Review Article

Potential Use of Insect-Based Feed as an Alternative to Conventional Feeds in Aquaculture: A Sustainable Approach

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Abstract | The world population is predicted to surpass 10 billion by the year 2050, intensifying the burden on environmental resources and escalating the demand for food consumption. The increase in the aquaculture industry, at an average of 5.70% is attractive and crucial to the rising need for fish protein due to the valuable amino acids and its affordability. It gives about 15-16% to the total animal protein used by 2.9 billion people in low-pay and food-undersupplied nations. With the maintained expansion in the perception of health advantages, the global requirement for aquatic foods, even in established countries, is projected to rise. Aquaculture production is liable for 50% of worldwide fishery production. Conventional feeds such as fishmeal, soyabeans and plant-based feed, are the ideal protein component in aquaculture feed and pay substantially to the making expenditure in the aquaculture production. On the other hand, reducing conventional feeds supply relative to need and growing costs compromise the sustainability and growth of the aquaculture industry. The climate fluctuation and falling availability of conventional feeds have substantially impacted the cost the supply, both aquaculture and poultry industries. In contrast, significant research focused on a sustainable feed to fill up the gap. Therefore, the current review study broadly evaluated the performance of insect-based feed components, as alternative feed ingredients. The study delves into the biology, nutritional profiles, while highlighting their suitability as feed additives. An in-depth exploration of the benefits and challenges accompanying incorporating insect-based feeds into diet for animals by assuring efficiency, growth performance, and overall health for the sustainable approach.

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Introduction

Approximately 10 billion of the population will live on earth by the year 2050. Environmental resources will experience immense strain in future years, leading to an increase in food consumption to fulfill the demands of an increasing population (Khan *et al*., 2024). The aquaculture sector, which is developing at a rate of 5.70% per year, ranks as one of the most rapidly expanding food-producing industries, providing a substantial portion of the world's edible fish food supply compared to other industry (FAO, 2020; Pinotti *et al*., 2016). Fishmeal is a cost-effective and nutrient-dense source of high-quality protein and is beneficial to both human and animal (Anater *et al*., 2016; FAO, 2018; Supartini *et al*., 2018; Hazreen-Nita *et al*., 2022; Valfre *et al*., 2003).Additionally, accessibility of conventional feed ingredients including soybeans, cereals and fishmeal significantly affected by extreme volatility, available resources under climate variability (Mugwanya *et al*., 2022). As a result, the predictable expansion of the fisheries sector has been disturbed, primarily due to the increasing cost for feed components used in the aquaculture sector (Dawood, 2021). As the expanding market demand for livestock-derived productswill primarily be fulfilled by specialized feeding operations for animals, with a subsequent significant rise in feed consumption, significant efforts in research have been conducted to produce new feed components. Moreover, feeds are among the key environmental expenses (Nijdam *et al*., 2012), there is an urgent need for finding alternate while considering eco-friendly components for the diets of animals. Insects are widely acknowledged as one of the possible answers since they contain abundant essential nutrients and have less of an ecological impact compared to other sources of protein (Lock *et al*., 2018; Smetana *et al*., 2019). Insects are the largest and most abundant category of animals on the planet Chapman (2009), There are around one million insect species, found in the dietary meals of both omnivorous and carnivorous fish (Henry *et al*., 2015). They might be regarded as a kind of "starving food" which is consumed only in times of severe food scarcity (Kinyuru *et al*., 2011; Looy *et al*., 2014). Andare significant sources of protein which can vary between 9.3% to 76% (Payne *et al*., 2015; Sanchez-Muros *et al*., 2014), as well as fat levels, which range from 7.9% to 40% (Meneguz *et al*., 2018; Finke, 2015). Khubaib *et al*., 2024 states that the crude protein (CP) needs for omnivore fish are between 35% and 45% and for carnivorous fish between 45%and 55%. Fish have specific protein needs, depending upon their amino acid profiles, which are dependent on the intrinsic amino acid patterns of every species (Kaushik and Seiliez, 2010). Additionally, due to consumer interest, fish farming has escalated by more than 200% in current decades (FAO, 2017). Due to the growing price and insufficient availability of commercial feeds, there is a significant need for inexpensive chicken feed (Mupeta *et al*., 2003). Farmers are also continuing their efforts on improving on wasp rearing approaches, which are sometimes ineffective and cost-effective, demonstrating that satisfaction and tradition are the main reasons for maintaining wasps (Payne and Evans, 2017). A broad variety of edible insects offer remarkable nutritional features (Cappelli *et al*., 2020ab), insects can be reared ecofriendly in much compact systems as compared to other animal and offer a chance for underprivileged families to make a living (Baiano *et al*., 2020; Gahukar, 2020; Rumpold and Schlüter, 2013; La Barbera *et al*., 2020).

