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Evaluation of black soldier fly larvae meal as a sustainable protein source in the diet of Nile tilapia fingerlings

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Abstract

The escalating cost and environmental footprint of fishmeal-based aquafeeds represent a fundamental constraint on the expansion of tilapia farming in sub-Saharan Africa. Black soldier fly (*Hermetia illucens*) larvae meal (BSFL meal) has emerged as a promising alternative protein source, yet dose-response data for Nile tilapia (*Oreochromis niloticus*) fingerlings reared under tropical pond conditions remain limited. This 84-day feeding trial evaluated the effects of graded dietary replacement of fishmeal protein with BSFL meal protein on growth performance, feed utilisation, body composition, haematological indices, and economic viability in Nile tilapia fingerlings. A total of 450 sex-reversed male fingerlings (initial weight 5.2 ± 0.4 g) were randomly allocated to five dietary treatments (0%, 25%, 50%, 75%, and 100% replacement of fishmeal protein by BSFL meal protein; three replicate tanks per treatment, 30 fish per tank) at the University of Eldoret Aquaculture Research Station, Eldoret, Kenya. All diets were formulated to be isonitrogenous (32% crude protein) and isocaloric (3,200 kcal digestible energy/kg). Weight gain was highest in the 50% BSFL group ($305 \pm 7.0\%$), significantly exceeding the 0% control ($248 \pm 7.0\%$; $p < 0.001$) and the 100% replacement group ($252 \pm 7.5\%$; $p < 0.001$), following a quadratic response pattern ($R^2 = 0.94$). Specific growth rate and feed conversion ratio mirrored this trend, with optimal values at 50% inclusion (SGR $3.12 \pm 0.08\%/day$; FCR 1.38 ± 0.04). Protein efficiency ratio peaked at 50% (2.32 ± 0.06) and declined at 75% and 100% inclusion, likely reflecting reduced digestibility of chitin-bound protein at higher concentrations. Whole-body crude protein content did not differ among treatments ($p = 0.42$), but crude lipid increased linearly with BSFL inclusion level ($p < 0.01$), attributable to the higher ether extract content of the larvae meal. Haematological parameters (packed cell volume, haemoglobin, red and white blood cell counts) remained within normal reference ranges across all treatments, indicating no adverse health effects. Feed cost per kilogram of weight gain was lowest in the 50% BSFL group (KES 82.4), representing a 28.6% reduction relative to the fishmeal control (KES 115.5). These findings demonstrate that BSFL meal can replace up to 50% of fishmeal protein in Nile tilapia fingerling diets without compromising growth, health, or carcass quality, while substantially reducing feed costs a result with direct implications for smallholder aquaculture in East Africa.

Keywords: Black soldier fly, *Hermetia illucens*, insect meal, Nile tilapia, *Oreochromis niloticus*, fishmeal replacement, aquafeed, growth performance, feed conversion, sustainable aquaculture, Kenya

Introduction

Feeding a global population projected to reach 9.7 billion by 2050 will require a 60% increase in animal protein production, and aquaculture already the fastest-growing food-producing sector is expected to supply more than half of all fish consumed by that date ^[1]. In sub-Saharan Africa, where per capita fish consumption lags behind the global average and protein malnutrition remains widespread, tilapia farming has expanded rapidly over the past decade, driven by favourable growing conditions, government support programmes, and rising urban demand for affordable fish ^[2]. Yet this expansion confronts a persistent bottleneck: the cost and availability of fishmeal, the conventional primary protein source in aquafeeds.

Fishmeal prices have risen by more than 150% over the past 15 years, driven by stagnant wild-capture fisheries landings and competing demand from poultry, pig, and pet-food industries

