Effect of Insect Feed on Fish Growth: A Review

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Abstract

The demand for sustainable and efficient protein sources in aquaculture has led to an increasing interest in exploring alternative feeds for fish. In recent years, insects have emerged as a promising option due to their nutritional value, economic viability, and potential to alleviate the environmental impact of traditional fish meals. This review critically examines the existing literature on the effect of insect feed on fish growth. Through a comprehensive analysis of relevant studies, we evaluate the performance of fish fed with insect-based diets compared to those fed with conventional feeds. The review encompasses various insect species, feed formulations, and fish species, providing insights into the factors influencing growth outcomes. Our findings highlight the potential benefits and challenges of incorporating insect-based feeds in fish farming practices, with implications for sustainable aquaculture and food security. By synthesizing current knowledge, this review aims to guide future research and decision-making processes for optimizing fish nutrition and production while promoting ecological sustainability.

Keywords: fish feed, growth performance, feed conversion ratio, arthropods feed, economical fish feed

Introduction

During the last 20 years, aquaculture has supplied more to the production of seafood than any other significant food-producing system, exceeding 46 % in 2016–2018, up from 25.7 % in 2000, with an annual rate of growth of 5.3 % from 2001–2018 (FAO, 2020). The trend is forecast to continue due to greater protein demand with the growing world population (Ghamkhar and Hicks, 2020).

Livestock production is one of the farming practices with the greatest environmental effect. Animal feeding is frequently the primary cause of negative environmental effects of animal agriculture. Consuming protein-rich feed is crucial to achieve sustainable production systems, especially for intensive production. The practical eating of soybean and fish meal is not possible because of negative environmental effects and growing expenses. Bugs, phytoplankton, and other invertebrates have been investigated as alternative protein sources by research institutions, and private companies over the past 20 years, and recently the use of earthworm meal for monogastric animals has received much attention. Utilising insects as a replacement for fish meal as a protein source (Fig. 1) presents an opportunity to adopt cleaner technology and deliver environmental benefits. Insects, organic material, and by-products of farming like wastes resulting from grain cleaning processes can all be valued from a cyclical perspective and are used as animal feed (Parolini et al., 2020).

A continuing difficulty in the aquaculture industry is the partial or total substitution of fish meal (FM) and fish oil (FO) in aquafeed compositions (Oliva-Teles et al., 2015; Tacon and Metian, 2015). Improvements using affordable and more sustainable substitute components are thus prioritised for advancing more sustainable fish farming (Gasco et al., 2018). Because of their dietary richness, bioconversion efficacy, and limited environmental demand, insects have attracted significant interest as a prospective

