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Review Article

FOOD SCIENCE AND AGRICULTURAL TECHNOLOGY

Potential of Black Soldier Fly (BSF) as Partial or Full Replacement of Fishmeal in Aquafeeds: A Review

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Abstract

For decades, fishmeal has been the major source of protein in aquafeeds due to its comprehensive amino acid composition with about 68% of global supply; however, there have been major concerns regarding the economic and environmental sustainability of fishmeal in aquafeed production and such concerns have led to the pressing need for alternative protein sources. Consequently, the aquaculture industry is shifting towards a sustainable feed ingredient to reduce reliance on wild-sourced fishmeal which has been heavily utilised over the decades. Recently, focus on insect-based protein has greatly increase with studies to evaluate their potential as protein sources in aquaculture as a natural replacer of fishmeal. The review considered the potential of black soldier fly (BSF), *Hermetia illucens* as a replacer of fishmeal in aquafeeds.

KEYWORDS: Black Soldier FLy (BSF), Fishmeal, Aquafeeds, Aquaculture

Introduction

Aquaculture is the fastest-growing food production sector and a major contributor to global food fish (FAO, 2020). It has been a rapidly developing industry during the past four decades and is expected to continue in the foreseeable future to feed the growing population (Garlock et al., 2022). However, the increasing costs of production in aquaculture due to the rising cost of feeding threaten the sustainability of the sector (Dawood, 2021). The future aquaculture expansion highly dependent on the efficacy of sustainable feed formulation due to shortcomings around the major ingredient in

production (Galkanda-Arachchige *et al.*, 2020). For decades, fishmeal has been the major source of protein in aquafeeds due to its comprehensive amino acid composition with about 68% of global supply; however, there have been major concerns regarding the economic and environmental sustainability of fishmeal in aquafeed production and such concerns have led to the pressing need for alternative protein sources (Prakoso et al., 2022). Consequently, the aquaculture industry is shifting towards a sustainable feed ingredient to reduce reliance on wild-sourced fishmeal which has been heavily utilized over the decades.

With attributes such as the comprehensive amino acids composition, digestibility and palatability, fishmeal is considered superior protein source in aquafeed formulation as it provides suitable feed intake and easy absorption of nutrients in fish (Abdel-Latif et al., 2021). The sustainability of the fishmeal has caused major concerns among feed producers and users due to the decline in catch rate of wild fish for fishmeal which has resulted to decrease availability and rising costs of fishmeal (Abdel-Latif et al., 2021). With the growth witnessing in aquaculture, the fishmeal production will not be sufficient to meet the demand; therefore, the fishmeal replacer must be sorted for the sustainable development of aquafeeds (Gasco et al., 2020). Furthermore, Gasco et al (2020) noted that researchers have turned to insect proteins as a promising alternative in feeding fish and shrimp culture.

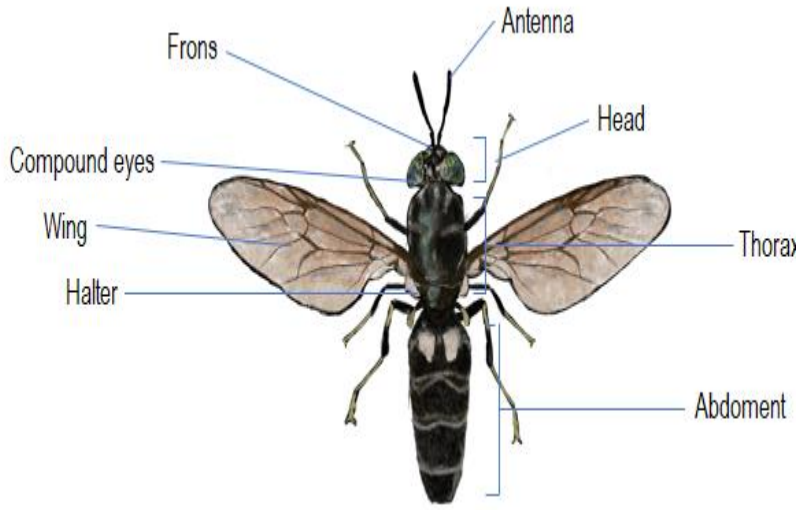
Likewise, plant-based ingredients have been reported to cause negative side effects in the gut of carnivorous fish due to the presence of anti-nutritional factors (Zhou et al., 2018) and complex indigestible carbohydrates (Gaudioso et al., 2021), consequently impacting growth and welfare of the fish. Therefore, recent studies have focused on evaluating potentially sustainable alternatives including insects (Li et al., 2019; Alves et al., 2021; Terova et al., 2021), bacteria (Maulu et al., 2021; Li et al., 2021) and organic by-products