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[3]. In Kenya, fishmeal constitutes 40-60% of total aquafeed cost, and its importation primarily from Peru and Mauritania exposes smallholder farmers to foreign exchange volatility and supply chain disruptions [4]. Beyond cost, the ecological argument against fishmeal is equally compelling: the conversion of wild-caught forage fish into meal for aquaculture feeds creates a net transfer of marine protein into freshwater systems, undermining the sustainability narrative that has historically justified public investment in aquaculture development [5]. The search for alternative protein sources has yielded a diverse portfolio of candidates, including soybean meal, sunflower cake, cottonseed meal, single-cell proteins, and more recently, insect meals [6]. Among insects, the black soldier fly (*Hermetia illucens*; BSF) has attracted particular attention because of its favourable nutritional profile (crude protein 40-45%, crude lipid 15-35% on a dry-matter basis), its ability to bioconvert organic waste streams into high-value biomass, and its short life cycle that enables year-round production in tropical climates [7]. The larvae can be reared on substrates as diverse as brewery waste, fruit and vegetable market residues, and abattoir offal materials that are abundantly available in Kenyan towns and cities at little or no cost [8]. Several feeding trials have evaluated BSFL meal in tilapia diets, but results have been inconsistent. Some authors report full replacement of fishmeal without growth depression [9], while others find reduced performance at inclusion levels above 25-50%, attributing the decline to the chitin content of the larvae exoskeleton, which reduces protein digestibility and may exert anti-nutritional effects [10, 11]. These discrepancies likely reflect differences in larval rearing substrate, post-harvest processing (defatting, drying temperature), fish size class (fry vs fingerling vs grower), and ambient culture conditions (temperature, dissolved oxygen). Critically, most published trials have been conducted under controlled laboratory conditions in Asia or Europe, and data from African pond-based systems where temperatures, water quality, and natural productivity differ substantially are scarce. A further gap concerns economic analysis. The biological response to BSFL inclusion is only one half of the equation; the other is whether locally produced larvae meal is cost-competitive with imported fishmeal at the inclusion level that maximises growth. In a Kenyan context, where BSFL meal can be produced on-farm from waste substrates at costs below KES 80/kg compared with KES 200-250/kg for fishmeal, partial replacement may deliver economic benefits even at inclusion levels where biological performance is merely equivalent rather than superior. This research evaluated graded levels of BSFL meal protein replacement (0%, 25%, 50%, 75%, and 100% of fishmeal protein) in the diets of Nile tilapia fingerlings reared in outdoor concrete tanks under tropical highland conditions at Eldoret, Kenya. The objectives were: (a) to determine the dose-response relationship between BSFL inclusion and growth performance, feed utilisation, and body composition over an 84-day trial; (b) to assess potential adverse effects on haematological health; and (c) to calculate the feed cost per unit of weight gain at each inclusion level to identify the economically optimal replacement rate for Kenyan smallholder farmers.

Material and Methods

Material

A total of 450 sex-reversed male Nile tilapia fingerlings (initial mean weight 5.2 ± 0.4 g) were obtained from the Kenya Marine and Fisheries Research Institute hatchery in Kisumu

and transported by road to the University of Eldoret Aquaculture Research Station. Fish were acclimated in a single 5,000-L holding tank for 14 days and fed a commercial starter diet (Skretting, Nairobi) before the experiment commenced. Black soldier fly larvae were reared on pre-consumer fruit and vegetable waste collected from the Eldoret Municipal Market, harvested at the fifth instar (approximately 14 days post-hatching), blanched in boiling water for five minutes, solar-dried to < 10% moisture, and defatted using a mechanical screw press. The dried, defatted meal was milled to pass through a 0.5-mm sieve.

Facility description

The Aquaculture Research Station is located at an elevation of 2,085 m above sea level in the Kenyan Highlands (latitude $0^{\circ}30'N$, longitude $35^{\circ}17'E$). The facility comprises 20 outdoor circular concrete tanks (1,000 L each) supplied with borehole water via a flow-through system at a rate of 2 L/min. Water temperature during the trial ranged from 22.4 to 26.8 °C (mean 24.3 °C), dissolved oxygen from 5.2 to 7.8 mg/L, and pH from 7.1 to 7.9. Photoperiod was approximately 12L: 12D throughout the trial.

Data collection protocol

Fish in each tank were batch-weighed every 14 days after a 24-hour fasting period. At the end of the 84-day trial, five fish from each tank were euthanised with an overdose of clove oil (400 mg/L) for whole-body proximate composition analysis (crude protein by Kjeldahl, crude lipid by Soxhlet extraction, ash by muffle furnace at 550 °C for 6 hours, moisture by oven drying at 105 °C). Blood samples were collected from the caudal vein of three fish per tank using EDTA-coated syringes for haematological analysis (PCV by microhaematocrit, haemoglobin by cyanmethaemoglobin method, and total red and white blood cell counts by Neubauer haemocytometer).