Bioconversion of organic waste by Insect species; Eco-friendly Approach

The worldwide population is predicted to increase by reaching more than 9 billion individuals by 2050, requiring the world to grow 70% additional food compared with present (FAO, 2009). Lindner (1919) the first to suggested, insects harvesting nutrients from insects, particularly fat from biological organic waste. The farming of insects has been determined to be ecologically useful, while causing no impact to nature. It is a super food, and the European Union has previously named it one of the innovative foods with the potential to reduce protein deficiency problems in nations with limited resources. Insects can survive in a wide range of environmental conditions, spawn rapidly, and consume a wide range of foodstuffs (Singh *et al*., 2023). Farming of insect-based conversion provides a possible step forward in supplying alternate source by reducing waste food and costly products (Nyakeri *et al*., 2019, Nyakeri *et al*., 2017; Wang and Shelomi, 2017; Veldkamp *et al*., 2012), which is an economically save method (Barry, 2004). Only several species of insects have been introduced commercially for bio conversion of waste food, particularly by black soldier fly larvae (*Hermetia illucens* L.) being the most widely used (Wang and Shelomi, 2017), ace fly larvae (Arends and Wright, 1981; Wang, 1964) and Larvae of houseflies may survive on a wide range of degrading organic substrates, particularly animal waste and feed (Hogsette and Farkas, 2000). The BSFL appears to breed effectively in more varieties of decaying substances and are usually found in rotten fruit and plant trash. Flesh flies and Blowflies, as typically might be more suitable for decomposing of wastes (Cˇicˇková *et al*., 2012). A fascinating option in insects are, they emit less greenhouse gas emissions (Oonincx *et al*., 2010). The small quantity of land required to produce 1 kilograms of protein (Oonincx and de Boer, 2012), their effective feed conversion rates (Van Huis, 2013) and as well as their capacity to convert organic waste into high-quality protein sources (Abbasi *et al*., 2015).

Insects as a Feed: The Legal Framework

Insect consumption is allowed 50-100% in developed and developing countries globally (FAO, 2021). The industrial usage of insects is controlled by the Food and Drug Administration (FDA) in the United States. Yellow mealworm, ouse crickets and silkworms are non-novel components for food as well as feed within Canada (Government of Canada 2012), According to healthcare rules Canada, insect-based animal feed is also accessible throughout Canada. The cultivation and harvesting of insects are not particularly restricted in Europe (Evira, 2018; FASFC, 2018). Rearing insects in the Europe countries adhere to raised dairy animal's rules as well as healthcare safety criteria for transmissible diseases (EU Regulation 2009, 2016). There are a few exceptions, such as protein products from seven insect species (*G.assimilis, A. diaperinus, M. domestica, H. illucens, G. sigillatus, T. molitor, and A. domesticus*) which are now used as a key component of diet for aquafeed and pet food in different countries of Europe (Belluco *et al*., 2017; EU Regulation, 2017). The product contains YMW (Yellow meal worm) flours, migrant locusts and house crickets (EFSA and Panel, 2016; EU Regulation, 2015; IPIFF, 2019). According to the International Platform for Insects as Food and Feed (IPIFF), the proportion of Europeans consumption of edible insect products will increase significantly and exceed over 390 million in 2030 (IPIFF, 2020). Numerous Asian countries, especially South Korea, Malaysia, Vietnam, Thailand, Laos, and Cambodia, have a long history of rearing insects and intake Nam (Reverberi, 2020, Durst and Hanboonsong 2015). The prospective use of BSFL technique for the biological conversion of organic trash into valuable resources still mostly unexplored within the Asia (Albizzati *et al*., 2021). Asia has the largest animal feed productivity rate in 2022 (Alltech, 2022). Insects are also consumed by humans as a food all over the word (Bodenheimer, 1951; De Foliart, 2012). More than 2000 different types of insect's species are eaten by people worldwide including Australia, Asia, Latin America and Africa (Jongema, 2015; Van Huis, 2016; Yen, 2015; Yhoung-Aree and Viwatpanich, 2005; Ramos-Elorduy and Moreno, 1989; Costa-Neto 2015; Van Huis 2003), like beetles (31 %), true bugs (11 %), caterpillars (18 %), ants, bees and wasps (15 %), crickets, grasshoppers, locusts (13 %), flies, dragonflies and termites others (12 %) (Alexandratos and Bruinsma 2012), insect as food and feed is shown in Table 1 across different region.

