Chapter

Insects in Aquaculture Nutrition: An Emerging Eco-Friendly Approach or Commercial Reality?

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Abstract

Animal-origin food production presents an accelerated growth worldwide due to an increase in human demand. The aquaculture sector is one of the major players in terms of volume of animal protein production, and the availability of feedstuff to supply aquaculture feed (aquafeed) chain will be one of the main challenges for the next decades. Aquafeeds are mostly based on cereals, oilseeds, and marine-origin ingredients. The competition for feedstuff from the terrestrial animal industries such as pet, poultry, and swine challenges the profitability of aquafeeds, and complimentary ingredients need to be found. Many studies have focused on alternative protein sources, but the benefits of plant proteins, microorganisms-based, and diverse animal by-products are still under intense investigation to address some constraints including antinutritional factors and unbalanced nutrient profile. In this sense, the use of insects on the nutrition of aquatic animals could be an alternative. This chapter was elaborated to be an introductory reading for both academic and private sector and will discuss (i) the benefits of insects in animal nutrition, (ii) elucidate the nutritional aspects of different insect meals, (iii) bring some practical developments on aquatic nutrition, and finally (iv) discourse about constraints on insect use and its future perspectives.

Keywords: animal nutrition, alternative feedstuff, additives, lipid, protein, chitin

1. Introduction

The demand for meat in 2050 will be 58% higher than the demand in 2010 [1], and revolutions in the form of animal protein production should happen to supply this demand; this will mean greater pressure on food resources especially on the ingredients for the formulation of rations [2]. In the quest for more sustainability in long-term animal production, the search for alternative ingredients is essential, since conventional ingredients such as soybean meal, wheat, corn, and animal meal have large price swings and exponentially high values years after years [2].

In this context, insect breeding is an alternative as a source of nutrients for animal feed and is a way to increase food and feed safety as an important source of protein [3]. In addition, insect breeding is considered a sustainable production, since these small animals feed on agroindustrial tailings, various organic wastes [3], and even inorganic ones [4].

The production of food of animal origin presents an accelerated growth in the world specially the chicken, swine, and cattle production [1]. These are produced with cereal and oilseed diets [2]. The nutrition of these animals requires high protein and energy levels that could be supplied by the use of insects. In addition, more than 1 million species of insects have been cataloged, and it is estimated that there are between 5 and 10 million, that is, only 10–20%, are known [5]; more than 1500 are used as food for about 3000 ethnic groups in more than 120 countries [6].

This scenario results in an emerging need for further studies to identify potential species to be produced and used in animal nutrition and as addressed by the FAO [7] as an alternative to traditional sources for human consumption. With these perspectives, it is exposed to the needs of recycling our ideas of human and animal feeding. In animal production, the mystification of this practice occurs more quickly, since many of the production animals, such as birds and fish, have the habit of feeding on insects.

2. Insects in animal nutrition

Agricultural production in the world faces many challenges to meet the growing demand for animal products, such as the demand for meat, which in 2050 will be 58% higher than the demand in 2010 [1]. Many studies have focused on new nutritional perspectives, but the benefits and weaknesses of vegetable protein sources and animal by-products are still under intense investigation. Ingredients of plant origin, for example, have several adverse effects on animal performance, attributable, among others, to antinutritional factors, inadequate profile of fatty acids, and amino acids [8, 9]. However, both are associated with environmental problems (e.g., exploitation of natural resources), economic (fluctuation of feed prices), or production (variation of quality and quantity) [10].

When considering the long-term sustainability of animal production, evaluations of alternative ingredients are essential because conventional ingredients, such as soybean meal and fishmeal [2], are raw materials that have been unstable due to the demand of other segments such as birds, swine, and pet [11]. Along with their derivatives and by-products, animal meal and soybean meal are two of the most widely used protein sources as feed ingredients. However, both are associated with environmental (e.g., exploitation of natural resources), economic (fluctuations in feed prices), or production (variation of quality and quantity) problems [10]. In this context, many studies have addressed new nutritional perspectives with alternative ingredients. However, the benefits and weaknesses of these sources are still the subject of intense research [11].

