Chapter

Potential Utilization of Insect Meal as Livestock Feed

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Abstract

Globally, the utilization of alternative protein sources in livestock feed has been extensively deliberated and established to be the best novel approach. Extensive research indicated that insects provide good opportunities as a sustainable, high quality, and low-cost component of animal feed. The use of insects in animal diet sounds to be the prospective opportunity leading to sustainability of animal feeds and meet the intensifying worldwide plea for livestock products. The value of these protein sources has, however, increased due to limited production, competition between humans and animals. The use of insects for feeding farmed animals represents a promising alternative because of the nutritional properties of insects and the possible environmental benefits, given the sustainability of this type of farming. Yet little has been documented about the nutrient composition of various insect meals, the impact of insect meal in the animal feed industry, safety, and attitude and willingness of farmers to accept insect-based animal feed and food. Therefore, this chapter seeks to document the potential utilization of insect meal as livestock feed.

Keywords: insect meal, safety, acceptance, chitin, benefits

1. Introduction

The Food and Agriculture Organization (FAO) emphasized the importance of alternatives to conventional animal feed due to limited amounts [1]. Currently, the core protein sources in monogastric animal diets are fishmeal, processed animal protein, milk by-product, soybean meal (SBM), rapeseed meal, and canola meal. The value of these protein sources has, however, increased due to limited production, competition between humans and animals [2]. In addition, Makkar et al. [3] stated that insects are good novel protein sources at a low-cost, with regard to their high nutritional value and low breeding space requirements. They are recommended as high quality, effective, ecological substitute sources of protein. More so, protein-enriched insects are another alternative reckoned to reduce the price of protein supplements in poultry diets. In addition, according to [4] insect components such as chitin, lauric acid, and antimicrobial peptides promote chicken health. Also, take into consideration that these insects can be utilized as a dried or fresh state in poultry diets [5]. Recently, scientists have started to study insects as state-of-the-art feed constituents for aquaculture [6, 7] and poultry [8, 9]. However, this chapter focuses on the documentation of the proximate nutrient composition, impact on the animal feed industry, consumer acceptance, and safety of insect meal as animal feed.

2. Chemical composition of different insect meals

Insects at all stages of their lives are potentially rich in protein [8]. Frantic efforts by researchers have dealt with different insect species, as indicated in **Table 1**. The protein content of insect meals varies considerably, from around 39% up to 64.4% even when the meals are based on the same insect species. The nutrient concentration of insects depends on their life stage as well as the rearing conditions and the composition of the growth media used for insect production [3, 20].

Insect spp.	DM	CP	EE	Ash	CF	Citation
Tenebrio molitor L.	94.56	52.18	32.19			[10]
Gryllus assimilis	90.15	58.14	29.52			[10]
T. molitor	99.20	58.80	17.1			[11]
Hermetia illucens	98.9	58.4	11.6			[11]
Periplaneta americana	94.6	64.4	23.6	3.98	4.36	[12]
Hydrous cavistanum	86.3	41.9	38.3	1.88	14.7	[12]
Zophobas morio	96.8	42.0	41.7	5.53	6.28	[12]
Locusta migratoria	91.9	58.5	12.7	4.56	12.7	[12]
Gryllus testaceus	92.2	53.3	22.6	5.05	8.98	[12]
Musca domesticus	93.8	54.8	21.7	6.78	9.65	[12]
Brachytrupes spp.		62.6	12.2	4.9	13.3	[13]
G. assimilis		56.0	32.0		7.6	[14]
Ruspolia nitidula		40.8	46.3	3.3	5.9	[15]
Macrotermes nigeriensis		37.5	48.0	3.2	5.0	[16]
Allomyrina dichotoma		54.2	20.20	3.9	4.0	[17]
H. illucens		39.0	32.6	14.6	12.4	[18]
Musa domestica	96.77	40.12	6.88	15.88	10.97	[19]

Table 1.
Summarized major chemical composition of different insect meals.

