Ann. Anim. Sci., Vol. 24, No. 2 (2024) 533–544 *DOI: 10.2478/aoas-2023-0088*

sciendo

WATER QUALITY CHANGE, GROWTH PERFORMANCE, HEALTH STATUS IN RESPONSE TO DIETARY INCLUSION OF BLACK SOLDIER FLY LARVAE MEAL IN THE DIET OF NILE TILAPIA, *OREOCHROMIS NILOTICUS*

Walied Mohamed Fayed[1], Abdallah Tageldein Mansour[2,1♦], Mohamed A. Zaki[3], Eglal Ali Omar[1], Abdelaziz Mousa Nour[3], Esraa M. Taha[1], Ghada Rashad Sallam[4]

[1]Department of Animal and Fish Production, Faculty of Agriculture at Saba Basha, 22 Tag El-Roassa, P.O. Box 21531, Alexandria University, Egypt
[2]Animal and Fish Production Department, College of Agricultural and Food Sciences, King Faisal University, P.O. Box 420, Al-Ahsa 31982, Kingdom of Saudi Arabia
[3]Department of Fish and Animal Production, Faculty of Agriculture (El-Shatby), Alexandria University, Egypt
[4]National Institute of Oceanography and Fisheries (NIOF), Qaitbay-Anfoushy, Alexandria, Egypt
♦Corresponding author: amansour@kfu.edu.sa; a_taag@alexu.edu.eg
https://orcid.org/0000-0002-5963-5276

Abstract

With increasing intensive aquaculture production, the search for nourishing, environmentally, and economically viable fishmeal (FM) alternative is an endless approach. Therefore, the present study examines the effect of the use of black soldier fly, *Hermetia illucens*, larvae meal (BSFM) as an alternative protein for FM in the diet of Nile tilapia, *Oreochromis niloticus*, on nitrogen wastes, zootechnical performance, body composition, and hematobiochemical parameters. A total of 315 Nile tilapia fingerlings (4.11±0.12 g/fish) were divided into seven treatments in triplicate. The fish were stocked in glass aquaria (50 × 40 × 30 cm; 60 L each) at a rate of 15 fish per aquarium. Experimental diets contained BSFM at increasing levels of 0, 5, 10, 15, 20, 25, and 30% as FM replacers were offered twice daily to apparent satiation for 84 days. The results revealed that BSFM replacements significantly (P = 0.001) enhance water quality and reduce the total ammonia, NH_3, and NO_2 levels compared to the control. The growth performance, feed conversion ratio, and survival were improved with increasing BSFM meal inclusion levels up to 25% (P = 0.001, 0.017, and 0.001, respectively). However, the zootechnical performance of the experimental fish started to decline with increasing replacement levels to 30%. Also, by an increase in BSFM level to 25%, hematobiochemical markers were considerably (P≤0.01) enhanced. The liver and kidney function indicators improved (P = 0.001) with dietary BSFM. The economic evaluation revealed that feed costs and fish weight gain were decreased by increasing BSFM levels in fish diets. The current study highlighted the potential environmentally beneficial use of BSFM as an FM replacer in terms of reducing water nitrogen waste levels and improving growth performance, health status, and enhancing the economic feasibility of the commercial tilapia diet.

Key words: black soldier fly, alternative protein source, sustainable production, growth performance, physiological status, Nile tilapia

One of the implemented strategies to sustain progression in the aquaculture sector is the improvement of aquaculture technologies, farming systems, productivity, water quality, and controlling production costs (El-Sayed, 2021). The core pillar of sustainable aquaculture progress is intensifying production (FAO, 2021) and triggering alternative animal feed sources other than relying on fishmeal (FM) (Guerreiro et al., 2020). The difficulty of providing farmed fish with feed that is nutritionally balanced but also economically and environmentally viable is one of the top priorities (Boyd et al., 2020). Therefore, to accommodate the anticipated increase in demand for feed for aquaculture production, researchers and feed manufacturers stressed the need for a wider variety of alternatives (FAO, 2021). Fish nutritionists aspire to improve the immune and performance status of cultured fish (Acar, 2018; Hassaan et al., 2019; Saleh et al., 2020; Wassef et al., 2020) as well as supplemented diets that are economically viable and eco-friendly (Ataguba et al., 2017; Espe et al., 1999).

Insects have recently been thought of as a sustainable resource for aquafeed production (Henry et al., 2018, 2015; Makkar et al., 2014; Nesic and Zagon, 2019). However, insect production has not yet increased to the point where it can compete with supplies of FM and vegetables for protein (Sogari et al., 2019). Insect farming provides several environmental advantages, including decreased greenhouse gas (GHG) and ammonia emissions (Oonincx et al., 2010), high-efficiency use of land (Alexander et al., 2017), and effective nutrient conversion (Oonincx et al., 2010; Van Huis, 2013). Moreover, recent research showed that the manufacture of insect meals also benefits the environment, especially in terms of energy use (Thévenot et al., 2018). Black soldier fly larvae (BSFM) are one of the most promising insect species that can be used as a replacer for conventional pro-

tein, as they are considered an environmentally friendly alternative to producing an animal protein with respect to GHG and NH_3 emissions (Oonincx et al., 2010; Van Huis, 2013). Moreover, BSFM is quite effective in turning inferior organic matter into superior nutrients (Diener et al., 2009). BSFM contains a high protein level (31 and 59%) and an amino acid composition that is nearly similar to the FM and superior to soybean (Barroso et al., 2014; Nogales-Mérida et al., 2019). In addition, BSFM is a rich source of minerals, particularly calcium and phosphorus (11–49%), according to Makkar et al. (2014) and Nogales-Mérida et al. (2019). For carnivorous fish species such as rainbow trout (*Oncorhynchus mykiss*), meals made from the insect meal have already been successfully used in fish diets, including Siberian sturgeon (Józefiak et al., 2019), rainbow trout (Rema et al., 2019), red seabream (*Pagrus major*) (Ido et al., 2019), and Atlantic salmon (*Salmo salar*) (Li et al., 2020).

The Nile tilapia is the most farmed tilapia species in the world, producing 70% to >80% of the total tilapia production between 2000 and 2019 (FAO, 2021). This species can eat a variety of food chains, such as bacterial films, phytoplankton, zooplankton, periphyton, and small invertebrates (El-Sayed, 2020, 2021; Tammam et al., 2020). This implies that FM can be successfully replaced with the insect protein in the diet of tilapia. On the other hand, additional research displayed that up to 50% inclusion had a favorable impact on a few adverse effects on some omnivorous finfish species. Regarding the possible use of BSFM as an FM replacement, there are also significant variations among species. More research would be necessary, according to Priyadarshana et al. (2022), to further validate the use of BSFM meal as a source of protein in finfish feeding. Furthermore, the impact of dietary BSFM on water quality has not yet been reported, especially with high expectations for an ammonia-nitrogen-reducing effect. Whereas, chitin has surface activity and can adsorb ammonia (Bernardi et al., 2018). It has also been reported to reduce ammonia excretion in broilers feces (Khempaka et al., 2011). Therefore, the current study aimed to determine the effect of dietary BSFM in practical diet as an FM replacement on water quality, zootechnical performance, proximate body composition, physiological status, and revenue of farmed Nile tilapia fingerlings for sustainable aquaculture.

Material and methods

Fish and experimental facilities

A total of 315 apparently healthy Nile tilapia fingerlings with an average body weight of 4.11±0.12 g were purchased from a local freshwater fish farm located in Kafr El-Sheikh Governorate, Egypt, and transported to the wet laboratory, at the Faculty of Agriculture, Alexandria University, Egypt. The fish were acclimated for two weeks to laboratory conditions in circular fiberglass tanks (1 m^3) supplied with continuous aeration dechlorinated tap water at a daily exchange rate of 50% and fed the control diet. After that, fish were distributed into 21 glass aquaria (50 × 40 × 30 cm; 60 L), each representing seven experimental treatments in triplicates, at a density of 15 fish per aquarium with continuous aeration using air pumps. Aquariums were supported with an automatic heater (Rena, France) to maintain the water temperature range of around 27.85±0.02°C. Also, dechlorinated tap water was used throughout the experimental period, and the lighting regime with 12:12-h light: dark cycle. The excreta was removed by manual siphoning and the water exchange rate was 30% per day. Water samples were collected weekly from each aquarium to monitor different parameters of water quality. The Institutional Animal Care and Use Committee of Alexandria University have approved the fish care used in the present study with approval No. AU:03/19/03/21/1/1. In the beginning, twenty fish fingerlings were frozen at –20°C for initial chemical analysis.