Supported by the problems mentioned above, it is necessary to search for alternatives. In this context, the use of insects could be a source of protein for animal feed. The commercial scale production of insects could guarantee a constant production in quantity, quality, and price. The use of this source to feed terrestrial animals and aquatic organisms already has some premises [7, 12] and brings, among others, the following advantages: (i) nutritional quality, (ii) noncompetition with food resources or land use, and (iii) use of "nutrients from residues" or "energy leftovers" from agro-food production as nutritional sources for insect growth. These small organisms can be grown in industrial plants and do not need large areas, especially when compared to other crops such as soybeans.

The use of insects contributes to the natural recycling of nutrients and could be a source of high-quality animal protein derived from environmentally sustainable technology. In addition, a survey conducted in northern Italy showed that 90% of consumers would buy fish fed with insect meal [13]. This makes perfect chain fitting ("agriculture + fish + consumer") in addition to a more sustainable production call. In this item it is worth mentioning that some insects have the capacity to reduce the final biomass of residues in 50%, and specifically of nitrogen residues in 30–50%, and phosphorus in 61–70% [3, 14]. In other words, they convert organic residues into high-quality fertilizers in addition to forming "protein biomass" with admirable figures (~40% crude protein and ~ 30% lipid) [15, 16]. The arguments that reinforce its use would be that insects grow and reproduce easily, have high feed conversion efficiency, and can feed on organic wastes [17].

In addition, studies have shown that it is technically feasible to produce large-scale insects and use them as a sustainable protein alternative in the diet of birds, swine, cattle, and aquatic animals [12]. Once mass production of these small animals has been achieved, it would be possible to lower their cost and achieve economic viability in replacing traditional protein ingredients in animal feed [2]. Today the cost per kilo of the flour of some species of insects in the Brazilian market reaches more than US$50.00/kg. In the literature we have some studies that used insects to feed fish such as house fly larvae (*Musca domestica*) as a source of protein for feeding tilapia and African catfish (*Clarias gariepinus*) [18–20]; larvae of butterflies (*Bematistes macaria*) for feeding African catfish hybrids (*Heteroclarias*) [21]; and *Tenebrio molitor* in the diet of African catfish [22], goldfish (*Sparus aurata*) [23], rainbow trout (*Oncorhynchus mykiss*) [24], European sea bass (*Dicentrarchus labrax*) [25], Nile tilapia (*Oreochromis niloticus*) [10], and cheap meal (*Nauphoeta cinerea*) [26].

The larvae and pupae of the *Tenebrio molitor* beetle are promising options with several studies mainly for feeding fish and birds. This short-lived, easy-to-breed insect would be an alternative to temperate Western countries where this small animal is endemic [27]. Information on the breeding, feeding, and nutrient needs of this insect is already available in the literature [28, 29]. The larvae of *T. molitor* are omnivorous but are usually fed wheat flour or meal and supplemented with soybean meal, skimmed milk powder, or yeast [1]. The moisture in the feed seems to be fundamental for *T. molitor* because it can affect the productivity and fat content [30]. However, breeding of *T. molitor* larvae with resources such as wheat flour, soybean, and skimmed milk cannot be considered sustainable, since these products could be considered more suitable for direct consumption for humans or used in the nutrition of domestic animals.

The larvae of *T. molitor* have the ability to recycle vegetable waste of low nutritional quality and turn them into high-quality food (biomass) [1]. Tea bag larvae were fed on food leftovers and turned this waste into a high-quality protein source, which reiterates the potential of tenacious larvae as a promising and sustainable alternative protein source [31]. In addition, it has been recently reported that this animal can even recycle plastics (**Figure 1**) because it has specific bacteria in its tract capable of degrading this material [4]. Thus, it would be possible to solve two major problems of the contemporary world: the scarcity of resources for human and animal food, besides the "biorecycle" of plastics. Another insect that has stood out with high potential for use in animal nutrition is the cinerea cockroach (*Nauphoeta cinerea*). Some companies in South America already produce it on a commercial scale to attend to zoos and feed rations mainly for birds. Due to its high protein content (approximately 60%), the demand for this flour has increased over the years. Some studies have demonstrated the potential of its use in fish diets [26].