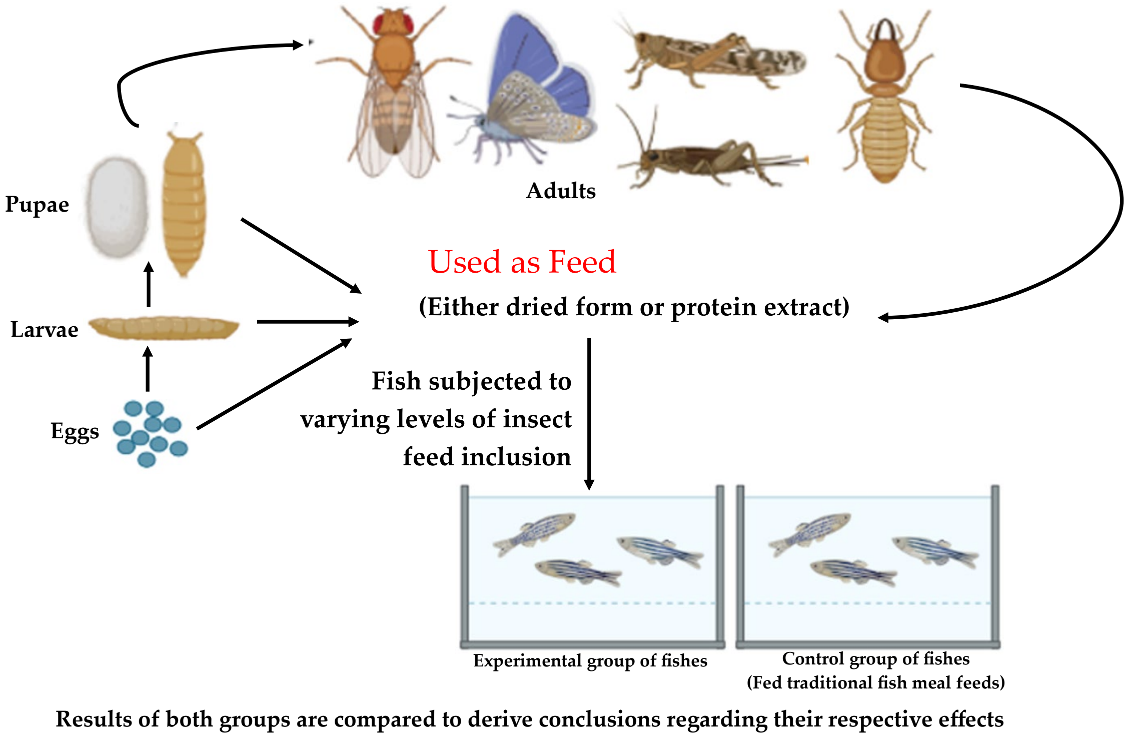

Fig. 1. Graphical illustration of insect usage as feed in studying the effects of insect feed on the growth of fishes. Control group of fish are fed traditional fish meal feeds.

aquafeed and poultry feed ingredient considering the recycling industry and the significance of by-product reuse (Berggren et al., 2019; Parodi et al., 2020). Insect meal used as an alternative protein source in aquafeeds is a potential solution to meet the increasing demand for red meat and increase the viability of aquatic production technologies over the long run (Tschirner and Kloas, 2017). Insect production needs only a tiny area of land and a finite amount of water. Large volumes of organic waste may be bio-converted into useful animal protein in this way, mitigating the contamination of organic wastes, with minimal to no greenhouse gas emissions (van Huis and Oonincx, 2017; Sogari et al., 2019). Insects may also be raised on biowaste, have excellent feed conversion efficiency, and grow and reproduce readily (van Huis et al., 2013; Makkar et al., 2014).

Several insects, such as the larvae or pupae of the Diptera house fly, *Musca domestica*, black soldier fly *Hermetia illucens*, and mealworm larvae *Tenebrio molitor*, are the best options for fish feed in partial or complete substitution. Other insect species like adult Orthopteran of the family Gryllidae (crickets), Tettigoniidae (katydids), and Acrididae (locusts and grasshoppers), and pupae of the silkworm *Bombyx mori* (Linnaeus, 1758) can also be used as feed. *Tenebrio molitor* has the potential to replace fish meal for carnivorous aquaculture species as a high-protein feed component (Riddick, 2014). The insect market is expanding quickly on a global scale. The International Platform of Insects for Food and Feed claims that the yearly global investment in insect production is estimated to be 355 million Euros or 6000 metric tons (Motte et al., 2019).

This review aims to investigate the impact of insect-based feed on fish growth through a meticulous analysis of scientific literature. It aims to provide a comprehensive assessment on the effects of incorporating insect-based diets in fish farming practices. The review encompasses various insect species, feed formulations, and fish species, allowing for a comprehensive evaluation of the factors influencing fish growth outcomes.

Through this review, we intend to shed light on the viability and efficacy of using insect feed in aquaculture, while also exploring the potential implications on fish growth performance, nutritional quality, and overall sustainability. By elucidating the current state of knowledge and identifying knowledge gaps, this review advances research in sustainable aquaculture practices, offering insights to researchers, policymakers, and stakeholders in the quest for efficient and environmentally friendly food production systems.

Literature Review and Selection Criteria

To provide a detailed and comprehensive review, original research articles and review articles were initially downloaded from different search engines, e.g., Google Scholar, Semantic Scholar, ISI Web of Knowledge, and PubMed. This review includes articles published between 2005 and 2023, which were searched using various keywords such as insect, fish,

fish feed, growth performance, feed conversion ratio, arthropod feed and economical fish feed. The Higher Education Commission (HEC) of Pakistan's digital library granted access to full-length articles. Even so, not all selected publications could be completely accessed, making it impossible to include those studies in the review article.

Reasons for Using Insects

The Food and Agricultural Organization (FAO) estimates that by 2050, food output must rise by 70 % to feed the 9 billion people on the planet. To satisfy future demand by 2050, global meat consumption, particularly fish consumption, is projected to increase by 50 % above 2006 levels. To enhance protein source manufacturing, an equivalent value of substitute protein sources is considered essential to achieve this increase in food production. Recently, researchers and farmers, have been very interested in the possibilities of insect-based protein as a food source. Insects such as caterpillars, crickets, and silkworms may soon provide a good source of food.

Raising insects and edible food that provides essential amino acids, minerals, and protein is advantageous. Insects may be raised from organic waste and benefit the environment as well. For instance, 900 kg of food waste requires 0.06 kg of *Hermetia illucens* (black soldier fly) larvae to digest the material, resulting in 60 kg of frass and 9.57 kg of black soldier fly (BSF) larvae, representing a 92.27 % conversion. Insects are nutritious as a source of vital proteins and amino acids for animal feed, and consume little water and energy, which are other factors that may be considered (Nugroho and Nur, 2018). Table 1 lists the effect of insect feed on the fish species, their stage at the time of feeding, their feeding habit, the type of insect used, insects' stage while meal preparation, percentage of inclusion in their meal, and the total time of feeding before studying their effects on their growth.

