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Review article

# Insects as a source of nutrients in animal feed

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**Global production of compound feed in 2018 was 1.103 billion tonnes, which was an increase of 3% compared to 2017. To meet the needs of the growing livestock population, a further increase in compound feed production is necessary. The need for new, alternative nutrient sources for feed production, in order to meet the anticipated consumer demand for animal products, has led to an increase in research on the potential uses and effects of insect-derived products, such as whole insects or insect meals and oils. Insects appear to be one of the most promising alternatives to nutrient sources such as soybean and fish meal, commonly used in feed for livestock and aquaculture. The purpose of the review was to present the currently available literature on the use of insects as feed in livestock production and to systematize it in one easy-to-read document. Particular focus has been placed on the use of insect products for animals such as poultry, rabbits and pigs, as well as their effect on productivity, nutrient digestibility, performance, and product quality. The results of numerous studies suggest that insects can be a source of nutrients in feed for poultry, rabbits and pigs.**

**KEY WORDS: insects, compound feed, poultry, rabbits, pigs**

The shrinking area of agricultural crops is a major challenge for the world's food economy [6], as the production of compound feed is increasing, amounting to 1.103 billion tonnes in 2018 – 3% more than in 2017. Conventional protein sources are no longer sufficient to fully satisfy the increase in feed production in a sustainable manner. The production and procurement of vegetable proteins for the agri-food sector has often stimulated political debate in the European Union. Poland imports over 75% of vegetable protein annually, mainly in the form of soybean meal, imports of which have recently increased to about 2.5 million tonnes [55].

The world's main source of protein in livestock diets is currently soybean extraction meal. Scientific research results indicate that it can be replaced by by-products from the agri-food industry, i.e. other meals, mainly rapeseed and oilseed cake, maize gluten, potato protein isolates, or dried distillers [1, 11, 17, 51]. Soybean meal in animal diets can also be replaced with the seeds of various legume plants [24, 53, 61].

The nutritional value of the abovementioned feedstuffs is lower than that of animal proteins, which due to the outbreak of bovine spongiform encephalopathy (BSE) have been withdrawn from the feeding of most livestock by various legal acts. This has created the need to find alternative protein sources, defined as those that have not previously been intended for feeding humans and animals, or have been used to a limited extent and only among certain populations. One alternative may be insect protein. The amino acid composition of insect proteins is the most similar to animal proteins, and its digestibility is very high, ranging from 77.9% to even 98.9% [8].

Currently, breeding of insects for the production of processed animal protein and other insect products for animal feed has begun in a few EU Member States. This production is subject to national control systems, for which the competent authorities of the Member States are responsible. Recent scientific research has shown that insects can be a sustainable alternative to conventional sources of animal protein for feed for non-ruminant livestock [42].

The European Food Safety Authority (EFSA) published a scientific opinion on 8 October 2015 on the risk profile of the production and consumption of insects in food and feed [14]. It stated that, compared to hazards associated with the presence of prions in currently permissible sources of animal protein, hazards in unprocessed insects are expected to be at the same level or lower, provided that the insects are fed with substrates that do not contain material derived from ruminants or material of human origin. As processing of insects can further reduce biological hazards, this statement also applies to processed animal proteins derived from insects [42].

According to Commission Regulation (EU) 2017/893 of 24 May 2017, insects bred in the European Union should not be pathogenic species; have other adverse effects on plant, animal or human health; be recognized as vectors of human, animal or plant pathogens; or be protected or defined as invasive alien species [42].

In accordance with national risk assessments and the EFSA opinion of 8 October 2015, insect species bred in the European Union that meet the above-mentioned safety conditions for production for feed purposes include flies – black soldier fly (*Hermetia illucens*) and housefly (*Musca domestica*); beetles – mealworm (*Tenebrio molitor*) and lesser mealworm (*Alphitobius diaperinus*); and crickets – house cricket (*Acheta domesticus*), tropical house cricket (*Gryllodes sigillatus*) and Jamaican field cricket (*Gryllus assimilis*) [42].

According to Commission Regulation (EU) 2017/893 of 24 May 2017, amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No. 142/2011, the abovementioned insects have been recognized as livestock animals and from that time are to be considered livestock animals as defined in art. 3 para. 6 lit. a) of Regulation (EC) No. 1069/2009. Permission has been granted for the production of processed animal protein from these insects in accordance with Chapter II, Section 1, Part A, point 2 of Annex X to Regulation (EU) No 142/2011 [42].