(Mo et al., 2014; Cheng et al., 2017). Among these, insects have attracted the most attention due to their wide application in aquaculture and ease of production. The Black Soldier Fly is a non-pest species, widely distributed and free of pathogenic agents. Its larvae have a high feed rate, consuming 25-500 mg of fresh matter/day, and can grow on various substrates, including manures and food waste. In 15 days, they can reduce waste by up to 70% and average 0.25g in weight, while also removing pathogenic bacteria, reducing odors, and inhibiting housefly breeding, making them a valuable asset in sanitation management (Maquart et al., 2018). The larvae have a high nutritional value; contingent on the substrate they were bred on, with crude protein levels ranging from 28 to 48 percent, and lipid levels from 12 to 42 percent. Apart from omega-3 fatty acid, the lipid profile is broadly similar to fishmeal. The essential amino acid profile of the insect meal meets the broad requirements of tilapias simplifying dietary formulation requirements (Maquart et al., 2018).

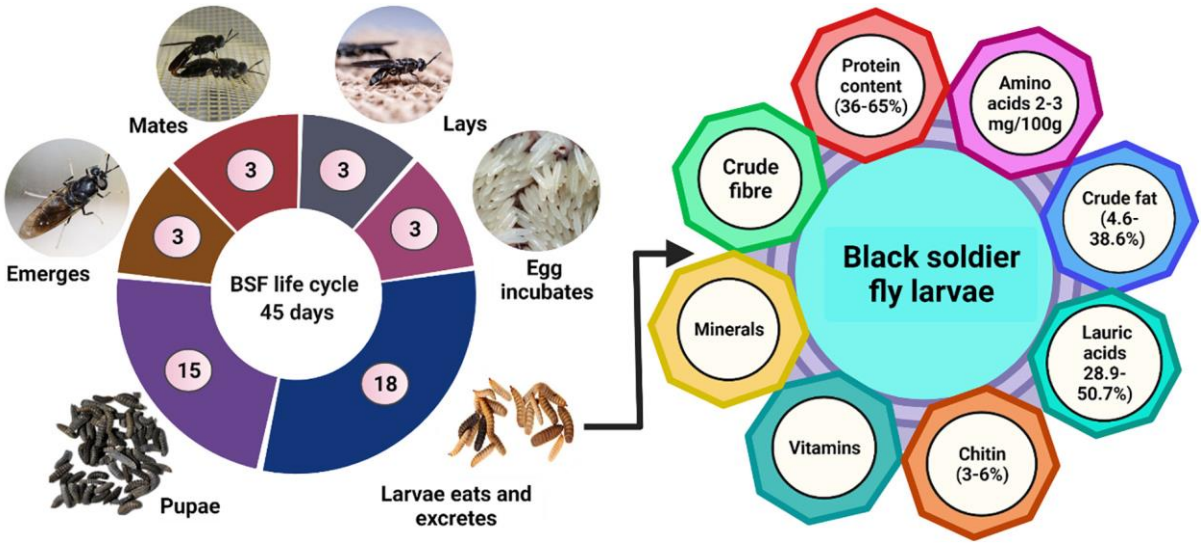
Biology and Life Cycle of Black Soldier Fly (BSF)

To promote sustainable aquaculture practices, several alternative protein-based have been proposed including insect-based protein which gained substantial recognition in recent time (Nogales-Mérida et al., 2019; Freccia et al., 2020; Xu et al., 2020). With the European Union (EU) approval of the use of insect processed animal protein in aquafeeds (EU commission regulation (2017/893–24/05/2017), insect species such as Black soldier fly (*Hermetia illucens, L*), Common Housefly (*Musca domestica*), Yellow Mealworm (*Tenebrio molitor*), Lesser Mealworm (*Alphitobious diaperinus*), House cricket (*Acheta domesticus*), Banded cricket (*Gryllodes sigillatus*) and Field Cricket (*Gryllus assimilis*) have been granted production. Among these insects, black soldier fly has been deemed as most promising for its life-cycle, protein composition and nutritional value (Gebremichael et al., 2021). According to Mohan et al. (2022), black soldier fly has four different stages

including eggs, larvae, prepupae and pupa or adult fly with 45 days of lifecycle. Based on the understanding of the life cycle, nutritional and chemical composition of the black soldier fly (Figure 1), several researches have been carried out regarding in partial and total replacement in aquafeeds and their outcome.