Experimental design and diets

Seven experimental diets were formulated to be isoproteic (~30% crude protein) and isocaloric (~475.59 Kcal/100 g DM). An FM-based diet was used as a control diet, and six other diets were formulated to include dry BSFM at substitution levels of 5, 10, 15, 20, 25, and 30% of FM. BSFM was obtained from a private farm, in the Burj Al-Arab, Alexandria Governorate, Egypt. The BSFM was dried in an oven at 60°C for 48 hours and ground to powder for proximate analysis. The studied level was selected to optimize the inclusion levels of BSFM in the diet of Nile tilapia according to the lower and higher previously recommended levels (Dietz and Liebert, 2018; Tippayadara et al., 2021).

The macro ingredients including FM, soybean meal, corn gluten meal, wheat bran, and BSFM meal were weighed and blended for 10 minutes. The blend material was then pressed in a small hammer mill (Bill bliss, horizontal, 18.5 kW, USA) with a 1 mm sieve. The fine ingredients were weighed together and entirely mixed for 10 min., additives were added then, oil was gradually added to the mix and further mixed for 10 min. Warm distilled water (300 ml kg^{-1}) was then added until a stiff dough was produced, then passed through a mincer (Oster, USA) with a 3.0 mm die, and the resulting pellets were dried in an oven at 65°C for 48 hours to get a moisture level of <10%. The parched diets were broken up into a convenient pellet size and stored at −20°C until further use. Fifty grams of each diet sample were honed using a hammer mill with a 1.5 mm sieve before further analysis. The ingredients and approximate composition of the experimental diets are conducted according to AOAC procedures (AOAC, 2016) presented in Table 1. The amino acids (AA) profile was determined using the method explained by Cunico (1986) and presented in Table 2. In brief, a 0.1 g sample was digested in a specialized hydrolysis tube with 6 ml concentrated HCl and 15% phenol solution. The tubes were then sealed off and left to hydrolyze at 110°C for 24 h. Once hydrolysis was

completed, the samples were transferred to Eppendorf tubes and refrigerated. The amino acid profiles were determined as described by Hopley (2016) and the results presented in Table 2. The daily amount of food was introduced by hand to *O. niloticus* fingerlings to obvious satiation twice daily (9:00 a.m. and 2:00 p.m.) for 84 days. Obvious satiation was considered to have occurred 30 minutes after the introduction of the diet, then the remaining feed was collected and dried to be excluded from the introduced feed.

Table 1. Ingredients and chemical composition (on dry matter basis) of the experimental diets

Ingredients (%)	Experimental diets							FM	BSFM
Replacement percentage	Control	5	10	15	20	25	30		
Fishmeal	23.00	21.85	20.70	19.55	18.40	17.25	16.11		
Soybean meal	23.00	23.00	23.00	23.00	23.00	23.00	23.00		
Wheat bran	10.00	10.00	10.00	10.00	10.00	10.00	10.00		
Yellow corn	39.00	38.46	37.94	37.40	36.88	36.35	35.80		
BSFL meal	0.00	1.69	3.36	5.05	6.72	8.40	10.09		
Corn oil	3.00	3.00	3.00	3.00	3.00	3.00	3.00		
Vitamins mixture	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
Minerals mixture	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
Proximate chemical analysis (%)									
Dry matter	90.87±0.65	90.85±0.76	90.79±0.82	90.70±0.31	90.66±0.67	90.52±0.14	90.45±0.21	92.17±0.38	88.12±1.94
Crude protein	30.42±0.34	30.45±0.21	30.43±0.11	30.44±0.46	30.34±0.38	30.29±0.65	30.25±0.83	65.00±0.72	44.59±2.43
Ether extract	10.09±0.34	10.14±0.38	10.20±0.87	10.26±0.67	10.32±0.38	10.38±0.49	10.41±0.89	16.00±0.45	21.12±1.65
ASH	5.69±0.65	5.60±0.05	5.53±0.73	5.47±0.83	5.41±0.23	5.43±0.65	5.40±0.93	15.20±0.44	16.15±0.27
Fiber	3.23±0.37	3.20±0.41	3.17±0.65	3.15±0.36	3.11±0.65	3.08±0.39	3.04±0.44	0.00±0.00	2.70±0.45
NFE*	50.57±1.34	50.61±1.41	50.67±2.75	50.68±0.64	50.82±2.81	50.82±1.72	50.90±0.80	3.80±0.08	15.44±0.97
Gross energy **	475.59±4.44	476.38±6.32	477.08±2.76	477.74±8.51	478.32±1.84	478.61±3.14	479.00±0.98	534.11±5.54	515.13±4.65
P/E ratio***	63.96±0.35	63.92±0.55	63.78±1.81	63.72±2.64	63.43±1.12	63.29±0.13	63.15±0.21	–	–

*NFE – nitrogen free extract (calculated by deducting the sum of percentages of moisture, CP, EE, CF, and ash from 100).

**Gross energy (Kcal/100 g DM) was calculated using factors 5.64, 9.44 and 4.12 kca gram of protein, lipid, and carbohydrate, respectively (after NRC, 1993).

***P/E ratio: protein to energy ratio (mg crude protein/Kcal gross energy) = 1000 × CP/GE.

Table 2. Amino acids (AA) profile (g/kg diet) of the black soldier fly larvae meal (BSFM) and experimental diets containing different levels of BSFM

Items	BSFM	BSFM levels (%)						
		0	5%	10%	15%	20%	25%	30%
Essential amino acids (g/kg diet)								
Arginine	23.70±0.56	27.45±0.34	27.26±0.29	27.11±0.30	26.91±0.55	25.66±1.02	25.31±0.93	24.77±1.56
Lysine	23.80±2.36	27.30±0.93	27.10±0.45	26.83±0.73	26.66±1.20	26.25±0.33	25.99±0.49	25.77±0.99
Histidine	14.20±0.90	14.77±0.51	14.91±1.21	15.11±3.44	13.99±1.43	15.97±0.85	15.22±0.44	15.91±0.78
Phenylalanine	18.80±0.84	24.95±0.69	24.33±0.95	23.99±0.77	23.22±0.29	23.11±1.83	23.09±0.54	22.99±0.55
Leucine	26.05±2.01	36.20±0.65	36.11±0.28	35.89±0.44	35.66±0.65	35.38±0.34	35.11±1.22	35.11±.099
Isoleucine	30.05±2.33	18.85±1.45	18.21±0.46	18.11±0.56	19.88±0.72	20.44±0.35	20.33±0.65	20.41±1.00
Valine	30.05±0.92	20.65±0.47	20.99±0.24	22.11±0.54	22.99±0.76	24.22±0.27	24.99±0.54	21.99±0.09
Threonine	23.40±0.97	17.60±0.77	16.31±0.49	18.55±0.56	17.99±0.47	17.81±0.43	19.11±1.32	18.91±0.93
Tryptophan	6.70±1.45	5.00±0.56	4.81±1.09	4.73±2.56	4.71±1.40	4.65±0.05	4.61±0.08	4.58±0.019
Methionine	7.45±0.83	9.50±0.49	9.10±0.57	9.00±0.54	8.55±0.72	8.72±0.65	8.77±0.72	7.85±0.44
Non-essential amino acids (g/kg diet)								
Alanine	34.15±0.65	27.70±1.43	27.11±0.92	26.77±0.89	26.71±0.61	26.58±0.92	26.31±1.82	26.11±0.95
Aspartate	44.20±2.30	50.60±1.60	57.99±0.98	55.61±0.69	51.55±1.99	47.99±2.46	51.11±0.92	46.99±1.55
Glutamate	50.05±1.98	65.71±2,32	61.66±1.54	59.44±1.09	57.99±2.27	58.11±3.98	56.88±2.04	56.19±3.10
Glycine	25.70±0.79	22.80±0.35	22.21±0.59	21.86±1.00	21.55±0.32	20.99±0.56	21.77±0.49	21.44±1.32
Proline	34.59±1.48	28.44±1.09	26.44±0.82	26.11±0.79	25.88±1.27	26.19±0.23	25.61±0.68	24.99±0.23
Serine	28.91±0.91	17.00±0.54	15.99±0.82	16.11±0.54	16.33±0.69	15.78±0.37	15.59±0.34	15.88±0.59
Tyrosine	26.18±0.48	19.00±0.99	17.88±0.34	17.59±0.59	17.11±0.83	18.09±1.04	18.00±1.35	17.22±1.03
Cystine	30.35±.006	0.87±0.19	0.88±0.06	0.91±0.89	0.92±0.11	0.94±0.16	0.955±0.03	0.96±0.05

Water quality parameters

Sampling of the water used in the experiment herein was performed according to the standard guidelines recommended by the APHA (1968). Water quality parameters, including total ammonia (NH_4), unionized ammonia (NH_3), nitrite (NO_2) and nitrate (NO_3) levels were measured each at 7-day intervals, whereas water temperature, pH, and dissolved oxygen were measured daily. Water temperature and pH were measured using pH and temperature testers (Research Model 211 Digital pH Meter, Hanna Instruments, US), while DO was determined using HI9142, Hanna Instruments, USA. Total ammonia (NH_4), NO_2, and NO_3 were measured spectrophotometrically using YSI 9300 photometer (YSI). Unionized ammonia (NH_3) levels were calculated as the percentage of total ammonia based on water temperature and pH according to the US Environmental Protection Agency (EPA) guidelines (EPA, 1989).