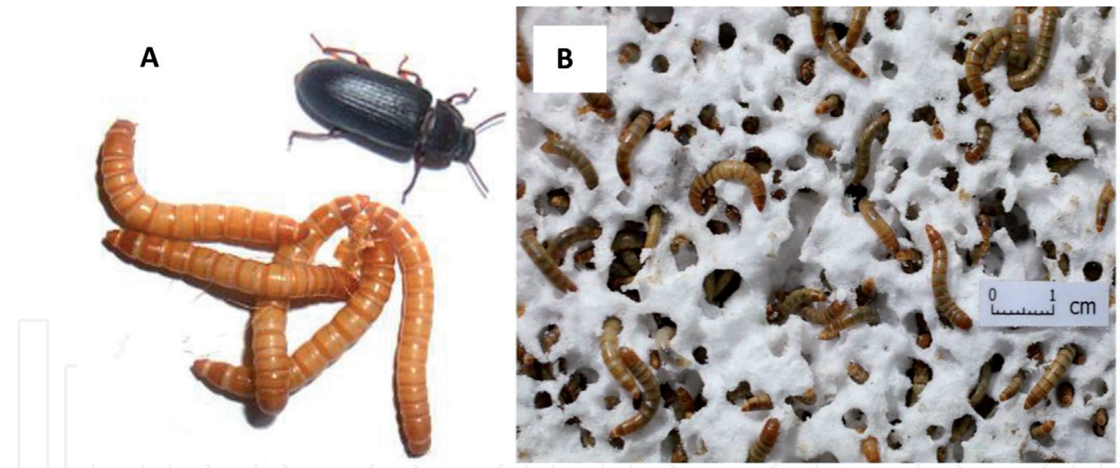

Figure 1.
Adult and larvae of Tenebrio molitor *(A) and feeding with plastic (B). Source: A, available at <plantascarnivoras.com.br> access 09/20/2016; B - [4].*

3. Nutritional aspects of insect meals

The proper way to go for the use of alternative ingredients in animal feed is to understand their nutritional characteristics (physical, chemical, and biological). Knowledge of these traits will be of paramount importance in assessing the potential for their use in animal feed, either as a substitute or complimentary. It is necessary to evaluate these ingredients in the diet of the animals, considering digestibility, performance, nutrient balance, carcass characteristics, economic results, and sustainability in the production chain.

The potential of insect use in animal and human food is mainly because there are more than 1 million known species. This generates innumerable possibilities and alternatives for its use; however, many studies are necessary since after identifying a species with potential, strategies should be created for production, reproduction, genetic evolution, and processing. The nutritional composition of several insect meals was compiled and divided into amino acid, bromatological composition, and fatty acid profile (**Table 1**).

Insect meal may have a high content of ethereal extract, and its variation influences the crude energy (kcal kg^{-1}) of the diets, the energy:protein ratio, as well as the ethereal extract of the carcasses. Other authors have also reported high values of ethereal extract in insect meal that prevented the high inclusion of these in the diets [18]. High values of ethereal extract are premises for the occurrence of oxidation (rancidity) of fats, reducing the shelf life of this product. The inclusion of antioxidant additives in insect meals is suggested. A short-term solution would be to further develop preprocessing and manufacturing procedures to extract the excess lipid in the meals and then utilize it as a lipid source in feeds or in any other industry, approach already adopted to manufacture terrestrial animal by-product meals.

Some studies show large crude protein variation and ethereal extract between the same species, found 40% of crude protein and 25% of ethereal extract for tenebrio, lower value than other studies [24, 25] that reported crude protein values higher than 50%, but lower ethereal extract levels than in the present study. In this context, insects can be used as a source of protein and energy. The larval stage of insects usually has higher ethereal extract values, as these accumulate energy for metamorphosis. Its fatty acid profile is very variable, suggesting that as feed occurs modulation of the fatty acid profile of the insects, which may be a prelude to the inclusion of EPA (eicosapentaenoic acid, 20:5n-3) and DHA (docosahexaenoic acid, 22:6n-3) of lower quality ingredients. Roasted meal is an excellent source of protein (~66.84%), being superior to