Insect Composition Versus Fish Requirements

Before introducing any insect species into the diets of fishes, it is essential to know the species distribution of the bug, which is highly dependent on its specific life-cycle stage, breeding environment, and nutrition, and to compare it with the demands of the aquatic desired species. The composition of fish fillets often follows these changes in the insect distribution and life-cycle (Magalhães et al., 2017). Increasingly, insects are used as a preferred feed component for farm animals and aquatic animals, mostly because of their high nutritional content. For example, the amino acid makeup found in insects is better than that found in soybean meal and, in the case of Dipterans, is equivalent to that observed in fish feed. Insects can contain up to 74.4 percent of their dry weight as high-quality protein. In addition, certain insects have high amounts of oleic and linoleic acid, as well as other mono- and poly-unsaturated fatty acids (C18:1n-9 and C18:2n-6, respectively). Insects, alone, are not suitable as marine fish feeds because they lack eicosapentaenoic and docosahexaenoic fatty acids (EPA and DHA). By adding these fats to insect substrates, insects' fatty acid profiles can be modified (Mastoraki et al., 2020).

Major Insect Species Consumed

There is evidence of insect ingestion throughout the world. The majority of the substantial numbers of insects ingested (Fig. 2) belong to one of the following six orders: Coleoptera, or beetles, which are mostly ingested as "grubs" (the juvenile stages), Lepidoptera, which includes monarch and moths, which are typically devoured as caterpillars, Orthoptera, which includes grasshoppers, crickets, and locusts, Hemiptera, which includes hemipteran bugs, Hymenoptera, which includes ants, bees, and wasps, and Isoptera, which includes termites (Bukkens, 1997). *Tenebrio molitor*, *M. domestica and H. illucens* are specifically the most promising species for fish feeds. Although considerable progress is predicted, technological, financial, and regulatory hurdles mean that insects are still underrepresented in the animal feed sector (Sogari et al., 2019).

Insects are rich sources of protein with a high proportion of protein like fish meal. For example, insect meal prepared with *Boopedon flaviventris* (76.0 %), *Melanoplus mexicanus* (77.1 %), or *Sphenarium histrio* (74.8 %) has a high proportion of proteins. In terms of crucial and limiting amino acids (AA), Diptera is the order that most closely resembles fish meal. Insect cultures are sustainable from an environmental standpoint since they don't require a lot of space or water, they help recycle trash, and they have a relatively low carbon footprint. The most promising insects among those tested as aqua feed for some fish species were *H. illucens* and *T. molitor* due to their capacity to convert food material into protein, fat, and energy by integrating the AA and fatty acids (FA) of dung and recyclables into their biomass. However, the type of food affects the amount and quality of fat for insects (Reyes et al., 2020).

Nutrient Composition of Edible Insects

Chitin and fibre in insects have been analysed using various tests, including crude fibre (CF), acid detergent fibre (ADF), and neutral detergent fibre (NDF), revealing significant fibre content (Finke, 2002). While a considerable quantity of cellulose is found in insects, it is uncertain what exactly makes up these fibres. Although it has been hypothesized that chitin is biologically comparable to cellulose present in plant products and corresponds to the fibre seen in insects. In truth, chitin, scleroproteins, and other components bound to chitin are likely among the

Table 1. The insects and stages of the insect life cycle used to feed different species of fish. The effects of feeding on food conversion ratio (FCR) and specific growth rate (SGR) are summarised.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
Heterobranchus longifilis	Fingerling	Omnivorous	*Macrotermes subhyalinus*	Adult	12	25, 75, 100	The FCR was increased but the PER and the SGR were decreased	Sogbesan and Ugwumba (2008)
						50	The FCR was decreased but the PER and the SGR were increased	
			Melanoplus differentialis		8	10	The SGR remained the same, but the FCR and the PER were increased.	Olaleye (2015)
						15	The SGR, FCR, and PER were increased	
						20, 30	The FCR was increased but the SGR and PER were decreased	
			Hermetia illucens	Larvae	6	25, 50	An increase in the SGR while a decrease in FCR and PER was observed	Adeoye et al. (2020)
						100	A significant decrease in the SGR and PER was observed but the FCR was increased	
	Fry		*Eisenia fetida*	Adult	7	15, 25	The SGR was increased but the FCR was decreased	Dedeke et al. (2013)
						30	The SGR was decreased but the FCR was increased	
						50	The SGR and the FCR were decreased	
Salmo salar	Juvenile	Carnivorous	*H. illucens*	Larvae	16	33, 66, 100	No significant change in SGR, feed intake, and FCR	Belghit et al. (2019)
					8	85	No change in digestibility and growth were observed but lipids and carbohydrates were increased	
					15	25, 50, 100	No change in weight gain, FCR, and SGR	Lock et al. (2016)
						25	No change in weight gain but a very low FCR and SGR were observed	