Growth performance

Growth performance was calculated as follows: The mean final body weight (FBW) in each experimental treatment was determined by dividing the total weight of the fish in each aquarium by the number of fish. Weight gain (WG), specific growth rate (SGR), survival (%), and condition factor were calculated using the following equations.

$$WG\ (g\ fish^{-1}) = W2 - W1$$

$$SGR\ (\%\ day^{-1}) = 100 \times [(Ln\ W2 - Ln\ W1)/days].$$

where: *W1* is the initial weight of the fish (g) and *W2* is the FBW of the fish (g).

Survival (%) =100 × (the final number of the fish/initial number of the fish).

K=100 × [Body weight (gm)/stander length (cm)^3].

Feed and nutrient utilization

The actual feed intake for each group was calculated by excluding the non-consumed feed, which was collected, dried, and weighed. Feed conversion ratio (FCR), voluntary feed intake (VFI), protein efficiency ratio (PER), protein productive value (PPV%), and energy utilization (ER%) were calculated as follows:

Feed intake (g) = offered feed (g) – non-consumed feed (g) / fish number

FCR = feed intake (g) / weight gain (g)

VFI (% body weight/day) = [dry feed consumed / (W1 + W2)/2/days] × 100.

PER = weight gain (g) / protein intake (g)

PPV = 100 × [protein gain (g) / protein fed (g)].

ER% = 100 × [energy gain in / energy intake in feed].

Proximate composition of the body of the fish

The proximate composition of the experimental diets and fish body muscles (n = 3) were determined, in triplicate samples, following the standard methods of AOAC (2016). Before the trial started, 20 collected samples were frozen to be later submitted for proximate analysis. At the end of the trial 5 fish samples per aquarium. The moisture content was determined by the sample drying in an oven adjusted at 105°C to a steady weight overnight, and the loss in weight was reported as a percentage of moisture. The nitrogen content was determined using the Kjeldahl (2200 Kjeltec Auto distillation, Foss Tecator, Hoganas) method, and the crude protein was calculated by multiplying the nitrogen percentage by 6.25. Ether extract (EE) was measured by solvent extraction method (1045 Soxtec Extraction Unit, Foss Tecator) using diethyl ether (boiling point, 40–60°C) as a solvent. Crude fiber (CF) refers to the organic matter of a sample that is insoluble in diluted acid and alkaline for 10 minutes each. Finally, the content was determined by incinerating the reweighed samples in a muffle furnace at 600°C for 2 hours.

Hematobiochemical parameters

At the end of the experiment, 15 fish per treatment were anesthetized with clove oil (50 mg L^{-1}), and blood samples were collected using sterile, disposable 1-ml syringes containing 50 µL heparin (IU mL^{-1}, Amoun Pharmaceutical Co. S.A.E., Egypt). Blood collected was divided into two tubes; the first was used for hematological assays and the second was centrifuged (1075 × g, 5 min) to obtain serum. The serum samples were stored at −80°C until being used for biochemical and immunological assays.

Total red and white blood cell counts (RBC, 10^6 mm^{-3} and WBC, 10^5 mm^{-3}, respectively) were determined using a standard Neubauer hemocytometer with Shaw's solution as a diluent (Martins et al., 2004). Hematocrit (Ht) values were immediately determined after sampling by placing fresh blood in glass capillary tubes and centrifuging for 10 min in a micro-hematocrit centrifuge. Hemoglobin (Hb) was determined by the cyanmethemoglobin method according to Van-Kampen and Zijlstra (1961) using a Hb reagent set (Zeist Chem Diagnostics). The blood indices of mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) were calculated according to Bain et al. (2016) as follows:

MCV (cm^3/erythrocyte) = 10 × Ht / RBCs.

MCH (pg Hb/erythrocyte) = 10 × Hb / RBCs.

MCHC (g Hb/100 ml erythrocytes) = 100 × Hb / Ht.

All biochemical indicators were determined using commercial kits (Biodiagnostic-Co, Cairo, Egypt). The total serum protein and albumin (g dL^{-1}) levels were determined according to Gornal et al. (1949) and Reinhold (1953). Globulin level (g dL^{-1}) was calculated as the difference between total protein and albumin levels. The activities of alanine aminotransferase (ALT) and aspartate aminotransferase (AST) in serum were estimated by a colorimetric method (Reitman and Frankel, 1957). The creatinine and urea were determined according to Henry (1964).

Economic evaluation

Due to the equality of fixed and variable values in all the experimental treatments, the economic evaluation was calculated based on the price of the feed and the rate of

its consumption by fish. The prices were calculated according to the local retail market prices of diets (in 2023). These prices (US$/kg) are as follows: soybean meal, 0.61; herring FM, 1.52; BSFM, 0.45; yellow corn, 0.21; wheat bran, 0.93; corn oil, 0.86; mineral mixture, 0.16, and vitamin premix, 0.35. A simple economic analysis of the tested compared to the control one was carried out as follows:

Cost reduction per ton gain (US$) = feed cost per ton gain of the FM control diet (US$) – feed cost per ton gain of BSFM-containing diets (US$).

Cost reduction per ton gain (%) = 100 (cost reduction per ton gain [US$] in BSFM-containing diets/feed cost per ton gain of the FM control diet [US$].

Statistical analysis

All data from the experimental trial were analyzed statistically using R according to Assaad et al. (2015) to evaluate differences among the tested treatments. Data were subjected to one-way ANOVA with post hoc analysis and the TUKEY test was calculated with $P<0.05$ as the significance level. Moreover, a polynomial orthogonal contrast was performed to determine the fit regression models for the fish responses to increasing BSFM levels using SPSS V. 21. The results are presented in tabular form as means ± standard errors.

Results

Water physio-chemical parameters

Table 3 displayed the results of substituting BSFM for FM on water physicochemical parameters. The study's findings showed that there were insignificant differences in water temperature, pH, and salinity. Total ammonia significantly ($P\leq0.01$) decreased with increasing BSFM levels in tilapia diets, along with unionized ammonia and NO_2 in a dose-dependent manner and a discernible rise in NO_3 at high levels of BSFM groups. The highest ammonia measurements in the control group were 0.15, 0.015, and 0.19 mg L^{-1} (NH_4, NH_3, and NO_2 respectively). Meanwhile, the BSFM treatment was successful in reducing the levels of various ammonia derivatives (NH_3, NH_4, and NO_2), especially in 30% replacement levels, where they reached 0.01, 0.0013, and 0.009 mg L^{-1}, respectively. Furthermore, as the replacement of BSFM increased, DO considerably ($P\leq0.01$) rose.

Growth performance parameters

Experimental treatments had a substantial ($P\leq0.01$) impact on fish growth performance, including FBW, gain, ADG, SGR, K factor, survival, and feed consumption indices (VFI, FCR, PER, PPV, and ER) (Table 4). Fish fed the BSFM diet showed significant improvement in a level-dependent manner on growth rates and feed efficiency, with the best performance at a 25% replacement level ($P\leq0.01$). Meanwhile, a considerable decline was seen at a replacement level of 30% BSFM. The 25% substitution with BSFM had the best FCR of 1.21 compared to the control treatment. With increasing BSFM levels to 20 and 25% in the diet, *O. niloticus* fingerlings showed a significant ($P\leq0.01$) improvement in survival of 97 and 98%, respectively, compared to 90% in the control.

Whole body proximate composition

The results in Table 5. showed that as the level of BSFM increased, the body lipid levels gradually decreased ($P\leq0.01$) up to 25% replacement and subsequently increased again in a 30% BSFM. On the other hand, as BSFM in diets rises, protein content increases as well. The results also showed that body moisture and ash contents decreased over time as the level of replacement of BSFM increased, with higher values in both the control and 25% group ($P\leq0.01$).