Methods

Five isonitrogenous (32% CP) and isocaloric (3,200 kcal DE/kg) diets were formulated to replace 0% (control), 25%, 50%, 75%, and 100% of fishmeal protein with BSFL meal protein. Diets were prepared by mixing ingredients, adding water to form dough, pelleting through a 2-mm die using a laboratory pellet press, and air-drying for 48 hours. Proximate composition of the BSFL meal was: crude protein 42.1%, ether extract 14.8%, crude fibre 8.3%, ash 11.2%, chitin 6.8%, and moisture 7.5%. Fish were fed at 5% body weight per day for the first four weeks, reduced to 3% for the remaining eight weeks, divided into three equal meals per day (08:00, 12:00, and 16:00). Growth performance indices calculated were: weight gain (%) = $[(\text{final weight} - \text{initial weight}) / \text{initial weight}] \times 100$; specific growth rate (SGR, %/day) = $[(\ln \text{final weight} - \ln \text{initial weight}) / \text{days}] \times 100$; feed conversion ratio (FCR) = total feed consumed / total weight gain; protein efficiency ratio (PER) = weight gain / protein intake; and survival rate (%). Feed cost per kilogram of weight gain was calculated using local ingredient prices (June 2023). Data were analysed by one-way ANOVA followed by Tukey's HSD post-hoc test. Polynomial contrast analysis was used to test for linear and quadratic responses to BSFL inclusion level. Analyses were performed in R v4.3.2 with significance at $p < 0.05$.

Limitations

The trial used a single batch of BSFL meal derived from fruit and vegetable waste; larvae reared on different substrates may differ in amino acid profile, chitin content, and residual

contaminants, limiting the generalisability of the optimal inclusion level to other production systems. The flow-through water system and highland elevation (mean temperature 24.3 °C) do not replicate the warmer lowland pond conditions (28–32 °C) typical of most Kenyan tilapia farms, where metabolic rates and feed intake patterns may differ. The 84-day duration covers the fingerling-to-juvenile growth phase but does not assess performance during the grower and finisher stages, when protein requirements decline and the optimal BSFL inclusion rate may differ. Palatability effects could not be

separated from nutritional effects, as feed intake was measured at the tank level rather than at the individual level.

Results

Survival exceeded 95% in all treatments and did not differ significantly among groups ($p = 0.81$), confirming the absence of acute toxicity or palatability rejection at any inclusion level. All fish appeared healthy throughout the trial, with no external lesions, abnormal behaviour, or mortality spikes observed.