(a) Adult Black Soldier Fly



(b)

Figure 1: Adult, Life Cycle, Nutritional and Chemical Composition of the Black Soldier Fly (Mohan et al. 2022)

Nutritional Profile and Quality of Farmed Fish Based on BSF Meal

To promote the sustainable aquaculture of overreliance on fishmeal and replaced partially or completely with other ingredient in aquafeeds, the nutritional composition of the promising replacer must be investigated for its nutritional and other performances potentiality (Zarantoniello et al., 2020). Black soldier fly has been considered as suitable replacer of fishmeal with the potential to supply all the needed fish nutrient for growth performance and economic viability (Zarantoniello et al., 2020). In this regard, the nutritional composition of the Black soldier fly has been duly investigated and some of the profile are presented in Table 1.

Table 1: *Nutritional Profile of Black Soldier Fly Meal for Aquafeed*

Nutrient	**Fishmeal+**	**Black Soldier Fly Larvae**				
		Ref 1*	**Ref 2**	**Ref 3***	**Ref 4**	**p-value**
Crude Protein	667.0	652.0	600.5	350	520.3	0.004
Crude Lipid	106.0	57.0	81.2	29.8	151.0	0.055
Ash	136.0	21	81.1	53.0	72.9	0.024
Essential Amino Acids						
Methionine	25.1	8.5	5.1	21.2	6.6	0.067
Asparagine	-	36.5	-	73.0	-	0.215
Threonine	40.5	25.3	30.6	44.3	17.0	0.014
Valine	52.8	22.7	50.1	67.9	25.6	0.030
Isoleucine	44.3	18.5	33.8	47.3	18.7	0.023
Leucine	75.9	42.3	57.9	78.3	32.3	0.013
Phenylalanine	42.8	23.8	35.3	77.6	16.3	0.068
Histidine	84.2	10.5	24.7	32.5	15.0	0.025
Lysine	26.2	30.1	50.3	68.2	27.1	0.020

Arginine	61.7	30.6	40.3	54.7	22.9	0.012
Non- Essential Amino Acids						
Cysteine	8.3	36.5	4.5	7.6	3.7	0.195
Serine	38.7	24.9	32.8	48.8	-	0.037
Glutamic Acid	137.0	50.4	90.1	131.0	-	0.060
Proline	44.1	23.0	42.8	66.8	-	0.073
Glycine	69.4	24.8	46.2	61.5	-	0.053
Alanine	65.7	32.7	53.6	82.1	-	0.059
Tyrosine	36.5	15.3	58.0	67.1	22.5	0.050
Total Amino Acid	853.2	456.4	656.1	1029.9	207.7	

+: provided by Kuo et al. (2022), Ref 1: Eide et al. (2024), all reading was in % and converted to g/kg, Ref 2: Kuo et al. (2022), Ref 3*: Rawski et al. (2020), Ref 4: Cummins Jr et al. (2017) p-value < 0.05 = Significance difference, p-value > 0.05 = No significance difference*

Among the reported black soldier fly larvae nutritional profile/composition reported, the crude protein reported by Eide et al. (2024) was the highest while those reported by Rawski et al. (2020) was the lowest. However, all the black soldier fly larvae the crude protein reported were lower than fishmeal crude protein concentration. Using the student t-test analysis, there was a significant difference in the crude protein concentration of the reported black soldier fly larvae (p-value < 0.05, where p = 0.004). Total amino acid was highest at 1029.9 g/kg which was reported by Rawski et al. (2020) while the lowest was 207.7 g/kg which was reported by Cummins Jr et al. (2017). The total amino acid reported for fish meal was higher than those reported for black soldier fly larvae except those reported by Rawski et al. (2020). The t-test analysis revealed that there was significant difference in the various amino acid concentration of the black soldier fly larvae reported (p-value < 0.05) except for Methionine, Asparagine, Phenylalanine, Cysteine, Glutamic Acid and Proline (where p-value > 0.05). As suggested by Li et al (2019), when a new ingredient is being introduced in aquafeeds, it must be

diligently analysed to ensure such ingredient meets the nutritional requirement to positively affect the fish physiological responses and gut microbiota.