Market Availability for Edible Insects

The global market for insect consumption to both humans and animals are not extensively explored (Cesard, 2004; De Foliart, 1997; Latham, 1999) According to the Global Market survey research from 2016, the average 2015 record of the globally traded insect market in countries such as the, US, Belgium, UK, Brazil, France, Thailand, Netherlands, Mexico, Vietnam and China were US$ 33 million (Global Market Insights Inc, 2016). With the progressive increase in financial stability and rising population density in developing nations, notably in Asia, are causing significant alteration in the overall demand for foodstuffs composition (Msangi and Rosegrant 2011).

Table 1: *Insect-based items, as a feed and food implementation across different regions.*

Authority	Regulation	Restriction/ Insects as feed and food	Reference
USA	FDA	Insect and insect-based items	Government of Canada 2012
Canada	Health care safety Canada	Food as well as feed (BSFL)	Government of Canada 2012
Europe	EU Regulation	Restricted because of transmittable disease but later use of insect as feed for animals *G. assimilis, A. diaperinus, M. domestica, H. illucens, G. sigillatus, T. molitor, A. domesticus*	EU Regulation 2017
Asia	---	As a feed and food	Reverberi 2020; Durst and Hanboonsong 2015; FAO, 2021; Alltech, 2022

This sum is expected to rise to $522 million by 2023. According to the reports, the market will grow up in the worldwide community, with both individual knowledge and acceptance rising (Global Market Insights Inc, 2016). Among European countries, the United Kingdom, the Netherlands, and France led the commercially viable insect's marketplace, which is expected to develop rapidly in the coming years. The edible-insect market in the US is expected to be over $50 million in 2023. In terms of particular industrial products, insect as a food one of the main sources (Global Market Insights Inc, 2016). In 2015, the market for insect-based protein was worth over US$ 11 million, and by 2023, it is anticipated that it will have increased by more than 42%. Additionally, it is predicted that by 2023, the value of insect-based flour will grow to US$ 165 million and consumption will rise by 42% (Durst and Hanboonsong, 2014). The large-scale breeding of insects in Western nations now presents various difficulties because of costly nature from rearing to its final production stage (Rumpold and Schlüter, 2013). Additionally, it is challenging to run small farms and include recyclable organic waste into the supply chain for insects (van Huis *et al*., 2013). Alexandratos and Bruinsma (2012) estimated that in the Western world, insects were lately thought of as food but between, 2005–7 to 2050, there will be a 76% rise in worldwide consumption of animal-based proteins. Wealth is one of the primary factors behind the rise in worldwide meat consumption (Tilman *et al*., 2011). In developed countries, per capita consumption of meat is likely to rise be 9% by 2030 (Msangi and Rosegrant, 2011). With each kilogram of high-quality animal protein produced, farm animals are fed around 6 kg of plant-based proteins (Pimentel and Pimentel 2003). By climatic changes and agriculture food productivity has led to a consequent 18-21% increase in pricing food crisis become a serious issue between 1990-2005 compared to 1961-1990 (Allotey and Mpuchane, 2003). Mostly insects that are edible are collected. But because of their by-products, insects like silkworms and honeybees have been farmed for an extended period; in both situations insects are also consumed (Bodenheimer, 1951). Cochineal (*Dactylopius coccus*) is another domesticated insect that produces carminic acid, which has applications in the cosmetic products and pharmaceuticals sectors (Van Itterbeeck and van Huis, 2012) and Cockroaches (*Periplaneta americana*) and Termites for biomedical purpose (Asad *et al*., 2024). Water beetles in China, giant water bug (*Lethocerus indicus*), palm weevil (*Rhynchophorus ferrugineus*) and house cricket reread in Thailand (Jach, 2003). Because of the ability to recycle waste products, insects like the drugstore beetle (*Stegobium paniceum*), termite Macrotermes subhyalinus and silkworm (*B. mori*) have been explored for space-based agriculture purposes (Katayama *et al*., 2008).

Dietary protein levels of formulated aquaculture of marine carnivorous finfish species

The needs of protein intake for marine finfish are typically high, due to their high metabolic needs for growth. Formulated diets for such species usually contain 40-55% protein, while the fish meal being the conventional protein source due to its ideal amino acids and high absorption (Maldonado-García *et al*., 2012). However, there is still a need for a sustainable alternative with no environmental impact such as insect meals, which are progressively being integrated into the aquaculture sector. Insect meals, such as mealworms and black soldier fly gained attention as a possible alternative in the aquaculture. They are rich in vitamins, fats, amino acids and minerals, their production makes them vital for fish diet inclusion (Gasco *et al*., 2021). Study showed that insect meal can replace a significant portion of fish meal in the diets of finfish deprived of any harm on development, and nutrient intake (Tuan and Williams, 2007) shown in Table 2.

