Scope of insect- based meal in supplementary feeding in aquaculture: specific reference of *Hermetia illucens* (Black Soldier Fly)

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Abstract

Aquaculture is the fastest growing sector to ensure the food security to the growing population of human globally. Availability of food becomes one of the limiting factors in aquaculture practices. Aquatic species, especially fish can be cultured anywhere provided a good quality of water. However, absence of soil substratum can limit the production of natural food in the water body. To fulfill this gap, organisms are supplemented with artificial feed. This feed can be formulated using plant (Soyabean, wheat, corn, cottonseed, peas, etc.) or animal-based materials (fish meal, fish oil, poultry and livestock by-products). Both the source materials come with certain ecological, economical and physiological restraints. To overcome these, insect- based meal is being considered as an option. Insects can be grown using organic waste matters as substratum. A large quantity of biomass can be produced while decomposing the waste. So, in the light of environment, they become an excellent alternative. Nutritionally they are laden with and can be fortified with nutrients essential for optimum growth and survival of aquatic species. However, not all the insects can be used for this purpose. Black soldier fly, Hermetia illucens, is one of the widely used insects in this regard. These saprophagous fly are not a carrier for any disease and can be grown using organic waste materials as substrate. Their dried larvae can be used as nutrient- rich feed. Now-a-days, they are commercially available worldwide as protein and calcium rich food supplement for fish and other carnivorous pet organisms. Extensive scientific research and regulatory guidelines and policies are necessary to optimize the insect farming and processing of insect meal to be used as supplementary feed to the aquaculture species.

Keywords: Insect, aquaculture, *Hermetia illucens*, Fishmeal, Lauric acid, supplementary feed.

I. Background of the study

Global human population is expected to reach 10 billion by 2050 [1]. To ensure the food security to this growing population, we need to increase the agricultural production by 50 % [2]. For agricultural land, the world has limitations. There are reports showing anticipated rise in the living standard of individuals in developing countries. These two factors will lead to a marked increase in the consumption of animal- based foods [2]. In this regard, aquaculture stands out first in the row to ensure global food security. An annual increase at the rate of 3 % in global apparent consumption of aquatic foods was reported from 1961 to 2019

[3]. In 2020, global production of aquatic animals was estimated to be 178 million tonnes, 90 million tonnes from capture fisheries and 88 million tonnes from aquaculture. Of the total production, 63 % were harvested from marine waters and 37 % from inland waters. Approximately 89 % (157 million tonnes) of total production of aquatic animals were used for human consumption. Remaining (20 million tonnes) were destined for non- food uses, such as, production of fishmeal and fish oil [3]. Among different aquatic organisms, fish, a rich source of protein and healthy fats, are being widely captured and cultivated. India is the second largest fish producing country with approximately 8 % share in global fish production. The fisheries sector in India is recognized as "Sunrise Sector", as it is supporting the livelihood of nearly 30 million people, specifically from marginalized and vulnerable communities [4]. During 2023-24, an impressive amount of fish production (184.02 lakh tonnes) has been reported in India. Inland fisheries and aquaculture production showed a growth of 114 %, rising from 61.36 lakh tonnes in 2013-14 to 139.07 lakh tonnes in 2023-24 [4]. India is moving forward to build ecologically healthy, economically viable and socially inclusive fisheries sector in a sustainable and responsible manner under the supervision and guidance of Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying. There are many government schemes and initiative to facilitate the aquaculture sector in India, namely, Kisan Credit Card (KCC) with lending limit of 5 Lakh rupees, blue revolution scheme, Pradhan Mantri Matsya Sampada Yojana (PMMSY), etc [5], Fisheries and Aquaculture Infrastructure Development Fund (FIDF), Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PMMKSSY) [4]. Combining policy initiatives, strategic investments, technological advancements and regulatory reforms, India is forging ahead to unlock the full potential of fisheries sector [4].