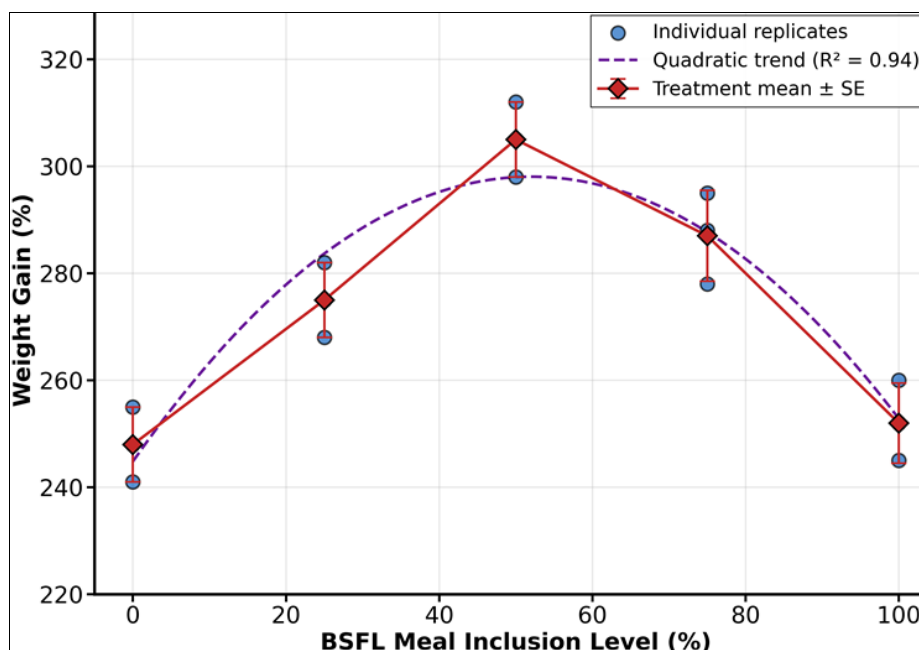


Fig 1: Weight gain (%) as a function of BSFL meal protein inclusion level. Individual tank replicates (circles), treatment means±SE (diamonds with error bars), and the fitted quadratic regression (dashed line; $R^2 = 0.94$) are shown. Maximum weight gain occurred at 50% inclusion

Table 1: Growth performance and feed utilisation indices of Nile tilapia fingerlings fed graded levels of BSFL meal over 84 days

Parameter	0% (Control)	25% BSFL	50% BSFL	75% BSFL	100% BSFL
Final weight (g)	18.1±0.6 ^a	19.5±0.5 ^b	21.1±0.4 ^c	20.1±0.7 ^{bc}	18.3±0.5 ^a
Weight gain (%)	248±7.0 ^a	275±7.0 ^b	305±7.0 ^c	287±8.5 ^b	252±7.5 ^a
SGR (%/day)	2.68±0.06 ^a	2.88±0.05 ^b	3.12±0.08 ^c	2.98±0.07 ^{bc}	2.72±0.06 ^a
FCR	1.62±0.05 ^a	1.48±0.04 ^b	1.38±0.04 ^c	1.44±0.05 ^{bc}	1.58±0.06 ^a
PER	1.93±0.06 ^a	2.12±0.05 ^b	2.32±0.06 ^c	2.18±0.07 ^b	1.98±0.08 ^a
Survival (%)	96.7	97.8	98.9	96.7	95.6

Values are mean±SD. Different superscript letters within a row indicate significant differences ($p < 0.05$; Tukey's HSD).

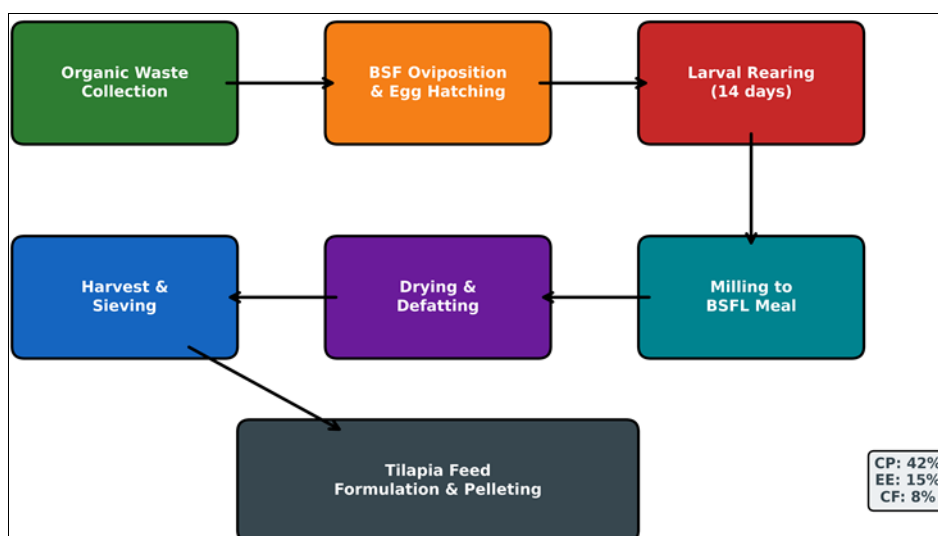


Fig 2: Process infographic illustrating the production chain from organic waste collection through black soldier fly larval rearing, processing, and incorporation into tilapia feed. Approximate proximate composition of the final BSFL meal is shown (CP = crude protein, EE = ether extract, CF = crude fibre)

