, "Methane production in terrestrial arthropods," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 91, no. 12, pp. 5441–5445, 1994.

[31] M. M. Rapatsa and N. A. G. Moyo, “Evaluation of *Imbrasia belina* meal as a fishmeal substitute in *Oreochromis mossambicus* diets: growth performance, histological analysis and enzyme activity,” *Aquaculture Reports*, vol. 5, pp. 18–26, 2017.

[32] L. Mwimanzi and C. G. Musuka, “The potential of mopane worm (*Gonimbrasia belina*) as an alternative protein source in fish feed,” *International Journal of Aquaculture*, vol. 4, pp. 73–78, 2014.

[33] A. Ashiru, S. A. Abdullahi, J. Auta, Y. P. Hussaini, and B. A. Muhammed, “Assessment of cotton-seed (*Gossypium species*) meal as ingredient in the diet of *Clarias gariepinus* juveniles,” *Bayero Journal of Pure and Applied Sciences*, vol. 8, pp. 34–38, 2016.

[34] G. Tran, V. Heuze, and H. P. S. Makkar, “Insects in fish diets,” *Animal Frontiers*, vol. 5, pp. 37–44, 2015.

[35] A. I. Ntukuyoh, D. S. Udiong, E. Ikpe, and A. E. Akpakpan, “Evaluation of nutritional value of termites (*Macrotemes* bellicosus): soldiers, workers, and queen in the Niger Delta region of Nigeria,” *International Journal of Food Nutrition and Safety*, vol. 2, pp. 60–65, 2012.

[36] T. Hecht, W. Uys, and P. J. Britz, “The culture of sharptooth catfish in southern Africa,” *South African National Scientific Programmes Report No.*, vol. 153, 1988.

[37] F. J. Fawole, A. A. Adeoye, L. O. Tiamiyu, K. L. Ajala, S. O. Obadara, and I. O. Ganiyu, “Substituting fishmeal with *Hermetia illucens* in the diets of African catfish (*Clarias gariepinus*): effects on growth, nutrient utilization, haemato-physiological response, and oxidative stress biomarker,” *Aquaculture*, vol. 518, 2020.

[38] N. Tippayadara, M. A. O. Dawood, P. Krutmuang, S. H. Hoseinifar, H. Van Doan, and M. Paolucci, “Replacement of fish meal by black soldier fly (Hermetia illucens) larvae meal: effects on growth, haematology, and skin mucus immunity of Nile tilapia, Oreochromis niloticus,” *Animals*, vol. 11, no. 1, 2021.

[39] L. Wang, J. Li, J. N. Jin, F. Zhu, M. Roffeis, and X. Z. Zhang, “A comprehensive evaluation of replacing fishmeal with housefly (Musca domestica) maggot meal in the diet of Nile tilapia (Oreochromis niloticus): growth performance, flesh quality, innate immunity and water environment,” *Aquaculture Nutrition*, vol. 23, no. 5, pp. 983–993, 2017.

[40] W. K. Ng, F. L. Liew, L. P. Ang, and K. W. Wang, “Potential of mealworm (Tenebrio molitor) as an alternative protein source in practical diets for African catfish,Clarias gariepinus,” *Aquaculture Research*, vol. 32, pp. 273–280, 2001.

[41] N. M. Taufek, F. Aspari, H. Muin, A. A. Raji, S. A. Razak, and Z. Alias, “The effect of dietary cricket meal (*Gryllus bimaculatus*) on growth performance, antioxidant enzyme activities, and haematological response of African catfish (*Clarias gariepinus*),” *Fish Physiology and Biochemistry*, vol. 42, no. 4, pp. 1143–1155, 2016.

[42] A. B. Gana, S. Tijani, and R. Ibrahim, “Nutrient utilization, haematological indices and carcass compositions of *heteroclarias* fingerlings fed *Hermetia illucens* (Linnaeus, 1758) larvae meal,” *International Journal of Fisheries and Aquatic Studies*, vol. 8, pp. 42–48, 2020.

[43] C. U. Igwe, C. O. Ujowundu, L. A. Nwaogu, and G. N. Okwu, “Chemical analysis on an edible African termite: a potential antidote to food security problem,” *Biochemistry and Analytical Biochemistry*, vol. 1, 2011.