Species	Stage	Proximate analysis (% dry matter)				Amino acid (% total)			Fatty acid (% total)	
		ASH %	EE %	CP %	NFE %	LYS	MET	THR	Satura.	Polyuns.
Phyllognathus excavates	Adult	7.8 ± 0.2	15.9 ± 1.4	65.7 ± 1.3	10.6 ± 0.1	6.34	1.42	4.1	28.7 ± 3.0	11.8 ± 0.4
Rhynchophorus ferrugineus	Larvae	6.6 ± 0.6	11.8 ± 1.5	34.6 ± 0.3	47.0 ± 1.3	6.18	0.45	4	42.5 ± 0.4	13.0 ± 0.4
Tenebrio molitor	Larvae	3.5 ± 0.2	30.1 ± 0.7	58.4 ± 0.4	8.0 ± 0.2	6.03	0.64	4.49	22.2 ± 0.1	31.5 ± 0.1
Zophoba morio	Larvae	2.5 ± 0.3	38.0 ± 0.3	53.5 ± 0.4	6.0 ± 1.1	5.82	0.76	4.33	38.8 ± 0.2	24.0 ± 0.0
Calliphora vicina	Larvae	8.0 ± 0.1	20.1 ± 0.7	48.3 ± 0.9	23.6 ± 0.1	7.99	2.16	4.86	28.5 ± 0.2	28.0 ± 0.1
Chrysomya megacephala	Larvae (L3)	7.2 ± 0.1	27.0 ± 3.2	61.8 ± 0.3	4.0 ± 3.4	8.53	2.22	4.51	35.9 ± 1.2	31.3 ± 0.7
Chrysomya megacephala	Pupae	6.1 ± 0.1	16.5 ± 0.0	46.8 ± 1.1	30.6 ± 1.1	7.87	2.76	5.02	35.4 ± 0.6	26.2 ± 0.1
Eristalis tenax	Larvae (L3)	13.9 ± 0.4	5.8 ± 0.6	40.9 ± 0.9	39.4 ± 1.1	8.45	2.37	5.02	41.7 ± 1.4	1.6 ± 0.0
Hermetia illucens	Larvae (L5)	9.3 ± 0.3	18.0 ± 1.6	36.2 ± 0.3	36.5 ± 1.0	7.6	1.5	5.39	67.1 ± 0.6	15.9 ± 0.6
Hermetia illucens	Pupae	19.7 ± 0.1	15.6 ± 0.1	40.7 ± 0.4	24.0 ± 0.7	7.31	3.26	4.95	65.8 ± 0.1	1.1 ± 0.0
Lucilia sericata	Larvae (L3)	4.9 ± 0.9	28.4 ± 1.5	53.5 ± 4.4	13.2 ± 4.6	7.66	3.36	5.38	27.8 ± 0.1	9.5 ± 0.4
Lucilia sericata	Pupae	4.9 ± 0.2	26.6 ± 1.0	59.0 ± 1.5	9.5 ± 0.1	7.91	3.08	4.6	28.8 ± 0.4	11.0 ± 0.1
Musca domestica	Larvae (L3)	6.5 ± 1.5	31.3 ± 1.6	46.9 ± 4.1	15.3 ± 4.0	8.36	3	4.87	32.6 ± 0.1	7.6 ± 0.1
Musca domestica	Pupae	8.4 ± 2.9	33.7 ± 0.7	40.1 ± 0.4	17.8 ± 0.3	7.57	3.44	5.28	30.0 ± 1.1	7.5 ± 0.4
Protophormia terraenovae	Larvae (L3)	3.9 ± 0.1	28.3 ± 0.6	46.3 ± 0.6	21.5 ± 0.1	8.23	2.3	4.78	27.1 ± 0.2	21.9 ± 0.2
Protophormia terraenovae	Pupae	8.8 ± 0.1	23.6 ± 0.3	56.0 ± 2.0	11.6 ± 2.2	7.89	2.55	4.83	26.6 ± 1.6	21.7 ± 0.2
Acheta domestica	Adult	5.6 ± 0.0	15.9 ± 0.2	73.1 ± 3.3	5.4 ± 0.3	6.16	1.49	4.1	34.2 ± 0.1	43.2 ± 0.1
Anacridium aegyptium	Adult	3.7 ± 0.1	17.6 ± 0.2	66.0 ± 5.0	12.7 ± 4.8	5.73	2.36	4.49	30.3 ± 1.7	30.0 ± 0.7
Gryllus assimilis	Adult	4.8 ± 0.1	23.2 ± 0.6	64.9 ± 0.5	7.0 ± 0.3	6.46	1.1	4.11	34.0 ± 0.6	37.5 ± 0.3
Heteracris littoralis	Adult	5.1 ± 0.1	8.8 ± 0.0	74.4 ± 1.0	11.7 ± 1.0	6.01	1.02	3.9	27.7 ± 0.6	42.1 ± 0.1
Locusta migratoria	Adult	4.0 ± 0.0	29.9 ± 0.5	58.5 ± 0.5	7.6 ± 0.1	6.33	0.54	4.28	36.4 ± 0.1	15.9 ± 0.4