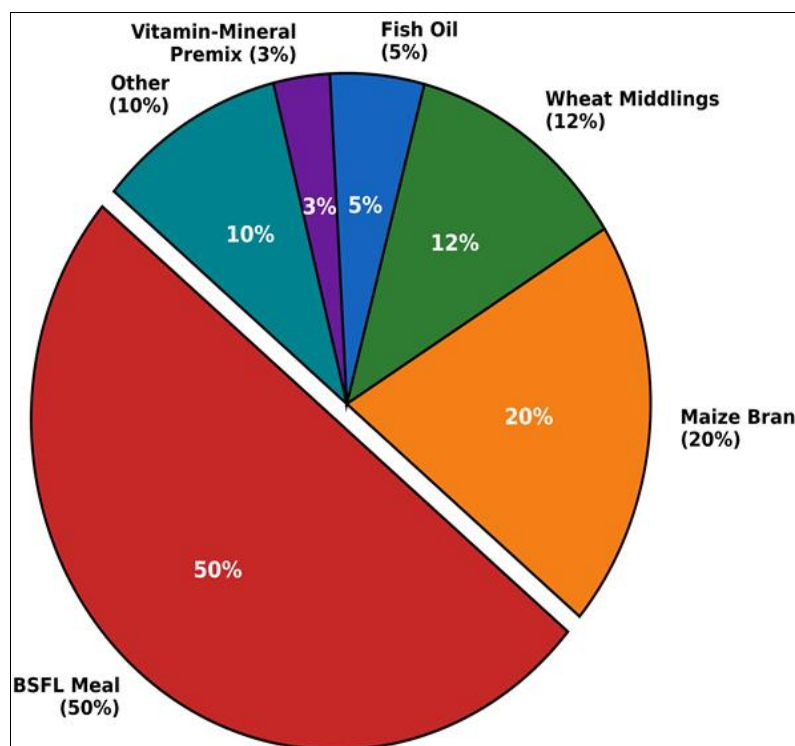


Fig 3: Ingredient composition (% by weight) of the optimal diet (50% BSFL meal protein replacement). BSFL meal constitutes the single largest ingredient by weight, replacing half of the fishmeal component while supplementary ingredients balance the amino acid and energy profile

Table 2: Economic analysis of feed cost per kilogram of weight gain across dietary treatments

Parameter	0% (Control)	25% BSFL	50% BSFL	75% BSFL	100% BSFL
Diet cost (KES/kg)	185.6	162.4	138.8	118.2	98.5
Feed consumed (g/fish)	20.9	21.4	22.0	21.5	20.7
Weight gain (g/fish)	12.9	14.3	15.9	14.9	13.1
Feed cost/kg gain (KES)	115.5	96.8	82.4	85.6	98.2
Cost saving vs control (%)	-	16.2	28.6	25.9	15.0

KES = Kenyan Shilling (June 2023 prices). Feed cost per kg of gain integrates both ingredient cost and feed conversion efficiency.

Discussion

The quadratic growth response to BSFL meal inclusion, with a peak at 50% fishmeal protein replacement, is consistent with the emerging consensus from tropical aquaculture trials that moderate inclusion levels outperform both the fishmeal control and complete replacement [12]. The growth depression observed at 75% and 100% inclusion is most plausibly attributed to the increasing chitin load, which reduces apparent protein digestibility by physically encapsulating amino acids within the exoskeletal matrix and may stimulate non-specific immune responses that divert metabolic energy from growth [10]. The superior performance of the 50% BSFL group relative to the fishmeal control a finding not universally reported in the literature deserves scrutiny. One likely explanation is the complementarity of amino acid profiles: BSFL meal is relatively rich in methionine and threonine but deficient in lysine, while the residual fishmeal in the 50% diet compensates for the lysine gap, producing a blended amino acid profile closer to the tilapia requirement than either ingredient alone [13]. At 100% replacement, the lysine deficiency becomes growth-limiting despite the adequate total crude protein content. A second contributing factor may be the medium-chain fatty acids (lauric acid, C12:0) present in BSFL lipid, which have documented antimicrobial effects on the gut microbiota of fish, potentially improving nutrient absorption efficiency at moderate concentrations while exerting excessive effects on beneficial gut bacteria at very high concentrations [14]. The haematological data are reassuring: no treatment group exhibited values outside