Table 1. Continued.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
						100	Low weight gain and extremely poor FCR and SGR were observed	
Pagellus bogaraveo	Juvenile	Omnivorous	*Tenebrio molitor*	Larvae	18.7	25	No significant change in daily feed intake and SGR were seen but the FCR was increased	Iaconisi et al. (2017)
						50	Slightly lower daily feed intake and SGR were observed but the FCR was increased	
Anabas testudineus	Larvae	Carnivorous	*H. illucens*	Pre-pupae	8.5	25, 50	Increased weight gain, SGR, and PER were recorded	Kattakdad et al. (2022)
						75, 100	Low weight gain, SGR, and PER were observed	
	Juvenile				17.5	25	No change in weight gain and FCR were seen but the SGR was increased	Vongvichith et al. (2020)
						30	No change in SGR and FCR was recorded but the weight gain was increased	
Cyprinus carpio	Fry	Omnivorous	*H. illucens*	Larvae	8.5	25	Significant increase in weight gain and FCR was seen but the PER was low	Jahan et al. (2021)
						50	A significant increase in weight gain and the PER was seen but a very low FCR was recorded	
						75	Increased growth rate was observed but no significant change in PER and FCR was recorded	
						100	Significant increase in weight gain, growth rate, and PER was recorded. While the FCR was decreased	
	Juvenile			Protein Extract	8	50, 100	No change in weight gain, FCR, and SGR was recorded	Gebremichael et al. (2021)

Table 1. Continued.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
	Fry		*Bombyx mori*	Pupae	20	10	Decrease in total weight gain rate and SGR was seen but the FCR was increased	Nandeesha et al. (1990)
						20	SGR remained the same while a decrease in total weight gain and increase in FCR was recorded	
						30	An increase in FCR, SGR, and total weight gain was seen	
Dicentrarchus labrax	Juvenile	Carnivorous	*Musca domestica*	Larvae	12	30	No effects on growth and feed conversion were observed, but high plasma glucose levels were recorded	Mastoraki et al. (2020)
			T. molitor			30	No adverse effects on growth were seen, and plasma glucose levels were recorded	
					10	25	No significant change in PER and FCR were recorded but SGR and weight gain were decreased	Gasco et al. (2016)
						50	Significant decrease in weight gain, growth rate, and PER was recorded but the FCR was increased	
					7	50	Low growth rate and weight gain were observed while no change in feed conversion efficiency was recorded	Reyes et al. (2020)
			H. illucens		12	30	No adverse effects on growth were shown but increased body weight and high plasma cholesterol levels were recorded	Mastoraki et al. (2020)

Table 1. Continued.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
					8.8	15, 30, 45	No significant change in feed efficiency was seen but an increased daily growth index and feed intake were recorded	Magalhães et al. (2017)
					7	30	Low growth rate and weight gain were recorded but the feed conversion efficiency was slightly low	Reyes et al. (2020)
						50	Worse growth rate, meagre weight gain along with very low feed conversion efficiency were recorded	
Lateolabrax japonicus	Juvenile	Carnivorous	*H. illucens*	Larvae	8	16	Increased feed intake, high FCR, and SGR were recorded	Wang et al. (2019)
						32	No significant change in feed intake and SGR were observed but the FCR was slightly increased	
						48	Slight increase in FCR was seen but a high increase in SGR and feed intake was recorded	
						64	High FCR, SGR, and feed intake were recorded	
Cyprinus carpio var. Jian	Juvenile	Omnivorous	*B. mori*	Pupae	8	50	A decrease in FCR, final body weight, and SGR were observed but the PER was increased	Ji et al. (2015)
						60	No significant change in PER was observed but final body weight, SGR, and FCR were decreased	
						70, 80	Decrease in final body weight, the SGR, and PER were observed but the FCR was increased	
			H. illucens	Larvae	8.4	100	Little high daily feed intake and FCR were observed but the SGR was slightly lower	Li et al. (2017)