Hematobiochemical parameters

The RBC count, Hb levels, and Ht were improved by switching from FM protein to BSFM (Table 6). RBC count, Hb level, and Ht (%) were considerably higher ($P\leq0.01$) in the 25% replacement group than in the control group. Additionally, all treatments showed significant differences in MCV, MCH, and MCHC demonstrating the superiority of fish fed BSFM in the diet at all levels. When different doses of BSFM were substituted into fish feed, the feed for the fish, the WBC, lymphocyte (%), myocyte (%), and granulocyte (%) levels varied considerably ($P\leq0.01$) among the control and fish fed BSFM diet (Table 6). In fingerlings fed on the highest amount of BSFM in the diet, the highest levels of WBCs and monocytes (%) were found, while lymphocytes (%) and granulocytes (%) showed the lowest values.

Fingerlings fed on BSFM had significantly higher levels of total serum protein ($P\leq0.05$) than those receiving control diets (Table 7). While globulin and albumin recorded the highest value in 25% replacement, with negligible differences ($P\geq0.771$ and 0.032, respectively). The experimental values of BSFM had a substantial impact on the serum AST and ALT activities (Table 7). The results showed that compared to the control group, AST, and ALT activity were considerably reduced in the groups fed BSFM. Additionally, kidney function as measured by levels of creatinine and urea-N showed that switching from FM protein to BSFM improves renal function in juvenile *O. niloticus* by lowering urea and creatinine ($P\leq0.01$) (Table 7).

Economic analysis

The economic analysis of the experimental diets was significantly affected by the partial replacement of FM by BSFM, as shown in Table 8. According to the simple economic analysis of fish production, increasing BSFM levels in formulating diets led to a decrease in the cost of the diet from 0.70 to 0.63 US$/kg of diet. Additionally, the feed cost per ton of fish gain was significantly decreased and the cost reduction per ton of fish gain (%) continuously climbed until they reached their highest values at 25% substitution level (781.80 US dollars and 29.00 percent, respectively).

Table 3. Mean water quality of Nile tilapia juvenile (*O. niloticus*) aquaria treated with partially replacing fish meal (FM) protein by different levels of black soldier fly larvae meal (BSFM) protein

Items	BSFM levels (%)							Contrast P Value		
	0	5	10	15	20	25	30	treatment	linear	quadratic
NH_4 (mg/L)	0.15±0.02 a	0.07±0.02 b	0.037±0.006 bc	0.049±0.005 bc	0.03±0.005 bc	0.029±0.001 bc	0.01±0.001 c	0.001	0.001	0.001
NH_3 (mg^{-L})	0.02±0.002 a	0.01±0.002 b	0.005±0.001 b	0.006±0.001 b	0.004±0.001 b	0.004±0.00 b	0.0013±0.00 b	0.001	0.001	0.001
NO_2 (mg/L)	0.19±0.001 a	0.17±0.00 b	0.13±0.001 c	0.11±0.00 c	0.08±0.02 c	0.01±0.003 d	0.009±0.00 d	0.001	0.001	0.116
NO_3 (mg/L)	0.18±0.01 d	0.24±0.01 c	0.31±0.001 b	0.28±0.02 b	0.30±0.001 b	0.37±0.002 a	0.35±0.00 a	0.001	0.001	0.001
O_2 (mg/L)	6.74±0.32 b	7.11±0.07 ab	7.33±0.06 ab	7.36±0.04 ab	7.46±0.08 a	7.58±0.05 a	7.48±0.10 a	0.001	0.001	0.004
pH	8.12±0.01	8.15±0.04	8.16±0.05	8.07±0.04	8.21±0.03	8.18±0.12	8.08±0.02	0.581	0.577	0.266

Values are means ± SEM, n = 3 per treatment group.
Means in a row without a common letter differ (P<0.05) as analyzed by one-way ANOVA and the Tukey test.

Table 4. Growth performance and survival of Nile tilapia (*O. niloticus*) fed diets with different levels of BSFM (%)

Items	BSFM levels (%)							Contrast P value		
	0	5	10	15	20	25	30	treatment	linear	quadratic
IBW	4.14±0.012	4.12±0.01	4.07±0.04	4.18±0.20	4.33±0.22	4.25±0.08	4.22±0.06	0.754	0.236	0.895
FBW	13.00±0.27d	14.10±0.36 cd	14.2±0.31 cd	14.6±0.35 c	16.5±0.32 b	20.60±0.31 a	15.10±0.07 bc	0.001	0.001	0.003
Gain	8.88±0.27 d	10.00±0.36 cd	10.20±0.28 cd	10.40±0.55 cd	12.10±0.38 b	16.30±0.39 a	10.90±0.13 bc	0.001	0.001	0.010
ADG	0.19±0.01 d	0.21±0.01 cd	0.21±0.01 cd	0.22±0.01 cd	0.25±0.01 b	0.34±0.01 a	0.23±0.00 bc	0.001	0.001	0.010
SGR	0.95±0.005 g	0.64±0.005 f	0.65±0.005 e	0.65±0.001 d	0.69±0.005 b	0.82±0.001 a	0.67±0.005 c	0.001	0.001	0.082
K	1.40±0.01 b	1.42±0.03 b	1.46±0.04 b	1.49±0.14 b	1.55±0.06 b	1.93±0.01 a	1.56±0.06 b	0.001	0.001	0.741
Survival (%)	90.00±0.58 b	94.70±0.33 a	95.00±1.15 a	95.00±0.58 a	97.00±1.15 a	98.00±0.58 a	96.00±0.58 a	0.001	0.001	0.002
VFI	1.36±0.05	1.31±0.08	1.24±0.05	1.27±0.09	1.31±0.03	1.35±0.09	1.21±0.04	0.569	0.354	0.812
FCR	1.57±0.005 a	1.43±0.004 b	1.33±0.005 c	1.36±0.005 c	1.34±0.001 d	1.22±0.005 e	1.38±0.005 c	0.017	0.001	0.149
FI	14.10±1.04 b	16.30±1.11 ab	20±1.48 a	14.30±0.05 b	13.50±0.28 b	13.90±0.47 b	13.90±0.52 b	0.001	0.007	0.398
PER	2.17±0.09 e	2.33±0.01 d	2.39±0.01 c	2.41±0.01 c	2.96±0.02 b	2.73±0.01 a	2.42±0.01 c	0.001	0.001	0.001
PPV	36.50±0.74 d	37.90±0.54 cd	39.60±0.38 bc	41.90±0.23 b	42.30±0.67 b	46.90±0.57 a	41.40±0.74 b	0.001	0.001	0.001
ER	23.20±0.16 d	24.20±0.16 cd	24.30±0.27 cd	25.40±0.45 b	26.00±0.04 b	28.60±0.26 a	25.30±0.13 bc	0.001	0.001	0.001

Values are means ± SEM, n = 3 per treatment group.
Means in a row without a common letter differ (P<0.05) as analyzed by one-way ANOVA and the Tukey test.
Abbreviations: IBW, initial body weight; FBW, final body weight; SGR, specific growth rate; VFI, voluntary feed intake; K, condition factor; FI, feed intake; PER; protein efficiency ratio; PPV, protein productive value; ER, energy retention.

Table 5. Whole-body chemical composition of Nile tilapia (*O. niloticus*) fed diets with different levels of BSFM (%)

Items	BSFM levels (%)							Contrast P value		
	0	5	10	15	20	25	30	treatment	linear	quadratic
Dry matter	28.60±0.10	28.40±0.27	28.40±0.33	28.40±0.15	28.40±0.15	28.70±0.04	28.30±0.09	0.748	0.617	0.789
Protein	55.80±0.30 c	56.10±0.00 bc	57.50±0.09 ab	57.60±0.53 a	58.80±0.12 a	58.70±0.29 a	58.30±0.25 a	0.001	0.000	0.004
Ether extract	24.70±0.20 a	24.20±0.33 ab	24.20±0.21 ab	23.80±0.07 ab	23.50±0.19 bc	22.50±0.25 c	24.10±0.24 ab	0.001	0.001	0.011
Ash	18.80±0.10 a	18.40±0.16 ab	17.90±0.27 ac	17.30±0.23 bcd	16.80±0.46 cd	16.10±0.06 d	16.90±0.34 cd	0.001	0.001	0.054

Values are means ± SEM, n = 3 per treatment group.
Means in a row without a common letter differ (P<0.05) as analyzed by one-way ANOVA and the Tukey test.