Table 2: *Protein levels for different fish species according to body need.*

Species	% crude protein	References
Malabar grouper	55	Tuan and Williams (2007)
Senegalese sole	53	Rema *et al*. (2012)
Salmo trutta caspius	50	Ramezani (2009)
Yellowtail kingfish	48.5	Jirsa *et al*. (2014)
Dicentrarchus labrax	38	El-Dahhar *et al*. (2006)
Gilt-head bream	44	Moutinho *et al*. (2016)
Lutjanus argentiventris	55	Maldonado-García *et al*. (2012)

Overview of Black Soldier Flies (*Hermetia illucens*)
Black soldier fly (*Hermetia illucens*) belongs to the family Stratiomyidae, is an attractive and important in ecological perspectives. It originally belongs to North America but now it can be found in various regions due to its more use by researchers and the local community. The adult in size is large of about 15-20mm in length, with a exclusive appearance of black coloration on their wings. One of the important friendly natures is that they don't transmit any disease, which makes them more attractive and harmless (Kim *et al*., 2021b). *H. illucens* is holometabolic insect, w, egg, larva, pupa, and adult. The most noteworthy and economically important is the larval stage, which is also useful for waste management and composting commonly known as black soldier fly larvae (BSFL) (Hasan, 2022). After female hatch eggs in organic matter, it hatches in larvae they feed on the organic food waste and takes 14-21 days. The larvae then convert into pupae, taking another 5-10 days. The adult emerges from the pupa, in this stage they stop feeding, but only mate and in a week die (Hasan, 2022).

The sustainable and nutritional potential of Hermetia illuscens as a substitute protein source for fishes
Black soldier fly is one of the possible alternative and getting popular for being used as protein source in animal feeds, including aqua culture, due to its high quality of nutritional profile (Randazzo *et al*., 2021). Hermetia illucens larvae meal in aquafeeds indicates its potential as a sustainable protein source (Figure 1). It has the potential to produce a wide range of organic substrate into proteins and lipids (El-Dakar *et al*., 2021; Rodrigues *et al*., 2022). BSFL after reaching the instar 7th, they develop into a non-feeding stage referred as prepupae and go away from the food substrate where they finally metamorphose into matting stage known as black soldier fly (Barros-Cordeiro *et al*., 2014). In aquaculture, there are distinct finding on the possibility of either replacing conventional fish feed with black soldier fly larvae (BSFL) or Black soldier fly prepupae as a dietary intake (Zarantoniello *et al*., 2021). In the early times, after the concept got known it was found that with increase of BSFP, from 0,17,33,49, 64 and 76 %, affected the growth, intake of nutrient in both *Psetta maxima* and turbot. Even applying the lowest 17% significantly affected the growth of *P. maxima* and it was hypothesized due to higher content of chitin along with no such evidence of intestinal chitinase role (Kroeckel *et al*. (2012) While in contrast study carried out by Fischer *et al*., 2021) studied the effects of black soldier fly referred as BSFL and prepupae (BSFP), in the diets of largemouth bass, *Micropterus salmoides*, which were not yet been compared by any other study. The study showed that the BSFL results better than BSFP by improving growth, survival rate, intake efficiency, composition of fatty acid, mineral and genes expression. Mohan *et al*. (2022) stated that the content of protein in BSFL is around 65% while lipids is from 4.6 to 38.6%. Some study shows that using black soldier fly larvae can be use in aqua-sector as a feed which can result in a sustainable management by enhancing growth and enzymatic activities of carnivorous fish such as red drum (*Sciaenops ocellatus*), rainbow trout, largemouth bass, and *micropetrus* (Yamamoto *et al*., 2022, Stadtlander *et al*., 2017; Fischer *et al*., 2021). Similarly, many researchers were conducted the full and partial replacement of BSFL; and it showed that without any harmful impact it can enhance growth of Oreochromis *niloticus*, *L*, Nile tilapia (Limbu *et al*., 2022) up to 50% in *Dicentrarchus labrax*, *Symphy sodon sp*, *Anabas testudineus*, and climbing perch (Abdel-Latif *et al*., 2021; Kattakdad *et al*., 2022; Tu *et al*., 2022) 25% in *cynoglossus semilaevis*, Tongue sole, (Li *et al*., 2022); and just 20% in Pylodictis olivaris, and Yellowhead catfish, (Hu *et al*., 2017). Table 3 summarizes the several insect-based feed additions that have shown significant benefits in improving fish health, enhancing growth performance, and immunological function.