Species	Stage	Proximate analysis (% dry matter)				Amino acid (% total)			Fatty acid (% total)	
		ASH %	EE %	CP %	NFE %	LYS	MET	THR	Satura.	Polyuns.
Fish meal	—	18.0 ± 0.2	8.2 ± 0.0	73.0 ± 0.8	0.8 ± 0.7	8.78	2.93	6.26	36.1 ± 1.1	37.3 ± 0.0
Soybean meal	—	7.8 ± 0.0	3.0 ± 0.0	50.4 ± 0.2	38.8 ± 0.3	6.34	1.01	4.17	24.0 ± 1.9	55.4 ± 0.8

EE, ethereal extract; CP, crude protein; NFE, nitrogen-free extract, includes fiber; LYS, lysine; MET, methionine; THR, threonine; Satura., saturated fatty acids, all fatty acids without double bonds; Polyuns., polyunsaturated fatty acids, all fatty acids ≥2 double bonds.

Table 1.
Proximate analysis, amino acids (lysine, methionine, and threonine), and fatty acid (saturated and monounsaturated fatty acids) of selected insects, fish meal, and soybean meal. Values were based on [33].

the main protein ingredients used in the formulation of diets for fish such as soybean meal, fishmeal, meat and bone meal, meal of viscera [32], and lower feather meal and blood meal, which rely on processing to improve their digestibility [32].

In terms of nutritional profile, the use of organic residues for insect production should be further investigated, especially when using foods with high levels of mycotoxins (residues). The mycotoxins, when is consumed by insects, besides being able to cause problems in the production, have the property of being bioaccumulative and being able to compromise the quality of insect meal and influence animal performance.

4. Practical developments: some examples on aquaculture nutrition

Many studies have been carried out to evaluate the use of insects in animal feed, including aquaculture. A study was performed with house fly larvae (*Musca domestica*) as a complimentary source of protein in Nile tilapia (*Oreochromis niloticus*) feeds. The authors observed superior growth rates (~3.76%/day) and reduced feed conversion ratio (1.05) possibly due to a better amino acid profile in this protein blend containing (28% fish meal, 25% house fly larvae, and 12% soy meal) [18]. In addition, the authors reported a high content of lipid (19.8%) in fly larvae, which should be considered when formulating diets. In a similar work, the replacement of 50–60% of fish meal by fly larvae meal (*Musca domestica*) in the feeding of tilapia fingerlings provided adequate growth and performance for the animals [20].

For feeding of African catfish (*Clarias gariepinus*), the larvae of flies have shown to be viable for their use [19]. However, the same positive response was not achieved by using butterfly larvae (*Bematistes macaria*) for feeding of African catfish, under experimental conditions [21]. The partial replacement of 40% fish meal with tenebrio meal for African catfish displayed no differences [22]. The animals have grown as well or better than those fed on the commercial diet. By partially replacing 25% of the fish meal with the tenebrio meal in gilthead seabream (*Sparus aurata*), no differences in weight gain and final weight were noticed [23]. However, for the 50% replacement level reduction in growth and specific growth rate, an increase in feed conversion was observed. One study tested levels of 25 and 50% of fish meal replacement by teneral flour for rainbow trout (*Oncorhynchus mykiss*) [34]. The results showed that there was no difference in performance and growth until the inclusion of 50% (isoprotein diets with 45% crude protein) [34].