Table 6. Hematological parameters of Nile tilapia (*O. niloticus*) fed diets with different levels of BSFM (%)

Items	BSFM levels (%)							Contrast P value		
	0	5	10	15	20	25	30	treatment	linear	quadratic
RBCs (10^6 × µL)	1.05±0.02 c	1.17±0.05 c	1.25±0.04 c	1.38±0.02 b	1.47±0.04 b	1.53±0.07 a	1.43±0.01 ab	0.001	0.001	0.021
Hb (g/dL)	4.80±0.02 b	5.52±0.02 a	5.84±0.02 a	6.07±0.01 a	6.52±0.02 a	6.75±0.01 a	6.30±0.01 b	0.001	0.001	0.001
Hct (%)	9.40±0.04 b	9.50±0.07 b	10.42±0.06 ab	10.87±0.01 a	11.25±0.02 a	10.57±0.06 a	11.00±0.05 a	0.001	0.001	0.007
MCV (fL)	89.5±0.06 a	80.9±1.15 ab	83.8±4.79 a	79.1±3.21 ab	76.8±2.89 ab	69.4±3.3 b	76.9±0.62 ab	0.006	0.001	0.207
MCH (pg/dL)	45.7±0.80	47.2±0.31	47±2.91	44.2±2	44.5±1.49	44.2±1.42	44.2±1.56	0.696	0.167	0.920
MCHC (g/dL)	51.1±0.93 c	58.3±1.21 ab	56±0.268 bc	55.8±0.26 bc	58±0.24 b	63.9±0.99 a	57.5±2.51 b	0.001	0.001	0.059
WBCs (10^5/µL)	0.97±0.06 d	1.15±0.01 cd	1.37±0.1 c	1.65±0.06 b	1.96±0.01 a	1.85±0.06 ab	1.86±0.09 ab	0.001	0.001	0.001
Lymphocyte (%)	83.4±0.64 a	82.9±0.64 a	82.1±0.64 a	82.03±0.32 ab	82.05±0.64 ab	81.1±0.06 b	81.7±0.06 b	0.001	0.001	0.656
Monocyte (%)	9.15±0.06 e	9.3±0.06 de	9.54±0.06 d	9.85±0.06 c	10.1±0.06 bc	10.8±0.06 a	10.4±0.06 b	0.001	0.001	0.346
Granulocyte (%)	8.56±0.06 a	8.21±0.06 bc	8.47±0.06 ab	8.12±0.06 cd	7.85±0.06 d	8.11±0.06 cd	7.91±0.07 cd	0.001	0.001	0.147

Values are means ± SEM, n = 15 per treatment group.
Means in a row without a common letter differ (P<0.05) as analyzed by one-way ANOVA and the Tukey test.
Abbreviations: RBCs, red blood cell count; Hb, hemoglobin; Hct, hematocrit; MCV, mean corpuscular volume; MCH, corpuscular hemoglobin; MCHC mean corpuscular hemoglobin concentration; WBCs, white blood cell count.

Table 7. Plasma biochemical parameters of Nile tilapia (*O. niloticus*) fed diets with different levels of BSFM (%)

Items	BSFM levels (%)							Contrast P value		
	0	5	10	15	20	25	30	treatment	linear	quadratic
Total protein (g/dl)	3.10±0.06 c	3.17±0.01 c	3.24±0.06 bc	3.46±0.06 ab	3.56±0.06 a	3.72±0.07 a	3.60±0.06 a	0.001	0.001	0.194
Albumin (g/dl)	1.10±0.10	1.05±0.10	1.20±0.04	1.15±0.07	1.19±0.06	1.26±0.18	1.14±0.04	0.771	0.284	0.516
Globulin (g/dl)	2.01±0.05	2.12±0.11	2.04±0.05	2.31±0.06	2.37±0.04	2.46±0.24	2.46±0.03	0.052	0.001	0.877
Albumin/Globulin (ratio)	0.55±0.06	0.50±0.07	0.59±0.02	0.50±0.04	0.51±0.09	0.51±0.14	0.47±0.02	0.859	0.441	0.743
AST (U/L)	62.55±0.07 a	61.72±0.01 b	61.13±0.04 c	62.10±0.04 b	61.32±0.02 c	60.30±0.02 d	60.85±0.05 d	0.001	0.001	0.002
ALT (U/L)	45.57±0.01 a	44.00±0.01 b	43.65±0.02 c	44.25±0.02 b	43.82±0.01 c	42.20±0.02 d	43.40±0.02 c	0.001	0.001	0.009
Creatinine (µmol/L)	4.97±0.07 a	4.92±0.06 a	4.89±0.01 b	4.72±0.02 bc	4.45±0.04 cd	4.32±0.06 d	4.56±0.05 c	0.001	0.001	0.063
Urea-N (mg/dL)	4.96±0.05 a	4.78±0.02 cd	4.85±0.04 a	4.63±0.02 b	4.37±0.04 bc	4.20±0.07 d	4.43±0.01 c	0.001	0.001	0.001

Values are means ± SEM, n = 15 per treatment group.
Means in a row without a common letter differ (P<0.05) as analyzed by one-way ANOVA and the Tukey test.
Abbreviations: ALT, alanine aminotransferase; AST, aspartate aminotransferase.

Table 8. Economic efficiency for producing of one kg gain of Nile tilapia (*O. niloticus*) fed diets with different levels of BSFM (%)

Items	BSFM levels (%)							Contrast P value		
	0	5	10	15	20	25	30	treatment	linear	quadratic
Feed cost (US$/kg diet)	0.70±0.71	0.68±0.32	0.67±0.31	0.66±0.23	0.65±0.02	0.64±0.07	0.63±0.06	0.93	0.20	0.90
Feed cost per ton fish gain (US$)	1100±22.12 a	972±12.90 b	891±17.32 c	898±12.23 c	871±9.32 c	781±13.21 d	806±17.48 d	0.001	0.001	0.001
Cost reduction per ton fish gain (US$)	–	127.00±2.62 e	208±2.30 d	201.00±4.60 d	228.00±3.33 c	318.00±7.16 a	293.00±4.27 b	0.001	0.001	0.001
Cost reduction per ton fish gain (%)	–	11.50±0.43 c	18.90±0.92 b	18.30±0.81 b	20.80±0.33 b	29.00±0.23 a	26.60±0.96 a	0.001	0.001	0.001

Values are means ± SEM, n = 3.
Means in a row without a common letter differ (P<0.05) as analyzed by one-way ANOVA and the Tukey test.

Discussion

Given the growing demand for FM alternatives in aquafeeds, BSFM has an acceptable nutritional profile and appeared to be a viable FM replacer (Guerreiro et al., 2020; Tippayadara et al., 2021; Weththasinghe et al., 2021). Numerous studies have reported successful results of replacing insect meals to FM in recent years (Gasco et al., 2018; Nogales-Mérida et al., 2019; Priyadarshana et al., 2022). However, results are still ambiguous, and BSFM was deemed unsuccessful as expected in some circumstances, with declining fish growth (Guerreiro et al., 2020, 2022; Karapanagiotidis et al., 2019). In the current study, Nile tilapia fed on BSFM had significantly better water quality than the control group; conversely, adding more BSFM to fish diets had a positive impact on various water quality parameters, particularly dissolved oxygen level and ammonia nitrogen derivatives (NH_4, NH_3, NO_2, and NO_3). In addition, when compared to the control group, increasing BSFM levels considerably reduced hazardous nitrogen derivatives. Chitin, which has surface activity and can bind to ammonia via glycol-component fractions that can trap ammonia, is what gives BSFM its potential control over ammonia levels (Bernardi et al., 2018). Additionally, chitin is a non-metal, biodegradable material that is friendly to the environment (Farzana and Meenakshi, 2015). In line with the present results, dietary shrimp head meal or purified chitin reduced ammonia production in broilers (Khempaka et al., 2011). Bernardi et al. (2018) found that insects had a lot of chitins, which may absorb ammonia. As a result, the direct application of chitin to freshwater and saltwater aquatic rearing systems decreased ammonia levels in a dose-dependent way (Yi et al., 2004). The rising NO_3 level with increasing BSFM could be due to the conversion of ammonia from the hazardous form NO_2 to the less damaging form NO_3, which was caused by increasing DO with increasing BSFM in the diet. Furthermore, according to Mansour et al. (2022), enhancing the nutritional metabolism of sea bass fed yucca extract resulted in better water quality.

In the present study, substituting FM with BSFM led to increasing Nile tilapia growth, feed utilization, and survival in a dose-dependent manner up to 25% of FM. In accordance, Aini et al. (2018) observed that Nile tilapia growth was boosted when 50% of the FM was replaced with a blend of BSFM and *Manihot esculenta* leaf meal. Furthermore, Rana et al. (2015) and Muin et al. (2017) explained that tilapia fed diets with BSFM replacements with 50% FM exhibited growth performance comparable to that of the control group. Belghit et al. (2019) and Renna et al. (2017) reported that BSFM included in the diet at high levels (20–40% for rainbow trout and 40–60% for Atlantic salmon), had no negative effects on growth performance. Similarly, Li et al. (2017) showed that defatted BSFM can completely replace FM in diets for Jian carp diets (*Cyprinus carpio*).