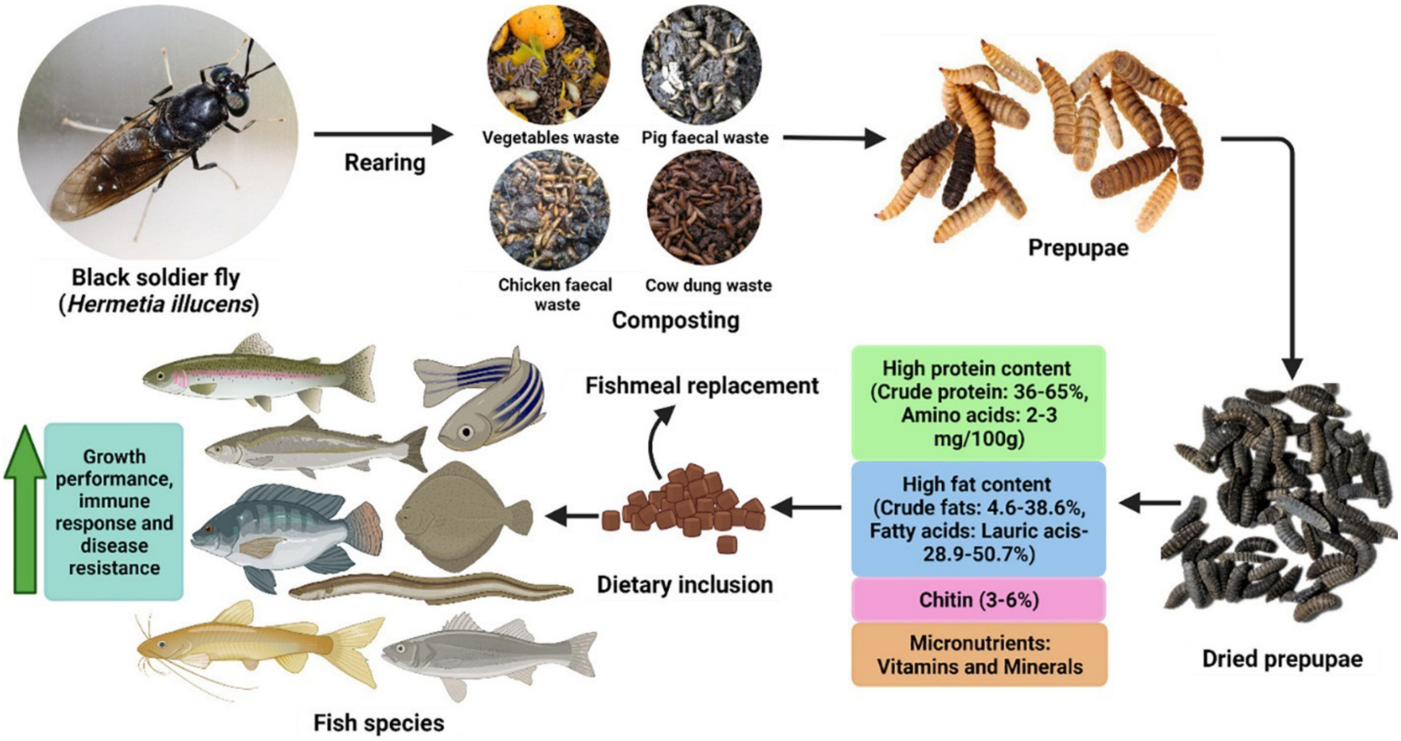

Figure 1: *Use of black soldier fly (Hermetia illucens L.) larvae meal in aquafeeds (Kannan, et al., 2022).*

Overview of Acheta domesticus

Crickets are abundant all over the regions except cooler parts of the world and somehow beyond these regions, while it can be found in warmer areas as the temperature is more suitable for their development. They are found in various habitats such as shrubs, forests, wetlands, beaches, caves, constructions and in underground parts. There are many different species of crickets but the two most widespread species for marketable agrobusiness and home consumption are the common cricket, *Gryllus bimaculate* and the house cricket, *Acheta domesticus*. Due to its diverse nutritional profile, it is one of the most appealing reared insects and it has the potential to enhance the nutritional quality of food. Oonincx, D.G. (2010) and it has high bio-conversion ratio, some of the positive aspects of crickets are, less production in emission of greenhouse gasses, using less land and feed water.

Life Stages and Development of (Acheta domesticus)

Acheta domesticus, is a hemimetabolous insect consist of three stages, egg, nymph, and adult. It is different from other species of cricket, sometimes called the two-spotted cricket. About 7 mm in width and 30 to 40 mm in length, it's a dark brown or black colour. This species is distinguished by yellow markings at the ends of its wings. It takes up to 45 days to reach adulthood, and mating occurs after two to three days. Crickets are a popular and sustainable source of protein in the aquaculture industry because of their short life cycle, quick development, low cost, good quality, and high amount of proteins (Prachom *et al*., 2023).