Table 1. Continued.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
					8	75	SGR, the FCR, and PER were increased	
Siniperca scherzeri	Juvenile	Carnivorous	*T. molitor*	Larvae	8	10	Increased weight gain and specific growth were recorded with a slight change in feed conversion efficiency	Sankian et al. (2018)
						20	Increased weight and the SGR were observed but a decreased feed conversion efficiency was recorded	
						30	Increased weight gain and specific growth were recorded with a slight change in feed conversion efficiency	
C. carpio	Juvenile	Omnivorous	*B. mori*	Pupae	11	6.33	Increase in mean weight gain, SGR, and PER were observed but the FCR was decreased	Wan et al. (2017)
			Nereis virens			7.52	Increase in SGR, PER, and mean weight gain was recorded. While a significant decrease in FCR was seen	
			B. mori and *N. virens*			3.30, 4.06	No significant increase in mean weight gain was recorded but a decrease in FCR and an increase in both PER and SGR were observed	
Oreochromis niloticus	Juvenile	Omnivorous	*Zophobas morio*	Adult	8	100	SGR and PER were decreased but the FCR was increased	Jabir et al. (2012)
			M. domestica	Larvae	10	9, 18	Increase in weight gain rate, SGR, and FCR was observed	Wang et al. (2017)
						27	Increase in weight gain rate and SGR was observed but the FCR was decreased	
	Fingerling				8	15, 25, 35, 45	The SGR and the PER were increased but the FCR was decreased	Ogunji et al. (2008)
						55	SGR, the PER, and the FCR were increased	

Table 1. Continued.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
						65	FCR was increased while the PER and the SGR remained the same	
Perca fluviatilis	Juvenile	Carnivorous	*Acheta domesticus* and *Z. morio*	Larvae	12	25	Decrease in weight gain and SGR was recorded but the FCR was increased	Tilami et al. (2020)
Epalzeorhynchos frenatum	Fingerling	Omnivorous	*B. mori*	Pupae	8.5	30	Significant increase in the SGR and the PER was seen but the FCR was decreased	Ponraj et al. (2020)
						40, 50	Decrease in FCR and an increase in SGR and PER were recorded	
Oncorhynchus mykiss	Juvenile	Carnivorous	*H. illucens*	Larvae	11	18	SGR and PER decreased but the FCR increased	Melenchón et al. (2022)
				Pre-pupae		25	Body weight increased while a lower percentage of fatty acids was observed	Dos Santos (2016)
						50	Body weight increased while the highest percentage of fatty acids was observed	
					10	20	An increase in PER, weight gain, and FCR was observed but the SGR decreased	Józefiak et al. (2019a)
				Larvae	11.14	20	Decrease in FCR but an increase in both SGRs and weight gain	Renna et al. (2017)
						40	FCR remains the same but the increase in the SGR and decrease in weight gain were observed	
					7	28	Increase in the FCR, SGR, and percentage weight gain was observed but the PER was decreased	Stadtlander et al. (2017)
			T. molitor		11	18	SGR and PER were increased but the FCR was decreased	Melenchón et al. (2022)
					22	25	FCR and growth rate were increased but the PER was decreased	Chemello et al. (2020)

Table 1. Continued.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
						50	The growth rate and FCR were slightly increased but the PER was decreased	
						100	Growth rate was increased but the FCR was decreased while PER remained the same	
					10	20	Decrease in the SGR but an increase in the weight gain, FCR, and PER were observed	Józefiak et al. (2019a)
			Gryllodes sigillatus			20	Decrease in weight gain and SGR was observed but an increase in FCR and PER was observed	
			Blatta lateralis			20	Decrease in SGR and the PER but an increase in weight gain was observed while the FCR remained the same	
Acipenser baerii	Juvenile	Carnivorous	*T. molitor*	Larvae	8.5	15	No change in FCR and the PER was recorded	Józefiak et al. (2019b)
			H. illucens			15	No change in PER and a minor change in FCR were recorded but weight gain was increased	
Psetta maxima	Juvenile	Carnivorous	*H. illucens*	Pre-pupae	8	17	FCR remained the same but a decrease in the SGR and final body weight was observed	Kroeckel et al. (2012)
						33, 49, 64, 76	Decrease in the SGR and final body weight was recorded while the FCR was increased	
						33	Decreased daily feed intake and SGR were observed but the FCR was increased	
						49	Deficient daily feed intake and SGR were recorded but the FCR was increased	

Table 1. Continued.

Fish	Stage of fish	Feeding habit of fish	Insect	Stage of insect	Feeding time (weeks)	Insect feed inclusion (%)	Effect	References
						64	Very deficient daily feed intake and SGR were recorded but the FCR was increased	
						76	Extremely deficient daily feed intake and SGR were observed but the FCR was high	
Pelteobagrus fulvidraco	Juvenile	Omnivorous	*T. molitor*	Larvae	5	9	No effect on SGR was seen but increased feeding rate and feed conversion efficiency were recorded	Su et al. (2017)
						18	No effect on SGR and feeding rate was recorded but the feed conversion efficiency was decreased	
						27	Feeding rate remained the same but a decrease in SGR and an increase in feed conversion efficiency were recorded	
			H. illucens			10, 15, 20, 25, 30	Decrease in weight gain rate and an increase in FCR was recorded	Hu et al. (2017)
					9.2	13, 25, 37, 48	Increase in weight gain, SGR, and PER was observed but the FCR was decreased	Xiao et al. (2018)
						68	No significant change in weight gain rate, FCR, and PER was recorded. While a slight decrease in SGR was seen	
						85, 100	Decrease in the SGR, weight gain rate, and PER was observed but the FCR was increased	
Danio rerio	Larvae	Omnivorous	*H. illucens*	Pre-pupae	3	25, 50, 75, 100	Significant downregulation of stress response markers and a positive modulation of inflammatory cytokines gene expression was observed	Zarantoniello et al. (2021)

SGR: specific growth rate; FCR: feed conversion ratio; PER: protein efficiency ratio.