The improvement of growth performance in the current study could be due to the active ingredients in BSFM diets, such as essential amino acids as indicated in the present study (Table 2) and in accordance with Sprangh-ers et al. (2017), besides a high level of omega-3, 6, and 9 (Liland et al., 2017). Furthermore, BSFM has a high protein content (60%) and a lipid content of 10–30%, as well as an amino acid profile that is more balanced than FM (Diener et al., 2009). Moreover, the improved FCR and feed utilization could be due to increased mucosal surface area associated with dietary insect meal (Priyadarshana et al., 2022; Talamuk, 2016). In addition, the enhancement in water quality as a result of the decrease in ammonia excretion in the present study may lead to improving growth performance, feed utilization, and survival. Reducing hazardous forms of ammonia in fish-rearing water could enhance growth performance and feed utilization (Fayed et al., 2019; Mansour et al., 2022, 2021). In addition, a rise in PER can be brought on by a decrease in ammonia nitrogen levels in the rearing water by a decrease in ammonia excretion from FM.

Meanwhile, the present findings revealed a decrease in growth performance in a group fed diet with 30% FM replacement with BSFM. This reduction could be explained by the high chitin content of BSFM, which increased with increasing the inclusion level. Additionally, chitin serves as a filler with a low digestible energy content and can inhibit the growth rate at high inclusion levels (Karlsen et al., 2017). Alegbeleye et al. (2012) described delayed amino acid absorption associated with high chitin concentrations, particularly in insect diets. In this regard, Guerreiro et al. (2020) found that switching from FM to BSFM resulted in a linear decrease in the growth of meagre when switching from 17%, 35%, and 52% of FM. Also, Dietz and Liebert (2018) showed that the Nile tilapia growth performance and feed conversion ratio declined by adding 50% BSFM as a replacement for soy protein concentrate.

In the current study, the whole-body proximate composition showed that switching from FM to BSFM in the fish diet modified the fish major constituents by increasing moisture contents and decreasing both ash and fish lipid content. Moreover, rainbow trout and juvenile turbot had their whole-body lipid composition significantly impacted by dietary BSFM meal (Kroeckel et al., 2012; St-Hilaire et al., 2007). These findings contradict those made by Zhou et al. (2018) and Abdel-Tawwab et al. (2020) who showed no significant variations in crude fat, intraperitoneal fat index, kidney index, and spleen indices in Jian carp fish fed low and moderate inclusion levels of BSFM. Similar findings were reported by Belforti et al. (2015) who showed that adding more *Tenebrio molitor* larvae meal to rainbow trout diets caused a significant drop in overall lipid contents and increases in crude protein contents. On the contrary, Zhou et al. (2018) showed no appreciable variations in the amounts of crude protein and crude lipid in the body as a whole, in the muscles, and in the hepatopancreas of Jain carp fed various BSFM doses.

To evaluate the general health state and physiological stress responses of formulated fish fed rations, hematological indices of fish are thought to be crucial as-

sessments (Mansour et al., 2021). The current findings showed an improvement in RBC, Hb, Ht, and WBC, as well as lymphocyte, monocyte, and granulocyte (%) values. Additionally, raising BSFM levels in the diet improves MCV, MCH, and MCHC in the current results. The increased chitin concentrations in BSFM and prepupa meals appeared to be a helpful factor in keeping blood parameters, such as blood hemoglobin content, RBC, and WBC within safe ranges and helpful for finfish blood chemistry (Fawole et al., 2020). Meanwhile, feeding hybrid tilapia (*O. niloticus* × *O. mozambique*) a 30% BSFM diet for 12 weeks did not affect hematological values (Yildirim-Aksoy et al., 2020). Also, Abdel-Tawwab et al. (2020) found no differences in WBC, lymphocyte, monocyte, or neutrophil counts between fish fed BSFM and fish fed FM. Likewise, it is possible to link changes in biochemical parameters in the control group in the current study with stress brought on by rising ammonia levels in the control group that affected the functions of various organs, WBCs, and substances involved in the synthesis mechanisms (Sadhu et al., 2014; Sallam et al., 2017).

To measure animal health, serum total protein represents the activities of the liver, kidneys, and immune system (Patra et al., 2011). Compared to the control group, fish fed 15, 20, 25, and 30% of BSFM had high amounts of total protein and globulin, and a lower albumin/globulin ratio in fish groups compared to the control, suggesting increased globulin contents and an improvement in the liver and general health of the fish (Schaperclaus, 1992). On the other hand, liver function enzymes (AST and ALT) are thought to be a marker for diseases and functions of the liver. They are produced in response to stress, liver damage, or liver function impairment (Zhou et al., 2018). With increasing BSFM in the diet compared to the control group, AST and ALT considerably decreased in the current study.

The current economic analysis of fish production revealed that raising the amount of BSFM in fish diets led to reducing the feed cost of the diet from 0.70 to 0.63 US$/kg (Table 8). The price values of feed price, feeding rate, fish output, and fish sales determine the profit at its maximum (Hebicha et al., 2013). The findings showed that increasing BSFM in diets considerably improved FCR. Since the water results showed a decline in hazardous ammonia levels with an increase in BSFM replacing FM, it is likely that the rate of conversion of fish to feed improved due to the improvement in water quality. Researchers found that lowering hazardous forms of ammonia in rearing water greatly enhanced FCR (Fayed et al., 2019; Mansour et al., 2022, 2021). According to the findings of the current study, adding BSFM as an FM replacer to fish diets has a good economic effect and lowers the cost of feeding by 28.95%. According to Abdel-Tawwab et al. (2020), the introduction of DBSL as an FM replacer in fish diets has a good economic consequence and reduces the feeding cost by 15.6% for producing one kg of *D. labrax*. This result supports their findings.

Conclusions

The results of this study demonstrate that partial replacement of FM with BSFM meal up to 25% in the diets of Nile tilapia fingerling improves water quality and growth performance without having any negative impact on fish health. BSFM may be regarded as an affordable and sustainable feedstuff for incorporation in fish diets due to changes in the environment around the world, the scarcity of fish used for FM, and its high price. BSFM could replace up to 25% of FM protein in Nile tilapia to provide a high-quality protein at a low price.

Acknowledgment

The authors would like to appreciate the valuable support of staff members at the Fish and Animal Production Department, Faculty of Saba Basha, and El-Shatby, Alexandria University. Also, we would like to thank Dr. M. Mohsen, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt for helping in the interpretation of some results.

Ethical approval

The Institutional Animal Care and Use Committee of Alexandria University have approved the fish used in the present study with approval No. AU:03/19/03/21/1/1.

Competing interests

The authors declare no competing interests.

Authors' contributions

All authors have equal contribution.

References

Abdel-Tawwab M., Khalil R.H., Metwally A.A., Shakweer M.S., Khallaf M.A., Abdel-Latif H.M. (2020). Effects of black soldier fly (*Hermetia illucens* L.) larvae meal on growth performance, organs-somatic indices, body composition, and hemato-biochemical variables of European sea bass, *Dicentrarchus labrax*. Aquaculture, 522: 735136.

Acar Ü. (2018). Effects of diet supplemented with ethanolic extract of propolis on growth performance, hematological and serum biochemical parameters and disease resistance of Mozambique tilapia (*Oreochromis mossambicus*) against *Streptococcus iniae*. Aquaculture, 495: 339–344.

Aini N., Nugroho R.A., Hariani N. (2018). Growth and survival evaluation of *Oreochromis sp.* fed *Hermetia illucens* larva and *Manihot esculenta* leaves meal. Biosaintifika: J. Biol. Biol. Educ., 10: 565–573.

Alegbeleye W.O., Obasa S.O., Olude O.O., Otubu K., Jimoh W. (2012). Preliminary evaluation of the nutritive value of the variegated grasshopper (*Zonocerus variegatus* L.) for African catfish *Clarias gariepinus* (Burchell. 1822) fingerlings. Aquacult. Res., 43: 412–420.

Alexander P., Brown C., Arneth A., Dias C., Finnigan J., Moran D., Rounsevell M.D. (2017). Could consumption of insects, cultured meat or imitation meat reduce global agricultural land use? Glob. Food Sec., 15: 22–32.

AOAC (2016). Official methods of analyses. 20th ed. Association of Official Analytical Chemist.

APHA (1968). Standard methods for the examination of water and wastewater (Vol. 20). American Public Health Association.

Assaad H.I., Hou Y., Zhou L., Carroll R.J., Wu G. (2015). Rapid publication-ready MS-Word tables for two-way ANOVA. SpringerPlus, 4: 1–9.