The sustainable and nutritional potential of Acheta domesticus as an alternative protein source for fishes

Acheta domesticus, an orthopteran species which composed of individuals that are studied to be among the important insect-based protein sources (Sánchez-Murós *et al*., 2014). It is one of the fascinating, and productive reared insects due to their promising and higher nutritional value compared to other animals the conversion of feed is also lower. Therefore, it has the potential to enhance the quality of food products, like after homogenizing it can improve the protein content of extrudates plus exact parameter of extrusion. The difference in protein content is due to the effect of the species, habitat, provided substrate and the development stage. *It consists of 29-31% protein and 4-7 gram of lipids in 100 gram of fresh weight, as same to conventional sources including chicken* (Kulma *et al*., 2019), around 30-31% polyunsaturated fatty acids, and due to their interesting composition it can be use as vital sources of vitamins (Rumpold and Schlüter, 2013). The feed conversion rate is high, they convert 2.1 kg dried feed into 1 kg edible production, while comparing to other animals such as beef, poultry, and pork needs 25, 4.5, and 9.1 kg respectively (Van Huis, 2013). Along with a vital protein content *A .domesticus*

Table 3: *Comparative analysis of insect-based feed as an additive in fish health.*

Species	Additives	Level of Inclusion	Findings	References
Largemouth bass	BSFL and BSFP	11.90% & 9.83%	BSF showed better results by enhancing growth and improving fatty acid and mineral composition.	Fischer *et al.*, 2021
Rainbow trout	BSFL	28%	Enhanced growth and enzymatic activity in a sustainable way.	Stadtlander *et al.*, 2017
Nile tilapia	BSFL	75%	Improved growth without causing any negative effects.	Limbu *et al.*, 2022
Flathead catfish	BSFL	10%, 15%, 25% & 30%	Improved growth.	Hu *et al.*, 2017
African catfish	BSFL	25%, 50% & 75%	Up to 75% enhances growth, nutrient intake, hematology, serum biochemistry, and oxidative status without any negative impact.	Fawole *et al.*, 2020
African catfish	BSFL	0%, 20% & 33%	Up to 25% can serve as a replacement to improve growth and fatty acid profile.	Azri *et al.*, 2022
Nile tilapia	BSFL	10%, 20%, 40%, 60%, 80% & 100%	Up to 100% improves mucosal immune response, while other parameters such as feed intake efficiency, hematology, and survival rate remain unaffected.	Tippayadara *et al.*, 2021
Yellowtail amberjack	BSFL	25%, 50% & 75%	Up to 30% can replace fish meal, improve fatty acid composition, and enhance immune response.	Henry *et al.*, 2019
Mozambique tilapia & Sharptooth catfish	Alates termite meal	0%, 10%, 30%, 50% & 70%	Alates termite meal can replace fish meal without affecting blood serum composition in O. mossambicus.	Nephale *et al.*, 2024
Wels catfish	Mendi termite	Not specified	The growth rate of the catfish was significant.	Ugwumba, 2008
Nile tilapia	Caterpillar meal	0%, 25%, 75% & 100%	Showed significant effect.	Ndione *et al.*, 2022
Sharptooth catfish	Caterpillar meal	0%, 10%, 30%, 50% & 70%	Improved growth performance for profitable feed formulation.	Anvo *et al.*, 2016
Nile tilapia	Grasshopper meal	0%, 10%, 15%, 20% & 30%	Showed significant effect.	Olaleye, 2015
African sharptooth catfish	Grasshopper meal	10%, 15%, 20%, 25% & 30%	Using 10% grasshopper meal and 30% fishmeal enhanced growth and food intake in fingerlings.	Okoye & Nnaji, 2005

is also a good source of fats, as the growth and health of fish depends on important fatty acids such as omega-3 and omega-6, which are abundant in their lipids. The lipid content changes from 10% to 15 of the dry matter (Józefiak *et al.*, 2019). The result confirmed that the level of fat in insects was higher than in fish meal while the protein content in fish meal was higher than insect meal except for some of the amino acids, lysine, histidine and threonine.

Mealworms life cycle, nnutritional value and its effect on fish feeds and other animals