For European juvenile sea bass (*Dicentrarchus labrax*), the inclusion of tenebrio meal at 25% had no adverse effects, but at 50% inclusion rate, the specific growth rate was reduced [35]. The use of tenebrio meal for Nile tilapia in partial replacement of fish meal at 25 and 50% levels reduced fish growth by around 29% [10]. According to the authors, the use of tenebrio meal for tilapia cannot be used in high proportions, because it is necessary to understand better the role of chitin in digestion and a better detection of possible toxins that can affect the growth of the fish. Another hypothesis may be related to the digestibility of tenebrio (FLT) meal, which in the form of the larvae's composition can influence its digestibility [36]. Studies evaluating the replacement of fish meal with giant tenebrio (*Zophobas morio*) for Nile tilapia obtained better feed conversion ratio and weight gain than the control, with ideal replacement value of 25%, which corresponded to 7.5% of inclusion of giant tenebrio meal in the feed [37].

Low survival rates were reported by other authors who worked with insect meal, for example, house fly larvae [38, 39] and tenebrio meals. The level of inclusion above 45% reduced survival to 70% [18]. The 50% fish meal replacement with FLT fish for common catfish (*Ameiurus melas* Raf.) resulted in inferior performance and survival, dropping of approximately 9% compared to the control (0% FLT) [40]. In contrast in rainbow trout, there was an increased survival with the inclusion of FLT but lower performance, digestibility, and alteration in the fillet fatty acid profile [24]. Jointly, these data suggest that in the early stages, FLT influences survival that is not pronounced in the final stages. In European juvenile sea bass (*Dicentrarchus labrax*), the inclusion of 25% FLT did not affect growth performance, while a higher inclusion level (50%) compromised the weight gain [25]; similar results were obtained in gilthead seabream juveniles, which included inclusions of 25–50%, compromising weight gain, specific growth rate, feed conversion efficiency, and protein efficiency ratio [23].

For tilapia [27], used the white larvae dry meal to formulate isonitrogenous and isoenergetic diets with maggot meal inclusions at 0, 30, 50, and 80 g/kg substituting gradually three conventional expensive feedstuffs: fish meal, fish oil, and soybean meal. The results showed no significant difference in growth parameters (final weight, weight gain, and SGR) and feed utilization efficiency (FCR and PER and feed intake) between treatments. Similarly fish whole body composition (dry matter, crude protein, lipid, ash, and fiber) was unaffected by the treatments except the fatty acid compositions which mirrored that of the diets. The cockroach (*Nauphoeta cinerea*) meal has also been tested for Nile tilapia with very promising results including superior zootechnical performance as compared to control diets [26].

Insect meals have also been evaluated in biofloc technology system [41–45]. As this system exhibits a series of particularities that separate it from the traditional clear and green water production systems such as recirculating aquaculture system, flow-throw, cages, and ponds, the following findings should be considered within the biofloc context and carefully extrapolated to other production systems. Levels higher than 10% of cockroach meal inclusion decrease the performance of the Nile tilapia juvenile in biofloc technology system, which may be related to the composition of the exoskeleton of the cockroach, especially chitin combined with sclerotin, which confers resistance and flexibility [41].

The use of tenebrio meal at 10% inclusion rate in the nursery stage of Nile tilapia in biofloc technology system did not affect the performance, somatic, hematological, and carcass composition indexes [42, 44]. Inclusion levels higher than 10% decreased productivity and survival and increased hepatosomatic index and lipid content, and in the carcass, consequence of the high lipid content and antinutritional factors is present in the tenebrio meal. Differently from the previous findings, a trial investigating gradual inclusion levels (0, 5, 10, 15, and 20%) of cockroach and tenebrio meal, individually, with *Litopenaeus vannamei* in biofloc technology system, concluded that juvenile shrimp accepted up to 15% of cockroach meal and up to 5% tenebrio meal [43, 45]. There is also a growing interest on the use of insects in shrimp feeds, as seen by several papers lately [46–50]. For additional and more scientific information, there are several papers on this topic [16, 51–54].