3. Impact of insect meal in the animal feed industry

In general, insects can be utilized for human and animal feed because of their high nutritive value [21]. Several studies have indicated that insect meal can be utilized to substitute soybean and fish meal in animal diets [22–26]. This is because these are rich sources of macro and micronutrients [27]. For instance, the black soldier fly (BSF) *Hermetia illucens* larvae has a protein content of 37–63 g/100 g and fat levels of 20–40 g/100 g with balanced fatty acids and amino acids profiles [9, 28]. Furthermore, grasshoppers (*Ruspolia nitidula* Linnaeus) family *Tettigoniidae* contains 36–40 g/100 g crude protein, 41–43 g/100 g fat, 10–13 g/100 g dietary fiber, and 2.6–3.9 g/100 g ash on a dry matter basis [29]. In addition, insects are excellent sources of minerals like potassium, calcium, iron, phosphorous, zinc, and magnesium and also vitamins covering riboflavin, thiamine, niacin, and vitamin B12 [30–32].

Furthermore, Onsongo et al. [24] reported that broiler chickens and quails fed on BSF larvae meal had a satisfactory taste, aroma, and nutritional composition of the meat. This denotes that BSF larval meal can be suitable to be incorporated in poultry diets. Also, insects have been fed to fish yielding good growth performance and feed conversion [33]. In addition, piglets fed with BSF larval meal exhibited good results on growth performance, with insignificant effects on blood

Pig age	**Insect species**	**Feed inclusion levels**	**Results**	**Citation**
Weaned pigs	*Tenebrio molitor*	0, 1.5, 3.0, 4.5, and 6.0% replacement of soybean meal	Linear increase in BW, ADG, ADFI, DM, and CP digestibility	[44]
Weaned female pigs	*Hermetia illucens*	0, 30, and 60% replacement of soybean meal	Linear increase in ADFI no effect on growth	[26]
Barrows	*H. illucens*	50, 75, and 100% replacement of soybean meal	No effect on base meat quality measures, increased juiciness ($P < 0.05$); higher back fat PUFA contents ($P < 0.05$)	[45]
Weaned pigs	*T. molitor*	0, 5, and 10% replacement of soybean	AID of all AAs, except aspartic acid, was lower at 10% inclusion than at the control diet	[46]
Growing pig	Dried BSF larvae meal	0, 9, 12, 14.5, and 18.5% replacing fish meal	Growth performance was not affected	[47]
Finishing pigs	Dried *H. illucens* larvae powder	0, 4, and 8% replacing soybean meal	BW and BWG at 4% inclusion was higher and FCR was lower than at 0 and 8% inclusion	[48]
Weaned piglets	*H. illucens* larvae oil	0, 2, 4, and 6% replacing corn oil	Evaluated biochemical parameters were not affected, except cholesterol that increased linearly at higher inclusion levels. Hematological parameters were not affected, but platelet count tended to linearly increase at higher inclusion levels	[49]
Nursing piglets	*H. illucens* larva	0 and 3.5% replacing fishmeal	Evaluated hematological and biochemical parameters were not affected	[50]
Growing quails	Defatted *H. illucens* meal		Reported no difference in average daily feed intake	[51]
Broiler chickens	Mopane worn (*Imbrasia belina meal*)	0, 4, 8, and 12% replacing soybean oil	Dietary inclusion levels of *I. belina* meal up to 12% had a positive effect on growth performance, meat quality, and sensory attributes	[52]
Broiler chickens	*Musca domestica*	0, 75, 50, and 25% replacing fish meal	No significant effect ($P > 0.05$) to the feed intake	[19]
Quails	*H. illucens*	0, 10, and 15% substituting soybean oil	No significant difference in daily gains to control	[52]
Broiler chickens	*T. molitor*	0, 50, 100, and 150%	Live weight and feed intake of broiler chickens improved with increasing levels of *T. molitor*	[53]
Broiler chickens	*H. illucens* and *Arthrospira platensis*	50%	Increased live weight of broiler chickens	[54]