Mealworm (*Tenebrio molitor*) belongs to the family Tenebrionidae, and among a highly nutritious promising insect which can be easily rear, that is the reason mealworm are used as feed for different animals including fish feeds, both larval and pupal stages have abundant lipid and protein (Ghaly and Alkoaik, 2009). They comprise a high amount of protein ranging from (47-60%) fat (31-43%) and a crude ash content of 1 - 4.5% and are being explored as good alternatives for fish meal in fish diets due to their high nutritional value, including essential amino acids and fats, despite some challenges like fiber content. In-addition, the above-mentioned features are reasons for confining their advantages in aquaculture up to 10% of dry matter of whole diet (Laiba *et al.*, 2021). Bovera *et al.* (2015) stated that *T. molitor* a potential protein source in aquaculture and can substitute soybean and fishmeal. Moreover , mealworm meals can be use at highest dietary concentrations of 25% without causing growth depression (Schiavone *et al.*, 2017). Further, using mealworm in aquaculture resulted in better growth and nutrient intake efficiency in different species, such as *Sparus aurata juveniles, clarias gariepinus, and Ameirurus melas fingerlings* (Piccolo *et al.*, 2017; Ng *et al.*, 2001; Roncarati *et al.*, 2015). Chemello *et al.*, 2020 suggested that inclusion of *T. molitor* depends on multiple factors such as, feeding rate, size of the specimen, and growing stage. Considering, species like carnivorous perhaps not able to absorb high *T. molitor*, while omnivorous can absorb high level of TM as an alternative of fish meal (Henry *et al.*, 2015). Similarly conducted by Antonopoulou *et al.*, 2019 showed that 50% of fishmeal changed with full-fat *T. molitor* larvae risen in considerable improvement of the gut bacterial diversity of the treated *D. labrax*. The feeding trial of Basto *et al.* (2019) suggested the potential capability of TM larvae to replace up to 80% of FM in *D. labrax* diets. A latest study by Mastoraki *et al.* (2020) indicated that 30% of FM can be efficiently replaced with whole TM larvae, with no detrimental impacts on the fish growth performance. Attractively, Reyes *et al.* (2020) stated that replacement of less than 50% of FM in sea bass diets with TM larvae did not affect growth indicators. Other species such as *Sparus aurata* Piccolo *et al.* (2020) stated that 25% of FM possibly will be effectively replaced with TM larvae, lacking any detrimental impacts on the growth or whole-body structure of *Sparus aurata*. In a similar meaning, Iaconisi *et al.*(2019) also showed that 50% dietary inclusion of full-fat TM larvae completely effect the amino acid components of the fish body.

Termites

Termites are known to be nutritious for both humans and animals (Sogbesan and Ntukuyoh *et al.*, 2012; Sogbesan and Ugwumba, 2008). Termites have high contents of protein, fat, lipids, minerals, vitamins and a balanced amino acid profile. The essential amino acid found in fish meal is present in termite meal (Igwe *et al.*, 2011; Chulu, 2015; Paul and Dey, 2011; Solavan *et al.*, 2006; Aduku, 1993; Fadiyimu *et al.*, 2003; Hlongwane *et al.*, 2022; Sogbesan and Ugwumb, 2008; Phelp *et al.*, 1975). Men *et al.* (2005) reported that fish meal, soybean can be replaced with termite. African termites (*Macrotermes falciger*) and *M. subhyalinus* have high level of caloric value (Hickin 1971; Phelps *et al.*, 1975).

Termites are being used as by humans (Paoletti *et al.*, 2003: Nutukuyoh *et al.*, 2012). Termites is commonly used as a feed in Africa, Asia, Latin America and Australia (Hardouin, 2003; Chrysostome *et al.*, 2009; Kinyuru *et al.*, 2009; Ntukuyoh *et al.*, 2012; Lavalette, 2013; Diawara, 2013; Sankara *et al.*, 2018; Boafo *et al.*, 2019; Gope and Prasad, 1983; Redford and Dorea, 1984; Solavan *et al.*, 2006). Termites are social insects, and the fish consume them alive when fall into pond (Madu *et al.*, 2003). The non-industrial scale production of termites limits their use as a feed (Kenis *et al.*, 2014).

Nephale *et al.* (2024) replace the fish meal with Alates termite meal for *O. mossambicus* and *C. gariepinus* and confirmed that Alates termite meal has no adverse effect on the health status of *O. mossambicus* and overall growth performance was recorded.

Serrano and Poku (2014) concluded that 35% fish meal can be replaced with termite and used for fresh water prawns (*Macrobrachium rosenbergii*) juveniles and the growth performance was significant. Inyang-Etoh *et al.* (2022) replace fish meal with termite in the diet of *African catfish (Clarias gariepinus*) and showed a significant result in in term of growth performance, enzyme activity and nutrients digestibility.

According to Rutaisire (2007) that the 5% fish farmers in Uganda used termite as a supplementary feed. Sogbesan and Ugwumba (2008) used termite meal from *Macrotermes subhalinus* replacement to fish meal for catfish. The growth rate of the catfish was significant. Macrotermes species are appropriate for animals and humans and are widely used as a feed due to high source of protein and nutrient. Termites are the most second eaten insects across the world (Anankware *et al.*, 2015; Józefiak and Engberg, 2015; Chung, 2010).