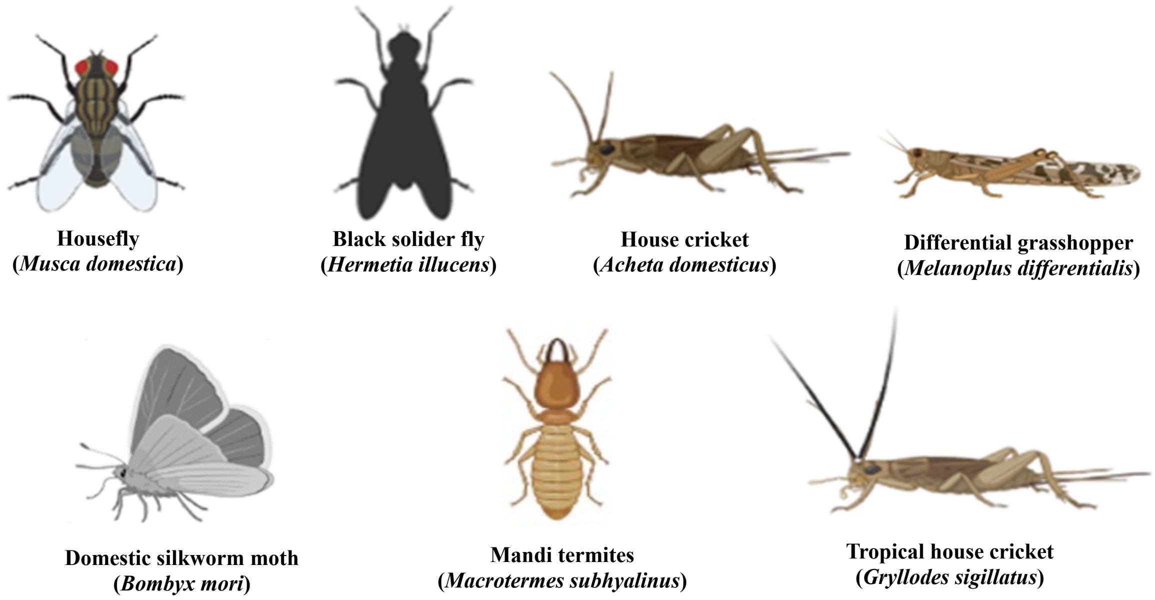

Fig. 2. Graphical illustration of common insects used in the study of effects of insect feed on fish growth.

several chemicals that make up the fibre in whole insects (Finke, 2007). Chitinase activity has been discovered in several species of amphibians, reptiles, turtles, salmon, and small mammals, suggesting that some insectivores may be capable of digesting chitin (Whitaker et al., 2004). Chitin coexists with proteins, lipids, and other substances in a matrix to form the cuticle in insects (Kramer and Bryant, 1995). Since chitin is only found in the exocuticle of insects, their chitin level is probably not very high. Lepidoptera larva, measured by an enzymatic technique, contained between 2.9 to 10.1 % chitin by dry-weight, according to the few quantitative data that are available on the chitin content of complete insects (Cauchie, 2002). In contrast, the most common substance in the cuticle of insects is protein, not chitin (Kramer and Bryant, 1995).

Both entire bugs and the ADF portions of proteins had diverse amino acid patterns, and the ADF fraction's amino acid patterns varied depending on the species of insects (Finke, 2007). The specificity of the dermal proteins found in insects, which support their distinctive characteristics, is probably reflected in these variations. Insects with "harder bodies" e.g., mature beetles, had higher amounts of ADF than insects with "softer bodies" (yellow mealworm larvae, silkworm larvae, and cricket nymphs), and their fibre quantity was caused by high ADF fraction of amino acids (Finke, 2007). Insects with "harder" cuticles may exhibit optimal levels of cross-linking proteins for sclerotization compared to those with softer bodies.