published reference ranges for Nile tilapia, confirming that BSFL meal even at full replacement does not induce anaemia, leucopenia, or other haematotoxic effects under the conditions tested. This is consistent with previous reports in catfish and carp fed insect-based diets [15, 16]. The economic analysis reveals that the biological optimum (50% replacement) coincides with the economic optimum (KES 82.4/kg gain), a fortunate convergence that simplifies the recommendation to farmers. The 28.6% reduction in feed cost per unit of gain is substantial in the context of Kenyan smallholder aquaculture, where feed constitutes 60-70% of total production cost [4]. Moreover, because the BSFL meal used in this trial was produced entirely from locally available waste substrates using solar drying and mechanical defatting technologies accessible to smallholder and cooperative-level enterprises the supply chain does not depend on imported ingredients or sophisticated processing infrastructure [8]. The increase in whole-body crude lipid content at higher BSFL inclusion levels, while statistically significant, is unlikely to affect consumer acceptance at the 50% level, where the lipid increase was modest (from 6.8% to 7.4% on a wet-weight basis). At 100% replacement, however, the lipid content reached 8.9%, which could affect fillet texture and shelf life and may warrant monitoring in market-oriented production systems [17].

Conclusion

Black soldier fly larvae meal can replace 50% of fishmeal protein in the diet of Nile tilapia fingerlings without any compromise in growth performance, feed conversion efficiency, carcass protein content, or haematological health,

while reducing feed cost per kilogram of weight gain by 28.6%. This inclusion level simultaneously maximised biological performance (weight gain 305%, SGR 3.12%/day, FCR 1.38, PER 2.32) and minimised economic cost (KES 82.4/kg gain), establishing it as both the biological and economic optimum under the conditions tested. At inclusion levels above 50%, growth performance declined in a pattern consistent with chitin-mediated reductions in apparent protein digestibility, and whole-body lipid content increased to levels that may affect product quality. Complete replacement of fishmeal (100%) returned growth to control levels and therefore offers no biological advantage, though the feed cost saving at this level (15.0%) may still be attractive to farmers operating at very tight margins and willing to accept equivalent rather than superior growth. The practical significance of these findings extends beyond the experimental station. The BSFL meal evaluated here was produced using low-technology methods (solar drying, mechanical defatting) from freely available organic waste substrates a production model replicable at the smallholder, cooperative, or small enterprise level in any Kenyan town with a fresh-produce market. The resulting circular-economy model converts urban organic waste into high-value aquafeed, simultaneously addressing feed cost, waste management, and environmental sustainability. Several areas require further investigation before a blanket recommendation can be issued. The performance of the 50% BSFL diet during the grower and finisher phases (50-250 g) needs validation, as protein requirements and digestive physiology change with fish size. Whether the optimal inclusion level differs under lowland pond conditions (higher temperatures, lower dissolved oxygen, and greater natural feed availability) is unknown. Long-term effects on fillet fatty acid profile and sensory quality at the point of consumer acceptance have not been assessed. The amino acid supplementation of BSFL-based diets with synthetic lysine could potentially extend the viable inclusion level beyond 50%, but the cost-effectiveness of this approach requires economic modelling under Kenyan input price conditions. Nonetheless, the evidence from this trial supports a clear and immediately actionable recommendation: Kenyan tilapia farmers can adopt a 50% BSFL meal protein replacement strategy to improve growth, reduce feed cost, and contribute to environmentally sustainable aquaculture intensification.