Pig age	Insect species	Feed inclusion levels	Results	Citation
Broilers chickens	*H. illucens*	0, 5, 10, and 15%	Live weight showed linear and quadratic responses to increasing levels of *H. illucens*	[55]
Muscovy duck	*H. Illucens*	0, 3, 6, and 9%	Live weight and average daily gain showed quadratic response to increasing *H. illucens*	[56]

DM, dry matter; CP, crude protein; BW, body weight; BWG, body weight gain; FCR, food conversion ratio; ADG, average daily gain; ADFI, average daily feed intake; AA, amino acids; AIA, apparent ileal digestibility; PUFA, polyunsaturated fatty acid.

Table 2.
Summary of effect of insect diet on growth performance of different animal species.

profiles [26]. However, generally, the use of BSF larval meal has been proven to be an excellent constituent of animal feed [23–26].

High nutritional value, minimal space requirements, and low environmental impact combine to make insects an appealing option for animal feed [34]. Another major advantage is that insects are already used for the natural part of many animal diets [35]. Insect-based animal feeds are particularly attractive when considering the cost of standard feeds, currently accounting for 70% of livestock-production expenses [36].

The most promising, well-studied candidates for industrial feed production are black soldier flies, larvae, yellow mealworms, silkworms, grasshoppers, and termites [37]. Such previous research has revealed that insect meal can partially replace commercial soybean or fish meal in broiler feed, particularly as protein sources. In addition, Pretorius [38] reported that broiler chicken fed with housefly larvae increased their average daily gain, carcass weight, and total feed intake. More so, a recent study by [9] asserted that broilers fed on BSF meal improved their growth performance. With regards to nutritional value, insect diets improved meat products' taste. Also, Marono et al. [39] reported that laying hens fed on insect larvae meal exhibited no negative effect on feed intake, feed conversion efficiency, immune status, egg production, and health. Smallholder farmers in Asia and Africa frequently utilize insect diets on fish production [37]. Mealworms and housefly-larvae meal can substitute up to 40–80% and 75% of fishmeal in Nile tilapia/standard catfish (*Ameiurus melas* Raf.) diets without any detrimental effects, respectively [40, 41]. Replacing a fish meal with black-soldier-fly larvae meal in diets does not alter the odor, flavor, or texture of Atlantic salmon (*Salmo salar*) [42]. Another viable alternative to a fish meal is silkworm pupa, which was tested successfully for African catfish (*Clarias gariepinus*) fingerling diets [43]. More so, some other outcomes on insects to benefit the industry are presented in **Table 2**.

4. Consumer's acceptance of insect-based animal feeds

The utilization of insect meal to replace unaffordable fish, animal, or plant protein ingredients in feeds is socially acceptable. This is because, naturally, fish and poultry are usually seen feeding on insects, for example, in the case of our free-range poultry production systems [53, 57], which roam around in search of feed. More so, various insects have higher protein levels than conventional fish and soybean meals [58] and are comparable in performance with conventional protein sources when completely or partially replaced with fish protein in poultry diets [59]. With the fact that protein is the most costly ingredient in livestock diets, the use of insects sounds like a positive novel idea [60, 61].

The consumer's acceptance of meat products derived from animals-fed insects ought to be put into account. Before introducing insects as a new ingredient, it is necessary to establish the current perceptions of the targeted processors, traders, and poultry farmers. This is because farmers' perceptions of technology characteristics significantly affect their adoption decisions [62]. A few studies surveyed the consumer's readiness to buy animal products that originated from animals fed with insect meal [63, 64].