Caterpillars

Caterpillars are mostly used for human consumption than for animal feed (van Huis, 2003). Srivastava *et al.* (2009) reported that caterpillar contains minerals and vitamins. The amount of protein in acridids is more than that of fish meal and soyabean meal (Anand *et al.*, 2008). Ndione *et al.* (2022) reported that partially replacing fishmeal with caterpillar meal up to 50% have no adverse effects on Nile tilapia (*Oreochromis niloticus). Anvo et al.* (2016) replaced fish meal with *Cirina butyrospermi* caterpillar's meal and used as a diet for *Clarias gariepinus* larvae. The 25% inclusion level improves growth performances for a profitable feed for catfish larvae. Ajani *et al.* (2004) fed fly maggot meal to Nile tilapia (*O. niloticus*) and reported that fly maggot was proficient of replacement fishmeal up to 100%.

The larvae of *Cirina forda* can be used as a poultry feed and reported that the total replacement of fish meal with *Cirina forda* larva have significant effect on growth performance (Oyegoke *et al*., 2006; Amao *et al*., 2010). Acrididis have more protein than soybean meal and fish meal (Anand *et al*., 2008). Grasshopper meal and Mormon cricket are used as alternative to fish meal and corn-soybean meal. (Hassan *et al*., 2009; Finke *et al*., 1985). The partly or completely replacement of fish meal shows significant result in terms of growth performance and can be used for feed formulation.

Grasshoppers

Grasshopper meal contains most of the important amino acids in higher proportion than other protein feed stuff. Some research studies have been conceded on the rearing of grasshoppers. (Heuzé and Tran, 2013b; Van Huis *et al*., 2013). Okoye and Nnaji (2005) replaced fish meal with grasshoppers to study the effect of substituted on Nile Tilapia *(Oreochromis niloticus)* fingerlings. Significant growth was observed. The growth performance of *Clarias Gariepinus* fed with grasshopper meal has shown significant performance (Olaleye, 2015). Alegbeleye *et al*. (2012) using *Zonocerus variegatus* as a feed for Nile tilapia and observed growth performance. The grasshopper meal could be integrated satisfactorily into aquaculture and broiler (Abanikanda, 2012; Emehinaiye, 2012; Nnaji and Okoye, 2005). The nutritional potential of grasshoppers and desert locusts, respectively to substitute fish meal as a protein source in broiler chicken diets and shows significant result without reducing growth or causing physiological disorders. The replacement of fish meal with grasshoppers and locusts for broiler chicken has significant affect (Adeyemo *et al*., 2008; Ojewola *et al*., 2005). The incomplete replacement of fish meal with grasshopper meal shows similar or higher performance compared to fish meal whereas the total replacement of fish meal with grasshopper meal reduced the growth and digestibility, probably due to the inferior protein value and higher level of crude fiber in grasshopper (Heuzé and Tran, 2013; Alegbeleye *et al*., 2012; Nnaji and Okoye, 2005).

Conclusions and Recommendations

The world population is anticipated to surpass over 10 billion people by the year 2050, increasing appeal for food, especially protein-rich foods. Studies showed that aquaculture played a major role in enhancing food security status of the developing nations. It's an important source of protein, vitamins, fatty acids, essential fatty acids and minerals for underdeveloped and countries with in-sufficient food (UN, 2010). An expected 520 million population, almost 8%, get their food from fisheries and fish-related economic activities. Additionally, with the renewed raise in the recognition of health values, the worldwide demand for aquatic foods, even in the established nations, is estimated to continue to rise. However, changes in the environment and the limited supply of conventional feeds like grains, fishmeal, and soybeans provide serious challenges for the sectors. The performance of the components of insect-based feeds, considering their life phases, developmental processes, and nutritional profiles, was thoroughly reviewed in this review, which highlights the potential benefits of using insect-based feeds in place of traditional feed ingredients. The findings indicate that insect-based feeds are not only effective as feed additives but also provide several benefits such as increased animal health, growth performance, and efficiency. This sustainable approach ensures a consistent supply of feed resources, mitigates the impact of variable feed costs, and handles the demand for alternate feeds. Insect-based feed production needs to be developed by utilizing economical, environmentally friendly techniques to fulfil the rising demand for protein.

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Novelty Statement

This review highlights the importance of insect-based feeds over conventional feeds in the aquaculture sector. In addition, it also emphasizes that it has the potential to reduce the cost and environmental impact while covering the rising demand for sustainable as alternative protein source.

Author's Contribution

Muhammad Salman Khan, Ikram Ullah: Conceptualization, writing original draft.
Muhammad Khubaib, Nafees Ahmad: Review & editing.

Khan Anwar Ullah, Syed Rahmanullah Shah: Helped in data collection
Zia Ur Rehman: Visualization, review & editing.
Muhammad Bilal and Farhad Badshah: Technically assisted at every step.
Mushtaq Ahmad Khan and Monsif Ur Rehman: Proof reading.

Conflict of interest
The authors declared no potential conflicts of interest with respect to research, authorship, and/or publication with the work submitted.

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