There are limitations to the capture fishery subjected to overfishing and deterioration of aquatic ecosystems. So, pisciculture becomes one of the robust alternatives to capture fisheries. Fish can be cultured in intensive, semi-intensive and extensive set-ups. In any type of set-up, feed becomes one of the prime limiting factors [2]. To obtain maximum yield of the fish, artificial or supplementary feed are given in addition to the natural food present in the water body.

II. Literature review and criteria for exclusion

For this review, a total of 85 articles were retrieved from scientific databases, ScienceDirect, PubMed, research gate and google scholar and government official websites. The articles were searched using keywords like, "Aquaculture", "Capture fisheries", "Fisheries", "Supplementary feeding", "Ingredients used in artificial fish feed", "nutritional quality of insects", "use of insects in fish feed", "black soldier fly supplementation in fish feed", etc. 49 articles were excluded due to duplications, review articles, use of other insect species for supplementation and non- availability of full articles. 36 articles were used in the preparation of present review paper.

III. Animal- based or plant- based artificial feed: Advantages and limitations

Fishmeal and fish oil are commonly used in formulation of supplementary feed for fish. They are easy to digest and provide a wide range of essential amino acid and long- chain polyunsaturated fatty acids to the fish. But these ingredients themselves are derived from fish. So, excess dependence of this feed can impose significant pressure on natural fish stocks and this increases the cost of the feed also [6]. There are many plant- based feed formulations made with ingredients like, wheat, corn, soybean, cottonseed, beans, peas, etc. They are widely available and cost- effective too. However, plant- based ingredients may contain antinutritional factors that may limit their digestibility [2]. They also contain complex indigestible carbohydrates which impact the growth and welfare of fare negatively [1]. Use of plant- based ingredients helps in alleviation of pressure on the natural fish stock, but they also demand increase in agricultural

production. In search of alternatives, by-products from poultry, ruminants and swine were also explored [2,7]. They were reported to be a good source of proteins and essential amino acids. But they lack long- chain fatty acids. So, we need an alternative which are nutritionally adequate for the fish fulfilling their physiological and metabolic requirements in addition of being eco-friendly and cost- effective.

IV. Insects as a promising ingredient in fish feed

Insects are being considered as a promising alternative of fishmeal and fish oil in formulation of artificial feed for fish. They have been reported to be a good source of protein and fat [8]. They are an excellent source of carbohydrates (chitin), essential amino acids, lipids (unsaturated fatty acids, lauric acid: medium- chain saturated fatty acids), vitamins (Riboflavin, B_{12}, biotin, folic acid, pantothenic acid), minerals (Zinc, Sodium, Potassium, Iron, Magnesium, Copper, Calcium, Manganese, Phosphorus) and anti- microbial peptides; promising a balanced nutrition to the fish for growth and development [6,9,10,11]. Insect meal has been reported with positive impact on growth performance, nutrient utilization, antioxidant capacity, disease resistance and immune response in many species of aquaculture practices [1, 12]. The nutritional value of insects varies depending upon the species, developmental stage, diet and method adopted for processing of the insects during feed formulation [10]. They consume decaying organic matter and have a lower feed conversion ratio. Being primarily ectothermic in nature, they are efficient food converters, as they don't need much of the energy to maintain homeostasis. They emit fewer greenhouse gases [8]. A large quantity of insects can be grown in a short time period using minimal day- to- day kitchen wastes and other organic substrates. We don't need much of infrastructure and resources to mass produce the insects. They can be cultivated while being used as decomposers of organic wastes, vouching for an eco- friendly alternative. However, not all insects can be used as food ingredient. Some of the widely documented insects with suitable nutrient profile to be utilized as an ingredient in fish feed are: *Hermetia illucens* (Black Soldier Fly), *Musca domestica* (House fly), *Zophobas morio* (Superworm), *Tenebrio molitor* (Yellow Mealworm), *Acheta domesticus* (House cricket), *Bombyx mori* (Silkworm), *Calliphora vomitoria* (Blue bottle), *Alphitobius diaperinus* (Lesser mealworm), *Macrotermes subhyalinus* (Mandi termites), *Gryllodes sigillatus* (Tropical house cricket), etc [2, 13, 11]. Out of these, black soldier fly is being extensively used in the formulation fish feed. So, in this study, an attempt has been made to review the advantages and scope of utilization of black soldier fly as an ingredient in the fish feed.