Ataguba G.A., Kamble M.T., Salin K.R. (2017). Food industry byproducts as protein replacement in aquaculture diets of tilapia and catfish. John Wiley & Sons Ltd, pp. 471–507.

Bain B.J., Bates I., Laffan M.A., Lewis S.M. (2016). Dacie and Lewis practical haematology: expert consult: online and print. Elsevier Health Sciences.

Barroso F.G., de Haro C., Sánchez-Muros M.-J., Venegas E., Martínez-Sánchez A., Pérez-Bañón C. (2014). The potential of various insect species for use as food for fish. Aquaculture, 422: 193–201.

Belforti M., Gai F., Lussiana C., Renna M., Malfatto V., Rotolo L., De Marco M., Dabbou S., Schiavone A., Zoccarato I. (2015). *Tenebrio molitor* meal in rainbow trout (*Oncorhynchus mykiss*) diets: effects on animal performance, nutrient digestibility and chemical composition of fillets. Ital. J. Anim. Sci., 14: 4170.

Belghit I., Liland N.S., Gjesdal P., Biancarosa I., Menchetti E., Li Y., Waagbø R., Krogdahl Å., Lock E.-J. (2019). Black soldier fly larvae meal can replace fish meal in diets of sea-water phase Atlantic salmon (*Salmo salar*). Aquaculture, 503: 609–619.

Bernardi F., Zadinelo I.V., Alves H.J., Meurer F., dos Santos L.D. (2018). Chitins and chitosans for the removal of total ammonia of aquaculture effluents. Aquaculture, 483: 203–212.

Boyd C.E., D'Abramo L.R., Glencross B.D., Huyben D.C., Juarez L.M., Lockwood G.S., McNevin A.A., Tacon A.G., Teletchea F., Tomasso Jr J.R. (2020). Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. J. World Aquacult. Soc., 51: 578–633.

Cunico R. (1986). High sensitivity amino acid analysis using a novel automated precolumn derivatization system. Bio-Chromatography, 1: 6–12.

Diener S., Zurbrügg C., Tockner K. (2009). Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. Waste Manage. Res., 27: 603–610.

Dietz C., Liebert F. (2018). Does graded substitution of soy protein concentrate by an insect meal respond on growth and N-utilization in Nile tilapia (*Oreochromis niloticus*)? Aquacult. Rep., 12: 43–48.

El-Sayed A.F.M. (2020). Tilapia culture (2nd ed.). Elsevier Inc, Academic Press, 348 pp.

El-Sayed A.F.M. (2021). Use of biofloc technology in shrimp aquaculture: a comprehensive review, with emphasis on the last decade. Rev. Aquacult., 13: 676–705.

EPA U.S. (1989). Ambient Water Quality Criteria for Ammonia (Saltwater). 440/5-88-004 E.P.A.

Espe M., Sveier H., Høgøy I., Lied E. (1999). Nutrient absorption and growth of Atlantic salmon (*Salmo salar* L.) fed fish protein concentrate. Aquaculture, 174: 119–137.

FAO (2021). Agriculture Organization of the United Nations. (2012) (Producción. Ganadería). Online http://faostat.fao.org/site/573/default. aspx# ancor

Farzana M.H., Meenakshi S. (2015). Visible light-driven photoactivity of zinc oxide impregnated chitosan beads for the detoxification of textile dyes. Appl. Catal. A: General, 503: 124–134.

Fawole F.J., Adeoye A.A., Tiamiyu L.O., Ajala K.I., Obadara S.O., Ganiyu I.O. (2020). 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, 518: 734849.

Fayed W.M.A., Khalil R.H., Sallam G.R., Mansour A.T., Elkhayat B.K., Omar E.A. (2019). Estimating the effective level of *Yucca schidigera* extract for improvement of the survival, haematological parameters, immunological responses and water quality of European seabass juveniles (*Dicentrarchus labrax*). Aquacult. Rep., 15: 100208.

Gasco L., Finke M., Van Huis A. (2018). Can diets containing insects promote animal health? In: J. Insects Food Feed, 4: 1–4.

Gornal A.C., Bardawill C.J., David M.M. (1949). Determination of serum proteins by means of the biuret reaction. J. Biol. Chem., 177: 751–766.

Guerreiro I., Castro C., Antunes B., Coutinho F., Rangel F., Couto A., Serra C.R., Peres H., Pousão-Ferreira P., Matos E. (2020). Catching black soldier fly for meagre: Growth, whole-body fatty acid profile and metabolic responses. Aquaculture, 516: 734613.

Guerreiro I., Castro C., Serra C.R., Coutinho F., Couto A., Peres H., Pousão-Ferreira P., Gasco L., Gai F., Oliva-Teles A. (2022). Oxidative stress response of meagre to dietary black soldier fly meal. Animals, 12: 3232.

Hassaan M.S., Mohammady E.Y., Soaudy M.R., El-Garhy H.A., Moustafa M.M., Mohamed S.A., El-Haroun E.R. (2019). Effect of *Silybum marianum* seeds as a feed additive on growth performance, serum biochemical indices, antioxidant status, and gene expression of Nile tilapia, *Oreochromis niloticus* (L.) fingerlings. Aquaculture, 509: 178–187.

Hebicha H.A., El Naggar G.O., Nasr-Allah A.M. (2013). Production economics of Nile tilapia (*Oreochromis niloticus*) pond culture in El-Fayum Governorate, Egypt. J. Appl. Aquacult., 25: 227–238.

Henry R. (1964). Determination of total protein by colorimetric method. Clin. Chem. Harper and Row Publishers, 181.

Henry M., Gasco L., Piccolo G., Fountoulaki E. (2015). Review on the use of insects in the diet of farmed fish: past and future. Anim. Feed Sci. Technol., 203: 1–22.

Henry M., Gasco L., Chatzifotis S., Piccolo G. (2018). Does dietary insect meal affect the fish immune system? The case of mealworm, *Tenebrio molitor* on European sea bass, *Dicentrarchus labrax*. Dev. Comp. Immunol., 81: 204–209.

Hopley D. (2016). The evaluation of the potential of *Tenebrio molitor*, *Zophobas morio*, *Naophoeta cinerea*, *Blaptica dubia*, *Gromphardhina portentosa*, *Periplaneta americana*, *Blatta lateralis*, *Oxyhalao duesta* and *Hermetia illucens* for use in poultry feeds. Stellenbosch University, Stellenbosch.

Ido A., Hashizume A., Ohta T., Takahashi T., Miura C., Miura T. (2019). Replacement of fish meal by defatted yellow mealworm (*Tenebrio molitor*) larvae in diet improves growth performance and disease resistance in red seabream (*Pargus major*). Animals, 9: 100.

Józefiak A., Nogales-Mérida S., Rawski M., Kierończyk B., Mazurkiewicz J. (2019). Effects of insect diets on the gastrointestinal tract health and growth performance of Siberian sturgeon (*Acipenser baerii* Brandt, 1869). BMC Vet. Res., 15: 1–11.

Karapanagiotidis I.T., Psofakis P., Mente E., Malandrakis E., Golomazou E. (2019). Effect of fishmeal replacement by poultry byproduct meal on growth performance, proximate composition, digestive enzyme activity, haematological parameters and gene expression of gilthead seabream (*Sparus aurata*). Aquacult. Nutr., 25: 3–14.

Karlsen Ø., Amlund H., Berg A., Olsen R.E. (2017). The effect of dietary chitin on growth and nutrient digestibility in farmed Atlantic cod, Atlantic salmon and Atlantic halibut. Aquacult. Res., 48: 123–133.

Khempaka S., Chitsatchapong C., Molee W. (2011). Effect of chitin and protein constituents in shrimp head meal on growth performance, nutrient digestibility, intestinal microbial populations, volatile fatty acids, and ammonia production in broilers. J. Appl. Poultry Res., 20: 1–11.

Kroeckel S., Harjes A.-G., Roth I., Katz H., Wuertz S., Susenbeth A., Schulz C. (2012). When a turbot catches a fly: Evaluation of a pre-pupae meal of the black soldier fly (*Hermetia illucens*) as fish meal substitute – Growth performance and chitin degradation in juvenile turbot (*Psetta maxima*). Aquaculture, 364: 345–352.

Li S., Ji H., Zhang B., Zhou J., Yu H. (2017). Defatted black soldier fly (*Hermetia illucens*) larvae meal in diets for juvenile Jian carp (*Cyprinus carpio* var. Jian): Growth performance, antioxidant enzyme activities, digestive enzyme activities, intestine and hepatopancreas histological structure. Aquaculture, 477: 62–70.