Potential of Black Soldier Fly (BSF) as Partial or Full Replacement of Fishmeal in Aquafeeds

Abdel-Tawwab et al. (2020) experiment a partial replacement (by 50%) of fishmeal by Black soldier fly in the growth performance of European seabass (*Dicentrarchus labrax*) and the outcome revealed no substantial changes by the replacement; however, the cost of feeding reduced by 15.6% as compared with 100% fishmeal feed. Similarly, Abdel-Latif et al. (2021) asserted no negative effect on fish nutritional performance after 50% replacement of fishmeal with Black soldier fly for European seabass while the performance suggested possible potentiation of the antioxidative status, and the immune responses of the European seabass. Partial replacement of fishmeal with Black soldier fly in feeding Nile Tilapia was conducted by Kariuki et al. (2024) and the outcome asserted that the replace had no impact on the growth performance of the fish rather increase the profitability from investment. Study noted the outstanding nutritional composition of approximately 30% - 58% protein, 10% - 30% lipids, with exceptional amino acids composition, macro-micro mineral and vital vitamins offering cheap protein source for aquatic animals (Kariuki et al., 2024). Munguti et al. (2024) noted optimal growth performance by Nile Tilapia under Black soldier fly partial replacement at 25% and 50% of fishmeal and suggested Black soldier fly as potential alternative to fishmeal in aquafeeds production for the fish species.

Similar partial or full replacement of fishmeal have been carried out using aquaculture fish such as Rainbow trout (*Oncorhynchus mykiss*) (Teroya et al., 2019) and Jian carp (*Cyprinus carpio* var. Jian) (Zhou et al., 2018), common carp (*Cyprinus carpio*) (Gebremichael et al., 2021) which outcome that suggested potential growth performance

with partial and total replacement of fishmeal with Black soldier fly. Yu et al. (2023) asserted improved overall growth performance and intestinal health of juvenile golden pompano (*Trachinotus ovatus) fed* with 25% Black soldier fly replacement of fishmeal. Although, a 50% Black soldier fly replacement of fishmeal had a negative impact on growth and intestinal health. Tippayadar et al. (2021) studied the growth performance, haematology and skin mucus immunity of Nile Tilapia (*Oreochromis niloticus*) fed with 10%, 20%, 40%, 60%, 80% and 100% replacement of fishmeal with Black soldier fly. The outcome suggested no significant different in overall growth performance of fishmeal and Black soldier fly feeding regime while Skin, mucus lysozyme, and peroxidase activities were improved in Black soldier fly fed fish. Furthermore, the fish showed no adverse effect upon 100% replacement of fishmeal suggesting possible overall replacement. In Magalhaes et al. (2017) feed trial of 6.5%, 13%, and 19.5% inclusion of Black soldier fly pre-pupae, replacing 15%, 30% and 45% of fishmeal respectively for European seabass (*Dicentrarchus labrax*) juveniles, it was observed that the food utilization efficiency and growth performance was not affected and 19.5% of Black soldier fly pre-pupae can replace 22.5% of fishmeal with no compromise.

Conclusion

The use of black soldier fly as the source of protein and nutrients for aquafeeds, produced under organic substrate and ensuring its sustainability offers an effective and eco-friendlier option against the traditional fishmeal with various sustainability challenges. The attributes such as rapid growth, low environmental effect and conversion of organic waste to valuable nutrient contents makes black soldier fly a sustainable candidate for aquafeed production. However, there is need to for establishment and full implementation of various legal framework that will stipulate appropriate substrate selection and production process. Adequate and sufficient pre-treatment and processing

procedures needed for nutritional improvement and final product quality must be outline. With effective and outlined regulations for its handling and safety, there will be an increase consumer acceptability and increase market size. Food production can be improved through the integration of black soldier fly into circular economy and conscious promotion towards sustainable food system.

REFERENCES

Eide, L.H., Rocha, S.D.C., Morales-Lange, B., Kuiper, R.V., Dale, O.B., Djordjevic, B., Jamie Marie Hooft and Margareth Øverland (2024) Black soldier fly larvae (Hermetia illucens) meal is a viable protein source for Atlantic salmon (Salmo salar) during a large-scale controlled field trial under commercial-like conditions. *Aquaculture*, 579 740194–740194.

Freccia, A., Tubin, J.S.B., Rombenso, A.N. and Emerenciano, M.G.C. (2020) Insects in aquaculture nutrition: an emerging eco-friendly approach or commercial reality. In: *Emerging Technologies, Environment and Research for Sustainable Aquaculture*. Intechopen, 1–14.