5. Chitin content

Chitin is a polysaccharide (linear polymer of β-(1–4)*N*-acetyl-glucosamine units) of the exoskeleton of arthropods [65]. However, chitin negatively affects the digestibility and nutritional traits of insects. In addition, it has been considered as indigestible fiber for the time in memorial. Chitin is the utmost form of fiber in insects [66], however, the nitrogen absence is also analyzed by the Kjeldahl method as a crude protein. It is, however, included in the nitrogen-to-protein conversion factor of 6.25, which overvalued protein content. For this reason, Janssen et al. [67] suggested a conversion factor of 5.60 ± 0.39. However, in some birds like chickens, the gastrointestinal tract (GIT) excretes the enzyme chitinase [68] which degrades chitin into its derivatives chitosan, chitooligosaccharides, and chitooligomers that are assimilated with easy into bloodstreams [68, 69]. Average chitin yields were 18.01 and 4.92% of dry weight from the exuvium and whole body of the *Tenebrio molitor* larvae [70]. The chitin composition depends on species and development stadium of the insect [66].

However, chitin has a positive effect on the operation of the immune system of poultry, which could reduce the use of antibiotics [1]. The prebiotic effect of chitin was observed by [71, 72] in increasing caecal production of butyric acid and [73] in improving the immune response of birds or due to reduction of albumin to globulin ratio [74]. In addition, chitin and its derivatives can aid to sustain a balanced and healthy GIT microbiota that keeps the amounts of potentially pathogenic bacteria (e.g., *Escherichia coli* and *Salmonella typhimurium*) low [75] and decreases the risk of intestinal diseases. By reducing the number of pathogenic microbiota, chitin encourages the proliferation of commensal bacteria. A positive effect of chitin was reported by [36] who also stated that a diet containing 3% of chitin decreased *E. coli* and *Salmonella* spp. in the 380 intestines. Chitin also has antifungal and antimicrobial properties [76].

6. Nutrient digestibility

Evaluating digestibility is a means to come up with an approximation of nutrient availability in a feed. In this regards, Woods et al. [77] reported that *H. illucens* larvae fed to quails have higher apparent digestibility for dry matter and organic matter to the control fed group. However, Bovera et al. [78] showed that the ileal digestibility coefficient of dry matter and organic matter in broiler fed *T. molitor* was lower by 2% than fed soybean diet. In addition, Cutrignelli et al. [79] reported reduced coefficients of the apparent ileal digestibility (AID) of dry and organic matter on laying hens fed *H. illucens* meal diet. These reductions were due to the strong decrease of the crude protein digestibility linked to the availability of chitin in the insect meals, which deleteriously influences the crude protein digestibility. However, no difference was observed between digestibility coefficients of the dry matter of *T. molitor* meal and *H. illucens* meal [80]. More so, Woods et al. [77]

observed a higher apparent metabolizable energy for *H. illucens* larvae fed quail compared well to the control fed group. On similar results [81] did not find the differences among *T. molitor* oil and palm oil on AID of crude fat, and metabolizable energy. Furthermore, the apparent metabolizable energy of the *T. molitor* meal and *H. illucens* meal [80] was higher than all the ingredients mainly utilized in the poultry diet [39], substituted 500 g kg^{-1} of a maize meal-based diet with *M. domestica* larvae meal for 3-week old broiler chickens and detected a crude protein digestibility coefficient of 0.69. However, De-Marco et al. [80] detected no difference in the digestibility coefficient of the crude protein between *T. molitor* and *H. illucens*. In their study, Schiavone et al. [82] observed that there was no effect on apparent crude protein digestibility in chickens fed *T. molitor* oil as a total replacement for palm oil. Whilst, Bovera et al. [78] and Schiavone et al. [82] reported 8.2% and lower crude protein digestibility on chickens fed *T. molitor* larvae respectively, compared to soybean diet. De-Marco et al. [80], found that the (AID) of amino acids in the *T. molitor* meal was higher and showed less variation than in the *H. illucens* meal. According to the afore-mentioned results, insect meals can be an alternative crude protein source for soybean meals or fishmeal.