Carbohydrates and minerals

The presence of carbohydrates in insects has received little attention in the literature. In general, insects have modest amounts of carbohydrates (Finke, 2002). The polysaccharide and carbohydrate content of the field cricket *Gryllus bimaculatus* is approximately 0.3 % of the fresh weight, whereas female *G. bimaculatus* has a fat body with less than 0.5 % of dry matter of free carbohydrates (Lorenz and Anand, 2004). The carbohydrate content of *T. molitor* can vary from 1 to 7% of dry matter, depending on their diet (Kröncke et al., 2023). Some of these variations may be attributed to the presence of food in the gastrointestinal tract. All insects have modest mineral ash concentrations, except black soldier fly larvae, which have reported values of above 15 %. Calcium is abundant in black soldier fly larvae (7.6 % DM). Even though the cuticle of some insects contains calcium and other minerals as a part of their mineralised exoskeleton, the exoskeleton of most insects is predominantly made of protein and chitin (Dashefsky et al., 1976). Examples include the black soldier fly and the larvae of the face fly *Musca autumnalis* (De Geer, 1776) (Finke, 2013). Other insects have a very low level of calcium, so calcium supplementation would be necessary. Black soldier fly larvae have a high level of calcium content and are now frequently sold in the market as food or as captive insects. Calcium levels in larvae can be increased by fortifying the substrate used for raising the larvae with calcium. Except for black soldier fly larvae (ratio of 8.4), calcium: phosphorus ratio in insects ranges from 0.2 to 1.2, which is lower than the ideal range that is advised for fish (1.1–1.4) (Chavez-Sanchez et al., 2000). Phosphorus levels in certain insects, such as *Anabrus simplex* and *M. domestica* meal, can reach 1.0 to 1.6%. Insects are excellent source of protein, fats, vitamins, and minerals, though their quantity might differ owing to animal diet and their life stage.

Protein and amino acids

According to numerous studies in insects (Finke, 2002), the protein content can vary greatly and ranges from 7.5 % to 91 %. The protein content is commonly analysed in terms of crude protein (CP), which is measured by the formula nitrogen ×6.25 (Finke, 2007). Insects generally have a high crude protein (CP) level of 42 % to 63 %, which is comparable to the range found in soybean meal but slightly lower than fish meal (Manzano-Agugliaro et al., 2012). The protein content of silkworm larvae was evaluated using the protein digestibility-corrected amino acid score (PDCAAS) (Schaafsma, 2000), which showed that the leucine was the most abundant amino acid present in silkworm larvae. The protein content of silkworm larvae was higher than that of other protein sources like poultry and meat on equivalent dry weight basis (Longvah et al., 2011).

Insects are a nutritionally superior protein source that can enhance diets by giving necessary and digestible amino acids, according to the PDCAAS study. Insect protein is typically considered to have good nutritional value, although the quality relies on how easily the amino acids can be digested and how well the amino acid profile fits the needs of the particular insectivore (Ramos-Elorduy, 2002). Insect protein digestion may vary greatly. One could anticipate that insects with a higher percentage of their amino acids present in cuticular protein complexes with chitin would have a lower protein digestibility than insects without such complexes (Finke, 2007).

The amino acid profiles of insect meals

The following ten amino acids - arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine — are regarded as necessary in fish nutrition. The concentration of protein in insect bodies varies depending on the developmental stage (larva, pupa, pre-pupa, and imago), the type of meal, and the environments under which they are raised. According to Finke (2002), in case of *Acheta domesticus*, the amount of lysine differed from 1.10 g per 100 g of sample in adults to 0.83 g per 100 g of sample in nymphs (expressed in wet weight). However, Spranghers et al. (2017) showed that *H. illucens* fed with various diets differed in terms of lysine content, ranging from 2.30 to 2.57 g per 100 g sample (expressed in wet weight). The lysine contents ranged from 3.98 to 4.58 g per 100 g sample, while the biggest fluctuations appear to be more pronounced in the dispensable amino acids (DAA), namely glutamic acid.

Lipid content and role of insects as a source of fats and fatty acids

Insect lipids are mostly stored in the fat body (Beenakkers et al., 1985). When an insect is given to insectivores, fat may contribute to the insect's edibility in addition to serving as an essential energy source. There have been significant documented differences in the lipid content of insects (4.6-64 % dry mass) (Finke, 2013).

Terrestrial insects possess more n-6 polyunsaturated fatty acids than fish oil, but much less eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3). The usage of terrestrial insects in marine fish is constrained by the absence of EPA and DHA since these fatty acids are needed by marine fish but are difficult for them to produce. Although salmonids can produce EPA and DHA from α-linolenic acid (ALA), dietary sources are more effective. On the other hand, aquatic insects have been suggested as a source of diet for freshwater fish since they contain substantial levels of EPA.