Li Y., Kortner T.M., Chikwati E.M., Belghit I., Lock E.-J., Krogdahl Å. (2020). Total replacement of fish meal with black soldier fly (*Hermetia illucens*) larvae meal does not compromise the gut health of Atlantic salmon (*Salmo salar*). Aquaculture, 520: 734967.

Liland N.S., Biancarosa I., Araujo P., Biemans D., Bruckner C.G., Waagbø R., Torstensen B.E., Lock E.-J. (2017). Modulation of nutrient composition of black soldier fly (*Hermetia illucens*) larvae by feeding seaweed-enriched media. PLoS One, 12: e0183188.

Makkar H.P., Tran G., Heuzé V., Ankers P. (2014). State-of-the-art on use of insects as animal feed. Anim. Feed Sci. Technol., 197: 1–33.
Mansour A.T., Fayed W.M., Elkhayat B.K., Omar E.A., Zaki M.A., Nour A.-A.M., Morshedy S.A. (2021). Extract dietary supplementation affects growth performance, hematological and physiological status of European seabass. Ann. Anim. Sci., 21: 1043–1060.
Mansour A.T., Fayed W.M., Alsaqufi A.S., Aly H.A., Alkhamis Y.A., Sallam G.R. (2022). Ameliorative effects of zeolite and yucca extract on water quality, growth performance, feed utilization, and hematobiochemical parameters of European seabass reared at high stocking densities. Aquacult. Rep., 26: 101321.
Martins M., Tavares-Dias M., Fujimoto R., Onaka E., Nomura D. (2004). Haematological alterations of *Leporinus macrocephalus* (Osteichtyes: Anostomidae) naturally infected by *Goezia leporini* (Nematoda: Anisakidae) in fish pond. Arq. Bras. Med. Vet. Zootec., 56: 640–646.
Muin H., Taufek N., Kamarudin M., Razak S. (2017). Growth performance, feed utilization and body composition of Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) fed with different levels of black soldier fly, *Hermetia illucens* (Linnaeus, 1758) maggot meal diet. Iran. J. Fish. Sci., 16: 567–577.
Nesic K., Zagon J. (2019). Insects – a promising feed and food protein source? Meat Technol., 60: 56–67.
Nogales-Mérida S., Gobbi P., Józefiak D., Mazurkiewicz J., Dudek K., Rawski M., Kierończyk B., Józefiak A. (2019). Insect meals in fish nutrition. Rev. Aquacult., 11: 1080–1103.
Oonincx D.G., Van Itterbeeck J., Heetkamp M.J., Van Den Brand H., Van Loon J.J., Van Huis A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS One, 5: e14445.
Patra R., Rautray A.K., Swarup D. (2011). Oxidative stress in lead and cadmium toxicity and its amelioration. Vet. Med. Int., 2011: 457327.
Priyadarshana M.K.C., Walpita C.N., Ruwandeepika H.A.D., Magamage M.P.S. (2022). Effects of black soldier fly, *Hermetia illucens* (Linnaeus, 1758), larvae incorporated feed on histomorphology, gut microbiota and blood chemistry of cultured fishes: a review. Asian Fish. Sci., 35: 269–281.
Rana K., Salam M., Hashem S., Islam M.A. (2015). Development of black soldier fly larvae production technique as an alternate fish feed. Int. J. Res. Fish. Aquac., 5: 41–47.
Reinhold R. (1953). Determination of serum albumin. Clin. Chem., 21: 1370–1372.
Reitman S., Frankel S. (1957). A colorimetric method for the determination of serum glutamic oxalacetic and glutamic pyruvic transaminases. Am. J. Clin. Pathol., 28: 56–63.
Rema P., Saravanan S., Armenjon B., Motte C., Dias J. (2019). Graded incorporation of defatted yellow mealworm (*Tenebrio molitor*) in rainbow trout (*Oncorhynchus mykiss*) diet improves growth performance and nutrient retention. Animals, 9: 187.
Renna M., Schiavone A., Gai F., Dabbou S., Lussiana C., Malfatto V., Prearo M., Capucchio M.T., Biasato I., Biasibetti E. (2017). Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens* L.) larvae meal as ingredient for rainbow trout (*Oncorhynchus mykiss* Walbaum) diets. J. Anim. Sci. Biotechnol., 8: 1–13.
Sadhu N., Sharma S.K., Joseph S., Dube P., Philipose K. (2014). Chronic stress due to high stocking density in open sea cage farming induces variation in biochemical and immunological functions in Asian seabass (*Lates calcarifer*, Bloch). Fish Physiol. Biochem., 40: 1105–1113.
Saleh N.E., Ismail R.F., Sayed A.E.D.H., Zaghloul E.H., Saleh H. (2020). Comprehensive assessment of benthic diatom (*Amphora coffeaeformis*) as a feed additive in Nile tilapia (*Oreochromis niloticus*) diet. Aquacult. Res., 51: 3506–3519.
Sallam G.R., Fayed W.A., El Absawy M.A., Ali H.A., El Greisy Z.A. (2017). Red tilapia broodstocks and larval production under different water salinities without acclimation. J. Aquac. Res. Dev., 08.
Schaperclaus W. (1992). Causes, development and prevention of fish diseases. A.A. Balkema, 5: 3–42.
Sogari G., Amato M., Biasato I., Chiesa S., Gasco L. (2019). The potential role of insects as feed: A multi-perspective review. Animals, 9: 119.
Spranghers T., Ottoboni M., Klootwijk C., Ovyn A., Deboosere S., De Meulenaer B., Michiels J., Eeckhout M., De Clercq P., De Smet S. (2017). Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. J. Sci. Food Agric., 97: 2594–2600.
St-Hilaire S., Sheppard C., Tomberlin J.K., Irving S., Newton L., McGuire M.A., Mosley E.E., Hardy R.W., Sealey W. (2007). Fly prepupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss*. J. World Aquacult. Soc., 38: 59–67.
Talamuk R. (2016). Comparisons of growth performance of African catfish (*Clarias gariepinus* Burchell, 1822) fingerlings fed different inclusion levels of black soldier fly (*Hermetia illucens*) larvae meal diets. Stellenbosch University, Stellenbosch.
Tammam M.S., Wassef E.A., Toutou M.M., El-Sayed A.-F.M. (2020). Combined effects of surface area of periphyton substrates and stocking density on growth performance, health status, and immune response of Nile tilapia (*Oreochromis niloticus*) produced in cages. J. Appl. Phycol., 32: 3419–3428.
Thévenot A., Rivera J.L., Wilfart A., Maillard F., Hassouna M., Senga-Kiesse T., Le Féon S., Aubin J. (2018). Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects. J. Clean. Prod., 170: 1260–1267.
Tippayadara N., Dawood M.A., Krutmuang P., Hoseinifar S.H., Doan H.V., Paolucci M. (2021). 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, 11: 193.
Van-Kampen E.J., Zijlstra W.G. (1961). Standardization of hemoglobinometry. Clin. Chim. Acta, 6: 438–544.
Van Huis A. (2013). Potential of insects as food and feed in assuring food security. Annu. Rev. Entomol., 58: 563–583.
Wassef E.A., Saleh N.E., Abdel-Meguid N.E., Barakat K.M., Abdel-Mohsen H.H., El-bermawy N.M. (2020). Sodium propionate as a dietary acidifier for European seabass (*Dicentrarchus labrax*) fry: immune competence, gut microbiome, and intestinal histology benefits. Aquacult. Int., 28: 95–111.
Weththasinghe P., Hansen J., Nøkland D., Lagos L., Rawski M., Øverland M. (2021). Full-fat black soldier fly larvae (*Hermetia illucens*) meal and paste in extruded diets for Atlantic salmon (*Salmo salar*): Effect on physical pellet quality, nutrient digestibility, nutrient utilization and growth performances. Aquaculture, 530: 735785.
Yi J.-H., Jang H.-K., Lee S.-J., Lee K.-E., Choi S.-G. (2004). Purification and properties of chitosanase from chitinolytic ß-*Proteobacterium* KNU3. J. Microbiol. Biotechnol., 14: 337–343.
Yildirim-Aksoy M., Eljack R., Schrimsher C., Beck B.H. (2020). Use of dietary frass from black soldier fly larvae, *Hermetia illucens*, in hybrid tilapia (*Oreocromis niloticus* × *O. mozambique*) diets improves growth and resistance to bacterial diseases. Aquacult. Rep., 17: 100373.
Zhou J., Liu S., Ji H., Yu H. (2018). Effect of replacing dietary fish meal with black soldier fly larvae meal on growth and fatty acid composition of Jian carp (*Cyprinus carpio* var. Jian). Aquacult. Nutr., 24: 424–433.

Received: 11 IV 2023
Accepted: 24 VIII 2023