7. Safety in utilization of insect meals

Utilization of insects as constituents in livestock feed should consider safe due to the fact that they contain toxic substances secreted by the exocrine gland [83]. Just as in plants and animal feed, some insects are not safe to eat, they trigger allergic reactions. For instance, African silkworm (*Anaphe venata*) pupae have a thiaminase which causes thiamine deficiency [84]. In addition, *T. molitor* contains toxic benzoquinone compounds secreted by the defensive gland [85]. This benzoquinone is toxic to humans and animals, hence affecting cellular respiration resulting in kidney destruction, and has a carcinogenic effect [85]. However, insects may have antibiotic resistance genes [86] indicating that they can be filled with disease-causing organisms or mycotoxin from adulterated diets. More so, Wynants et al. [87] affirmed the contamination of wheat bran by the *Salmonella* spp. in *T. molitor* larvae. However, it is imperative to consistently monitor microbial pathogens of the substrate and the larvae in order to reduce pathogens in the *T. molitor*. Interestingly, Van Broekhoven et al. [88] reported that *T. molitor* larvae fed with diets contaminated with the mycotoxin deoxynivalenol were not affected in their growth and degraded the mycotoxin.

Besides, mycotoxins, insect feed can be contaminated with heavy metals, pesticides [89]. Mycotoxins from feed or substrate for insects rearing can negatively affect the growth, inhibit larval development or increase mortality of insects. More so, consumption of mycotoxin-contaminated insects can present a risk to animals. However, Schrogel et al. [90], reported no accumulation of mycotoxin in experiments fed with various insect species. Furthermore, Charlton et al. [91] reported that heavy metals accumulate in resultant insects. However, of the 1140 compounds measured, only seven were detected in the larvae, with Cd posing the greatest risk [91]. The *T. molitor* and *H. illucens* larvae consume feeds containing mycotoxins and pesticides, the removal of these would render the resultant larvae free from toxins [92, 93]. More so, Purschke et al. [94] affirmed that there was no build-up of pesticides in BSF larvae raised on substrates spiked with pesticides. As a result, this renders it safe to be used in animal feed diets.

Some insects contain repellent or toxic chemicals, which they use as their defense mechanism. Grasshoppers spit brown juice as a means of defense while laybugs protect themselves from predators by releasing toxic fluid hemolymph.

This yellowish fluid released from the leg joints is toxic in nature. Some insects are reported to transmit zoonotic agents such as bacteria, viruses, parasites, and fungi as vectors. According to [95] cases of botulism, parasites and food poisoning have been reported in using insect meal. In management, these health risks, proper processing, handling, and storage are a necessity in order to prevent contamination and spoilage. However, it is imperative to apply decontamination methods and shelf-life stability of insect meals in order to ensure and achieve marketability and food and feed safety.

8. Production and availability of insect meal

Insects have some valuable biological traits, which include being prolific, high feed conversion rate, and easy to raise with low feed cost [96]. According to [51] insects need less amount of feed for the production of 1 kg biomass, have higher fecundity, for instance, the common house cricket lays up to 1500 eggs over a period of about a month. Insect species are efficient feed converters as they are cold-blooded [51] and do not use energy to maintain body temperature [53]. Insects effectively utilize water and, in most cases, the feed is the main source of water [97]. Generally, the breeding of insects does not require complex infrastructure and their care is simple [98]. Insects propagation can be on several substrates, for example, cereals, decomposing organic materials, fruit or vegetables, poultry, pigs and cattle manure, industry by-products, or waste products, which would be environmental problems [51, 99]. According to [100, 101] utilization of insect meals or larvae meals can reduce the cost of poultry feed when nurtured on bio-waste. Insects can convert waste into valuable biomass [102] and convert low-quality plant waste into high-quality crude protein, fat, and energy in a short time [3]. Insects can effectively convert low-grade organic waste into high-quality protein. They utilize the organic waste, which could otherwise end up on dumpsites, causing environmental pollution. Insects have higher feed conversion efficiency. Most insects are produced on organic wastes or material that could not be consumed by humans. In their production, insects use minimal space, in the rearing process. Reports indicate that insects contribute less greenhouse gases than pigs and cattle [37].