The commercially available dried larvae of black soldier fly promise a great deal of nutritional benefit not only for fish but other pet animals also. It has been said to be rich in calcium and protein leading to faster growth of the individual. Presence of natural antioxidants not only enhance the color but also provide immunity and digestive health. It has been reported to be palatable also (Table 1). In this review, an effort has been made to affirm these promises by the scientific reports published in this regard.

V. Why *Hermetia illucens* (Black soldier fly)?

Black soldier fly, a dipteran fly insect, can be cultivated using food wastes, agricultural wastes, fruits and vegetable wastes and slaughter house wastes. They are extremely resistant species which can tolerate environmental adversities like drought, shortage of food or deficiency of oxygen. They degrade organic wastes rapidly, turning them into protein and fat- rich biomass suitable for various purposes, like, animal feeding, production of biodiesel and chitin. Moreover, they make the region unsuitable for the house fly to grow, thereby keeping the surrounding safe and nuisance free [14]. They are not attracted to human habitat or food. Moreover, they are not potential carrier for any diseases. Their larvae can be dried easily for long-term storage. One more advantage of using this fly for biomass production is that its adult does not feed and so does not require any particular care. Major disadvantage for using this fly for biodegradation is that it

requires a warm environment to grow, which may be a limiting factor in temperate regions. The life cycle of the fly is completed within 23- 25 days depending upon the type of substrate used and prevailing environmental condition (Fig 1) [14]. Black soldier fly is native to tropical and warm climate of America, but now can be found in sub- tropical regions across the globe [15].

VI. Nutritional profile of Black soldier fly larvae

Apart from being a rich source of protein, the larvae of black soldier fly have been reported to be an excellent source of minerals (Phosphorus, Potassium, Calcium, Magnesium, Sodium, Iron, Copper, Manganese, Cobalt, Zinc, etc.), amino acids (Histidine, Arginine, Lysine, Proline, Valine, Methionine, Tyrosine, Isoleucine, Leucine, Phenylalanine, etc.), flavonoids (Luteolin, Apigenin, Quercetin, Rutin, Kaempferol, etc.), vitamins (Gamma Tocopherol, Alpha Tocopherol, Provitamin D3, etc.) and fatty acids (Lauric acid, Myristic acid, Palmitic acid, Stearic acid, Arachidic acid, Palmitoleic acid, Oleic acid, Linoleic acid, g- Linolenic acid, Arachidonic acid, Eicosapentaenoic acid, etc.). The proportion of these nutrients vary in the larvae grown on different substrates, namely, chicken manure, kitchen waste and spent grain [16]. Effect of substrate quality on nutritional component of the fly larvae have been reviewed by Lievens et al., 2021 [15].

VII. Use of Black soldier fly larvae as feed

Utilization of black soldier fly larvae in partial or complete substitution for fish meal has been reported in Channel catfish, yellow catfish, blue tilapia, rainbow trout, Atlantic salmon and Turbot [17, 18]. The mature larvae and pre- pupae stage has been reported to be rich in protein content. Inclusion of black soldier fly larvae meal in the diet of red hybrid tilapia (*Oreochromis* spp.) increased the feed utilization and elevated the protein content of the fish. It was suggested to be used as 30 % partial replacement for corn grain and soybean meal in the fish feed [8]. No negative effect was observed on digestibility coefficients of nutrients, activity of digestive enzymes, liver health, feed intake, daily growth increase, feed conversion ratio and composition of whole-body protein, lipid and amino acid composition in Atlantic salmon (*Salmo salar*) following dietary replacement of fishmeal with BSF larvae meal [19]. Replacement of soyabean meal with defatted BSF larvae-based meal up to 50 % did not show any alteration in growth performance, feed efficiency, proximal composition of muscle and hepatic morphology in *Ctenopharyngodon idellus* (grass carp). Moreover, the substitution improved the antioxidant capacity by increasing the catalase activity and decreasing malondialdehyde activity. Substitution of BSF larvae feed also decreased the abundance of *Aeromonas* and *Shewanella* in the gut of grass carp [20]. Increase in feed intake, increased activity of intestinal lipase, reduction in level of lipid in blood and liver and decreased blood level of malondialdehyde advocated for the use of defatted larvae of BSF as efficient protein alternative in diets of juvenile Japanese Seabass [21]. Efficacy of BSF larvae-based diet on growth performance, feed digestibility, nutrient deposition, gut health, antioxidant potential, lipid digestibility and muscle protein level has been documented in *Oncorhynchus mykiss* [22], *Acipenser baerii* juveniles [23], *Clarias gariepinus* [24], *Salmo salar* [25], *Dicentrarchus labrax* [26], *Cyprinus carpio* [27], *Monopterus albus* [28] and *Lates calcarifer* [29].