Gebremichael, A., Hancz, C. and Kucska, B. (2021) Effect of total or partial replacing of fishmeal with black soldier fly (Hermetia illucens) meal on growth performance and body condition indices of common carp (Cyprinus carpio). *AACL Bioflux*, 14(4) 2280–2286.

Kariuki, M.W., Barwani, D.K., Mwashi, V., Kioko, J.K., Munguti, J.M., Tanga, C.M., Kiiru, P., Gicheha, M.G. and Osuga, I.M. (2024) Partial Replacement of Fishmeal with Back Soldier Fly Larvae Meal in Nile Tilapia Diets Improves Performance and Profitability in Earthen Pond. *Scientific African*, 24 e02222–e02222.

Li, Y., Kortner, T.M., Chikwati, E.M., Munang'andu, H.M., Lock, E.-J. and Krogdahl, Å. (2019) Gut health and vaccination response in pre-smolt Atlantic salmon (Salmo salar) fed black soldier fly (Hermetia illucens) larvae meal. *Fish & Shellfish Immunology*,

86 1106–1113.

Magalhães, R., Sánchez-López, A., Leal, R.S., Martínez-Llorens, S., Oliva-Teles, A. and Peres, H. (2017) Black soldier fly (*Hermetia illucens*) pre-pupae meal as a fish meal replacement in diets for European seabass (Dicentrarchus labrax). *Aquaculture*, 476 79–85.

Munguti, J., Wekesa, F., Osuga, I., Kariuki, M., Yossa, R., Mungai, D., Kyule, D., Abwao, J., Opiyo, M., Obiero, K., Outa, N., Ogello, E., Iteba, J., Kirimi, J., Maundu, A., Liti, D. and Tanga, C. (2023) Utilization of Black Soldier Fly (Hermetia illucens) Larvae as a Potential Substitute for Fish Meal in the Production of Nile Tilapia (Oreochromis niloticus L.). *Sustainable Agriculture Research*, 13(1) p40.

Nogales-Mérida, S., Gobbi, P., Józefiak, D., Mazurkiewicz, J., Dudek, K., Rawski, M., Kierończyk, B. and Józefiak, A. (2019) Insect meals in fish nutrition. *Reviews in Aquaculture*, 11(4) 1080–1103.

Rawski, M., Mazurkiewicz, J., Kierończyk, B. and Józefiak, D. (2020) Black Soldier Fly Full-Fat Larvae Meal as an Alternative to Fish Meal and Fish Oil in Siberian Sturgeon Nutrition: The Effects on Physical Properties of the Feed, Animal Growth Performance, and Feed Acceptance and Utilization. *Animals*, 10(11) 2119.

Terova, G., Rimoldi, S., Ascione, C., Gini, E., Ceccotti, C. and Gasco, L. (2021) Rainbow trout (Oncorhynchus mykiss) gut microbiota is modulated by insect meal from Hermetia illucens prepupae in the diet. *Reviews in Fish Biology and Fisheries*, 29(2) 465–486.

Tippayadara, N., Dawood, M.A.O., Krutmuang, P., Hoseinifar, S.H., Doan, H.V. and 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(1) 193.

Xu, X., Ji, H., Belghit, I. and Sun, J. (2020) Black soldier fly larvae as a better lipid source than yellow mealworm or silkworm oils for juvenile mirror carp (Cyprinus carpio var. specularis). *Aquaculture*, 527 735453.

Yu, Z., Sun, Z., Ou, B., Zhou, M., Huang, Y. and Tan, X. (2023) Effects of partial replacement

of fish meal with black soldier fly (Hermetia illucens) larvae meal on growth performance, lipid metabolism and hepatointestinal health of juvenile golden pompano (Trachinotus ovatus). *Aquaculture Reports*, 33 101824–101824.

Zarantoniello, M., Zimbelli, A., Randazzo, B., Compagni, M.D., Truzzi, C., Antonucci, M., Riolo, P., Loreto, N., Osimani, A., Milanović, V., Giorgini, E., Cardinaletti, G., Tulli, F., Cipriani, R., Gioacchini, G. and Olivotto, I. (2020) Black Soldier Fly (Hermetia illucens) reared on roasted coffee by-product and Schizochytrium sp. as a sustainable terrestrial ingredient for aquafeeds production. *Aquaculture*, 518 734659.

Zhou, J.S., Liu, S.S., Ji, H. and Yu, H.B. (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). *Aquaculture Nutrition*, 24(1) 424–433.