The other benefit is the larvae's ability to decrease bacterial growth in the manure and thus reduce odor [97] *H. illucens* larvae has a 66% potential waste reduction and also waste reduction of 51–80% was recorded on pig, chicken, and kitchen waste [103]. Insect farming can also provide environmental benefits. Feeding waste materials to insects protects air, land, and water from potential contamination [104]. For example, the black soldier fly (*H. illucens* L.) (Diptera: Stratiomyidae), can be fed food waste that would typically be placed in landfills [105]. Accordingly, digestion of these materials suppresses noxious odors [105] greenhouse gases [106], and pathogens [107]. Furthermore, less land, water, and space are needed to produce insects, such as the black soldier fly, than traditional animal production [107]. Other benefits include fast development time (e.g., black soldier fly can develop to harvestable size within 14 days) [108], versus beef (e.g., 12–18 months of feeding to reach the needed weight to slaughter) [109]. It is also worth noting that the full insect is edible unlike beef (48.5%) [36]. Because of the ability of the black soldier fly to consume a variety of organic wastes, while offering benefits to the environment, it is now viewed as the "crown jewel" of the insect.

Insects' growth rate depends on microclimate. The optimal temperature for most insect species rearing is 27–30°C [110]. The insect's larvae are the most effective for production and it is possible to produce more than 180 kg of live weight of *H. illucens* larvae in 42 days from 1 m^2 [110]. The insect market for animal feed is continually increasing globally, especially focused on *T. molitor* larvae (mealworm).

T. molitor and *H. illucens* (black soldier fly) are two of the most promising insect species for commercial exploitation and for use in poultry feeds [110] their production is seamless and well understood [111].

Even though raising insects seem to be a positive move, there is a dearth of information with regards to insect production methods and technologies, mainly in mass production [112–114]. This may be due to the fact that private companies hardly share that kind of information as they are in business. However, indigenous technical knowledge is mainly utilized in raising these insects, eventually becoming the basis of any technological improvement. For instance, in Indonesia, a complete guide on how *H. illucens* on medium-scale production has been circulated [115]. General, insect husbandry includes two main distinct units, which include the maintenance of the breeding colonies and the growing larvae [28]. In the event that business deals with adult insects, this requires more space for rearing purposes. As this implies to where crickets are raised [116]. Improved systems usually include an area to process insects and improve resultant products. Production wastes, like substrate remains and frass, may be utilized to come up with fertilizers in a devoted facility, hence leading to circularity and sustainability.

Insects can thrive in thickly populated areas, which permits mass production even in limited spaces. Generally, larvae and pupae are retained together with a nourishing substrate in small trays made of diverse materials like wood, high-density polyethylene, or fiberglass. According to [116] trays for fattening *T. molitor* larvae are standard ones measuring 65 × 50 × 15 cm^3 box, which are handled with ease and are deep enough to avert larvae or adults from fleeing. A recent study by Thevenot et al. [114] reported that a mill was designed to produce 17 tones of *T. molitor* annually with a density of 5 larvae cm^{-2}.

Currently, insect raising is appealingly increasing awareness in developed countries, which are not enthusiastically normally involved in harvesting insects. This involves countries like Europe and the United States of America. As a result, promoting insect-based products to increase their market share. Indeed, insect husbandry linked with economic benefits produce food and feed ingredients that can benefit the developing and developed nations [117].

9. Conclusion

Insects pose an attractive opportunity to come up with novel sustainable protein source in monogastric animal diets taking into account their nutritive value, biosafety, and consumer acceptance. In addition, they also represent a means of converting food waste biomasses/streams into valued feed materials. However, it appears that there is nothing much barring us from utilizing insect meals as feed material. As a result, we need to get started and reduce the feed costs and also get rid of other insect limitations in their use as animal feed. Insect farming has great potential with regards to sustainably providing feed for the livestock. It can be concluded that insects can be an excellent alternative to partly replace soybean and fishmeal. However, further technological development of this sector and monitoring of the effects of these developments are needed. Also, further exploration is needed to assess the estimation equations parameters tied to these insect species.

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Conflict of interest

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