Graded substitution of protein- rich fishmeal diet with BSF larvae meal showed better growth performance and maximum whole-body content of protein and lipid at inclusion rate of 25 %, 29 % and 15 % of the diet, respectively, in pacific white shrimp [30]. In a study conducted by Biancarosa *et al*., 2019 [31], successive substitution of fish meal with insect meal made up of BSF larvae (33 %, 66 % & 100 %) did not alter the level of contaminants absorbed from the rearing substrate in the feed, but a lower level of arsenic was recorded in the fillet when fish were fed with insect meal rich diet. Upon further speciation analysis of diet showed that the level of arsenic was equal in all the diets containing different proportions of fishmeal and

insect meal, but insect meal diet was having arsenic species with lower bioavailability, leading to reduced feed-to-fillet transfer.

The Indian Council of Agricultural Research- Central Marine Fisheries Research Institute (ICAR-CMFRI) has developed an eco- friendly fish feed using black soldier fly larvae meal. These larvae are packed with essential nutrients, namely, proteins, amino acids, fats and other vital micronutrients, and may offer a balanced diet suitable for growth and health of farmed fish. For large- scale commercial production of this formulation, ICAR-CMFRI has transferred this technology to Amala Eco Clean Private Limited, a company known for its valuable contribution in sustainable waste management [32]. ICAR- NBAIR (National Bureau of Agricultural Insect Resource) in collaboration with ICAR- CIFRI (Central Inland Fisheries Research Institute) have developed a fish feed pellet using BSF larvae. They observed a significant gain in weight of fish (Tilapia, amur carp and pungas) along with lower feed conversion ratio, when fed with BSF based feed. The technology used for feed formulation is under evaluation [33].

VIII. Limitations and future prospects

Despite of being a sustainable and nutritive alternative to expensive and ecologically undesirable ingredients being used in fish feed, entofeeds have to face challenges and constraints. To obtain a biomass of insect of good quality, selection of suitable substrate is important. The substrate should be free from contaminations with heavy metal, pesticides, fertilizers, pharmaceuticals and pathogen- laden fecal matter. These substances may become an integral part of insect body and further cause damage to organisms at subsequent trophic level via biomagnification [34, 35]. The nutritional quality of meal depends upon the developmental stage of the insects being selected [36]. So, it becomes a necessity to optimize the nutritional composition as per the need of different aquaculture species for optimal growth and health [6]. Insects accumulate fat during immature larval stages, so defatting also becomes essential to make a protein- rich substitute [17]. Although the primary product of insect production is larval biomass, other by products, such as, frass and chitin also accumulate during production, which needs to be managed properly [35]. One more aspect that influences the quality and marketing of the insect meal is the method adopted during its processing and storage [36]. Research and development regarding optimization of insect farming processes, improvement in nutritional profile, consumer awareness, advancement in processing and storage techniques and collaboration with aquaculture industry are warranted for unlocking the full potential of insect meal in aquaculture [34-36].