4.1 Constraints and future perspectives

Besides the cost and reliable commercial scale production, the diversity in terms of nutritional profile is considered one of the major issues of insect meal inclusion in aqua feeds. Some constraints were already discussed such as (i) excess lipid, (ii) amino acid imbalance, (iii) the presence of mycotoxins and possible antinutritional factors such as chitin [10], and the endogenous production of 1,4-benzoquinone toxin [55]. These isolated or combined factors may compromise the animal's immune system [10] and survival rates [56].

Chitin is an acetylated aminopolysaccharide similar to cellulose, but with a greater number of hydrogen bonds established with adjacent polymer chains, this confers extra resistance [56], which suggests greater difficulty in digestion. Tilapia fed diets with chitin and purified chitosan had impaired weight gain and feed conversion, and the chitin level of 2% was already harmful [57]. In addition, insects have between 11.6 and 137.2 mg kg $^{-1}$ of body chitin [57]. The estimation done by [56] indicated an average value of 74.4 mg kg^{-1} of chitin in *Nauphoeta cinerea* meal, and when included in a ratio of 10%, inclusion will represent ~0.74% of dietary chitin, and for 20% inclusion will represent 1.50% of dietary chitin reaching critical levels. Some authors related high chitin levels with the reduction of feed consumption, availability of nutrients, and negative effects on performance [10, 22, 42, 44]. In this sense, it is fundamental to better understand the factors that limit the inclusion of insect meal into diets, either antinutritional or nutritional limit factors. Cost-effective formulations that met all animal requirements and selection of the other ingredients are crucial for good results. The diets isonitrogenous and isoenergetic with similar amino acids and fatty acids profile that met the nutritional requirement of the target species are fundamental points when comparing insect meal-based diets.

But one question remains unanswered: does insect in aquaculture nutrition a future eco-friendly approach or a commercial reality? The answer depends on the industry. For salmon, one of the biggest and high-value chain aquaculture sectors, the insect meal already offers an alternative to fish meal and soya in early stages of salmon production [46, 49, 50]. An example such as Skretting in Norway observed that fish showed the same zootechnical performance with feeds using insect meal as with traditional protein sources. The diets were normally made from the larvae of the black soldier fly. This feedstuff is an EU-approved commodity, and recent surveys show that Norwegian consumers are positive to eating salmon that has had insect meal in the feed formulation. In the future, an educational approach (e.g., focused on the blue economy) will play a major role to increase consumers' acceptance.

In order for such eco-friendly approach to reach another level, the industrial production of insect meal must be increased to meet the actual aquaculture demand. For example, in the European market, there is now little available insect meal for use on a large scale. To supply the feed mill demand, companies need to work together with manufacturers who wish to come up at a commercial level [46, 49, 50]. According to [46, 49, 50], by 2022 there will be at least five different European suppliers, each producing 20,000 tonnes of insect meal per year, that is, two thirds of the amount of soybean concentrate Skretting Norway uses today. In regard to other industries, although tests were successfully performed with tilapia [18, 27, 36, 37] and *L. vannamei* [46–50], the use of insects in a short-term due to massive volumes of feed demand for these industries is unlikely. The salmon example applying insects in early stages of production is one alternative that will be followed.

5. Conclusion

The use of insect meal in animal feed has been the subject of research, but the results are varied and divergent. Much is explained by the nutritional variability of insect meal production. In addition to knowing the nutritional values of insects, we must consider the study of insect nutrition, since depending on the species we can modulate the fatty acid profile with EPA and DHA and amino acid profile, mainly in the lysine, methionine, threonine, and tryptophan ratios. Understanding better the factors that limit the inclusion of insect meal, whether there is the presence of mycotoxins, fat rancidification, or unknown antinutritional factors, is one of the challenges to be understood. Some insects may have nutraceutical factors in their composition, which can confer exponential positive results on animal performance and human health. In this sense, the prospects of the use of insect meal in animal nutrition are very encouraging and new nutritional approaches are just starting.

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