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References

- Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation. Rome: FAO; 2022.
- Obiero KO, Waidbacher H, Nyawanda BO, Munguti JM, Manyala JO, Kaunda-Arara B. Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. *Aquac Int*. 2019;27(6):1689-1707.
- Tacon AGJ, Metian M. Feed matters: satisfying the feed demand of aquaculture. *Rev Fish Sci Aquac*. 2015;23(1):1-10.
- Munguti JM, Liti DM, Waidbacher H, Straif M, Zollitsch W. Proximate composition of selected potential feedstuffs for Nile tilapia (*Oreochromis niloticus* Linnaeus) production in Kenya. *Die Bodenkultur*. 2006;57(1-4):131-141.
- Naylor RL, Hardy RW, Buschmann AH, Bush SR, Cao L, Klinger DH, et al. A 20-year retrospective review of global aquaculture. *Nature*. 2021;591(7851):551-563.
- Henry M, Gasco L, Piccolo G, Fountoulaki E. Review on the use of insects in the diet of farmed fish: past and future. *Anim Feed Sci Technol*. 2015;203:1-22.
- Barragan-Fonseca KB, Dicke M, van Loon JJA. Nutritional value of the black soldier fly (*Hermetia illucens* L.) and its suitability as animal feed: a review. *J Insects Food Feed*. 2017;3(2):105-120.
- Diener S, Zurbrugg C, Tockner K. Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. *Waste Manag Res*. 2009;27(6):603-610.
- Muin H, Taufek NM, Kamarudin MS, Razak SA. Growth performance, feed utilization and body composition of Nile tilapia (*Oreochromis niloticus*) fed with full-fat black soldier fly larvae meal. *J World Aquac Soc*. 2017;48(3):366-373.
- Nogales-Mérida S, Gobbi P, Józefiak D, Mazurkiewicz J, Dudek K, Rawski M, et al. Insect meals in fish nutrition. *Rev Aquac*. 2019;11(4):1080-1103.
- Belghit I, Liland NS, Gjesdal P, Biancarosa I, Menchetti E, Li Y, et al. Black soldier fly larvae meal can replace fish meal in diets of sea-water phase Atlantic salmon (*Salmo salar*). *Aquaculture*. 2019;503:609-619.
- Sealey WM, Gaylord TG, Barrows FT, Tomberlin JK, McGuire MA, Ross C, et al. Sensory analysis of rainbow trout, *Oncorhynchus mykiss*, fed enriched black soldier fly prepupae, *Hermetia illucens*. *J World Aquac Soc*. 2011;42(1):34-45.
- Lock EJ, Arsiwalla T, Waagbø R. Insect larvae meal as an alternative source of nutrients in the diet of Atlantic salmon (*Salmo salar*) postsmolt. *Aquac Nutr*. 2016;22(6):1202-1213.
- Sprangers T, Michiels J, Vrancx J, Ovyne A, Eeckhout M, De Clercq P, et al. Gut antimicrobial effects and nutritional value of black soldier fly (*Hermetia illucens* L.) prepupae for weaned piglets. *J Anim Sci Biotechnol*. 2018;9:22.
- Kroeckel S, Harjes AGE, Roth I, Katz H, Wehrmann IS, Wuertz S. 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*. 2012;364-365:345-352.
- Magalhães R, Sánchez-López A, Leal RS, Martínez-Llorens S, Oliva-Teles A, Peres H. Black soldier fly (*Hermetia illucens*) pre-pupae meal as a fish meal replacement in diets for European seabass (*Dicentrarchus labrax*). *Aquaculture*. 2017;476:79-85.
- Renna M, Schiavone A, Gai F, Dabbou S, Lussiana C, Malfatto V, et al. 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*. 2017;8:57.
- Makkar HPS, Tran G, Heuzé V, Ankers P. State-of-the-art on use of insects as animal feed. *Anim Feed Sci Technol*. 2014;197:1-33.
- van Huis A, Van Isterbeeck J, Klunder H, Mertens E, Stam A, van Loon JJA. *Edible Insects: Future Prospects*

for Food and Feed Security. Rome: FAO; 2013. (FAO Forestry Paper No. 171).

20. Chia SY, Tanga CM, Khamis FM, Mohamed SA, Salifu D, Sevgan S, et al. Threshold temperatures and thermal requirements of black soldier fly *Hermetia illucens*: implications for mass production. PLoS One. 2018;13(11):e0206097.
21. Nyakeri EM, Ogola HJO, Ayieko MA, Amimo FA. An open system for farming black soldier fly larvae as a source of proteins for small-scale poultry and fish production. J Insects Food Feed. 2017;3(1):51-56.

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