IX. Conclusion

Insect meal is laden with protein, calcium and good fatty acids necessary for optimal growth and survival of fish being cultured. The meal can be easily fortified with required minerals, vitamins and functional components by altering the substrate used for production of insect biomass. It can reduce our dependency on fishmeal and fish oil in formulation of supplementary fish feed. Insect meal not only provide nutritional benefit to fish, but can be used to biodegrade the organic wastes. Thus, insect- based meal can be an ecofriendly and cost-effective alternative to plant- and animal based supplementary feed in aquaculture.

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Table 1: Commercial availability of Black Soldier Fly as fish food (Retrieved from: Amazon.in)

Product name	Nutritional info.	Suitable for	How to feed?
Boltz Black Soldier Fly Larvae 	Protein: 45 %, Calcium: 0.2 %, Fiber: 12 %, Moisture: 04 %, Fat: 10 %, Ether extract: 33 %, Phosphorus: 0.78 %	Goldfish, Guppies, Betta, Oscar, Discus, Hikari, Gappies, Cichlid, Arowana	Small fish: 4-5 BSF (2 times a day), Medium fish: 8-10 BSF (2 times a day), Large fish: 14-15 BSF (2 times a day)
Keetup Whole dried BSFL grubs 	Crude protein: 40 %, Crude fat: 32 (Omega 3) %, Fiber: 7 %, Lysine: 0.5 %, Phosphorus: 0.7 %, Calcium: 3 %	Fishes, turtles, reptiles	Small fish: 2-3 larvae (Twice a day), Medium fish: 8-10 larvae (Twice a day), Large fish: 12-15 larvae (Twice a day)
Jothi Aquatics Dried Black Soldier Fly Larvae 	Crude protein: 68 %	Carnivorous fishes, Livestock, Reptiles, Birds, Small Mammals, Spiders, Amphibians	NA
Zewa Feeds Dried BSFL	Crude Protein (min): 36 %, Crude Fat (min): 28 %, Crude Fibre (max): 10 %, Moisture (max): 7 %, Ash (max): 10 %, Calcium (min):	Oscar, Flowerhorn, Arowana, Carp	Small fish: 2-3 larvae (Twice a day, need to be crushed before giving to fish), Medium fish: 5-6 larvae (Twice a day), Big fish: 9-10 larvae (Twice a day, feed directly).

	1 %, Phosphorus (min): 0.5 %		Gradually introduce larvae over a period of a week or more.
TUNAI Black Soldier Fly Larvae 	Protein: 40 %, Fat: 30 % (Omega 6 and 9), Fibre: 05 %, Moisture: 10 %, rich in Calcium and Lauric acid	Oscar, Arowana, Flowerhorn & other omnivores	Feed 2 or 3 times a day, increase or decrease the amount based on how much the fish is consuming in 5 minutes.
WiggleBoo Black Soldier Fly Larvae 	Protein: 40 %, Fat: 30 % (Good in Omega 6 and 9), Fibre: 05 %, Moisture: 10 %	Arowana, Flowerhorn, Oscar, Parrot fish & other fishes, turtle, birds, gecko and other carnivorous reptiles	NA

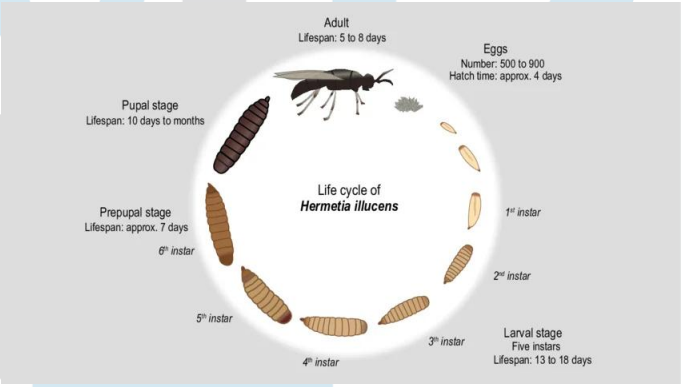

Fig 1: Life cycle of *Hermetia illucens* [15].