Lipids make up the second-largest portion of the nutritional profile of edible insects, and they are more abundant in larval insects. On a dry weight basis, their composition varies from 10 to 50 %. For insect larvae, migratory behaviour and environmental temperature are connected to species, sex, life stage, nutrition, and the number of fatty acids in the lipids. The primary fatty acids in adult insects are palmitic and linoleic, whereas the primary fatty acids in the oils are palmitic and oleic. Insects either consume lipids in their food or produce them on their own. These lipids are delivered to the location of usage after being broken down, digested, and stored in body fat where it acts as a store of energy for times when there is a strong demand for energy (Jantzen da Silva Lucas et al., 2020).

Sensory Quality of Insect Meals

Whether an insect can be utilized as feed is also significantly influenced by how tasty it is. Insects contain a "natural attractant" element since they are a part of a fish's normal diet. However, fish might reject an insect meal-based diet just like other animals if it has an unpleasant flavour, bitterness, sourness, or odour. These disagreeable tastes, such as bitterness or sourness, can occasionally conceal poisons and/or pollutants that make a food source instantly unpalatable (Reed and Knaapila, 2010). In other instances, these disagreeable tastes may be connected to the method used to prepare the insect meal, by drying or freezing, which might impact its taste and quality. This element is connected to the Maillard reaction, which can happen throughout the drying process of insect meal and either benefit or negatively impact the process and palatability of the meal (Tamanna and Mahmood, 2015).

Palatability was not an issue for European sea bass fed *H. illucens* pre-pupae meal since no variations in the amount of feed ingested by the fish were found (Magalhães et al., 2017). The issue of palatability is a vital aspect of insect farming and may play a key role in providing insect meals of excellent quality and palatability. However, research linking the palatability of bug meals to fish nutrition has not been conducted.

Main Processes of Making Insect Feed

Drying of insect biomass

Fresh insects are difficult to mechanically grind, and the resulting slurry could be challenging to preserve and treat. Drying the insects comes first in the processing procedure after collecting the insects. Drying lowers the moisture contents in the product, lowering the potential for microbiological activity and extending the product's shelf life, particularly if the product is stored at room temperature. For example, it is predicted that *A. domesticus* and the larval powder of *H. illucens* may be kept at 25 °C for 7 months when desiccated to a moisture level of ~5 g per 100 g (Kamau et al., 2018).

Fermentation of insects

Insects are either fermented alone or in combination with grain flour when they are fermented. Before fermentation, the larvae need to be ground into a paste to avoid developing an unpleasant, "rotten" smell and the fermentation failing. It is possible that the starter culture of microbes cannot break down the exoskeleton's proteins because bacteria that remain in the stomach are metabolically active after blanching and generate putrefaction. Additionally, following the addition of glucose and salt (to suppress the background bacteria), fermentations are conceivable (to provide substrate to the meat starter). The mealworm paste's much-extended shelf life, even longer than when it was treated with conventional meat preservatives, instead of being fermented, is the most noteworthy success of fermentation (Van Campenhout, 2021).

Safety Aspects

Not all insects are suitable for consumption. Some insects are deadly or can induce allergic reactions, just like foods made from plants and animals. For instance, thiaminase can be found in the pupae of the African silkworm *Anaphe venta*, which might result in thiamine deficiency. For the past 40 years, *A. venta* has caused seasonal ataxic syndrome every year in Nigeria. Even as a protection measure, some insects have compounds that repel people or are poisonous. Additionally, pesticides residues are present even in wild insects due to their rearing in pesticide affected areas. The eating of typical edible bug species raised on pollutant-free feed can eliminate all health hazards. To prevent contamination and spoiling and to assure the safety of food and feed, all insects, whether they are caught in the wild or raised on farms, must be processed, handled, and stored properly (Rumpold and Schlüter, 2013).

Conclusion

Due to their adaptability and capacity to vary their fatty acid and amino acid profiles, insects are one of the finest alternatives to fish meals when replacing them partially or entirely. In addition, fish, particularly continental species, naturally consume insects. All of these factors support the inclusion of insects in fish, but it's important to remember that in nature, fish consumes a variety of bug species at once, and fish ingestion of insects might change seasonally. We should think about creating insect diets by combining many bug species at once to increase the feed quality to make better use of insects. The phases at which fish may eat more insects in nature must be identified.

Because insects contain both chitin and antimicrobial peptides (AMPs), we should think about employing them as probiotics as well as meal replacements. Therefore, by enhancing their performance, the addition of insect meal in the diets of fish, even in very small amounts, may strengthen the immune systems of fish. More than 200 kinds of fish are farmed, but it's important to keep in mind that we don't fully understand their nutritional requirements. Therefore, before preparing the insect meal, it is important to consider the impact of insect meal on target fish species. When deciding on a target fish, other factors such as the Maillard effects on protein quality and the amount of an insect meal to include in the diet should be taken into account. Once the right species and the right breeding techniques have been found and proven, the next study and challenge in employing insects as feed for farmed fish will be to convince industry personnel to accept the new method.

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