Processed animal protein derived from farmed insects may be imported into the European Union if it has been produced in accordance with the following conditions. The insects must belong to one of the abovementioned species, and the substrate used for their feeding must contain only non-animal products or Category 3 animal-derived products, i.e. fishmeal, blood products derived from animals other than ruminants, animal-derived dibasic and tribasic calcium phosphate, protein hydrolysates derived from animals other than ruminants, protein hydrolysates derived from ruminant hides and skins, gelatine and collagen derived from animals other than ruminants, eggs and egg products, milk, milk-based products, milk and colostrum derivatives, honey, or rendered fats. In addition, care should be taken to ensure that the substrate used for feeding insects, the insects themselves and their larvae do not come into contact with materials of animal origin other than those referred to above, and that this substrate does not contain manure, catering waste or other waste.

In many Asian, African and Latin American countries, invertebrates are a common source of protein in compound feeds for livestock, and are used in human nutrition as well. It is estimated that at least 2 billion people around the world consume them in various forms, and contrary to popular belief, not only in times of food scarcity. In many cultures (local culinary traditions), people eat them by choice, for their taste as well as their high nutritional value [3, 23, 48].

Insects (Insecta) are a very diverse group of animals belonging to the phylum Arthropoda. They are divided into subclasses – wingless insects (Apterygota) and winged insects (Pterygota). Thus far, over 1,900 species of insects used as human food have been described. This suggests that they can ensure sustainable and environmentally friendly production of both food for humans and animal feed, especially since over the course of evolution many species, including birds, have developed numerous adaptations for obtaining and digesting this type of food [23, 54].

Analysis of the chemical composition of insects has revealed great interspecific variation, as well as differences depending on the stage of development, habitat, food type, and finally the components of the substrate on which they are bred [43]. The main nutrient in insects is protein. Its content in full-fat meal from insects in all developmental stages ranges from 40% to 60%. It should be emphasized that this value is obtained through highly favourable bioconversion of feed materials with a low, 8-9% total protein level [25, 40, 54]. The digestibility of insect protein is comparable to that of chicken eggs, and it is considered a complete protein at a level comparable to milk and beef proteins [41, 47]. Insect proteins are a good source of amino acids such as threonine, valine, histidine, phenylalanine and tyrosine, and in the case of some species, tryptophan and lysine as well [43, 59]. Insects of the order Diptera have an amino acid profile similar to that of fishmeal, while insects of the order Coleoptera or Orthoptera have an amino acid profile similar to that of soybeans, with a possible deficiency of lysine or methionine [2]. Zielińska et al. [60] have shown that consumption of edible insects can have potential health benefits due to the strong antioxidant activity of the peptides obtained from them. Digested insects were shown to have higher antioxidant activity than other protein hydrolysates obtained from animal and vegetable products.

The second most important nutrient in insects is fat. Its average content in insect meal ranges from 14.41% to 37.1%, with a higher level in larvae and pupae than in adults. Among farmed insects, mealworm larvae are the richest in fat [54]. Insect meals are relatively rich in unsaturated acids, including oleic, linoleic and α-linolenic acid [57]. They contain more polyunsaturated fatty acids (PUFA) than fishmeal or poultry meal, as well as saturated fatty acids, among which palmitic and stearic acid are found in the highest concentrations. Research by Yang et al. [57] has shown that the composition of fatty acids can be modulated by modifying the diet of insects. In the process of defatting of insect meal it is possible to obtain oil that can be widely used in human and animal nutrition, as well as for biodiesel production [15, 38]. For example, St-Hilaire et al. [50] have shown that black soldier fly larvae fed on cow manure contained 21% lauric acid, 16% palmitic acid, 32% oleic acid and 0.2% omega-3 fatty acids, while larvae fed 50% fish offal and 50% cow manure contained 43%, 11%, 12% and 3% of these acids, respectively. Total lipid content also increased from 21% to 30% dry matter. The use of fish offal containing beneficial omega-3 fatty acids to feed black soldier fly larvae is therefore a means of enriching the final biomass with these acids. Tzompa Sosa and Fogliano [52] compared animal fats – butter, pork lard, and beef tallow – with oils obtained from insects – superworm, mealworm, lesser mealworm, cricket and cockroach – and vegetable oils from flax seeds, rapeseed, sesame, pumpkin, sunflower and soybean. The analysis revealed that insect oils fall between vegetable and animal fats in terms of fatty acid profile, with a higher SFA content than that of vegetable fats (mainly C16:0 and C18:0).

Initially, some nutrition scientists expressed concern that the relatively high proportion of chitin in insects could be an obstacle to their use in animal nutrition. This depends largely on the species and stage of development; the chitin content of cricket meal, for example, can be as high as 8.7%. It is widely accepted that chitin is not digested by monogastric animals or by fish [12]. However, scientific research has determined that this chemical compound has no cytotoxic effect in vitro, is physiologically neutral and biodegradable, has antibacterial properties, and exhibits an affinity for proteins [44]. Chitin can also be removed from insect meal by alkaline extraction [4, 54, 57].

Insects also contain vitamins, mainly thiamine, riboflavin, cobalamin, folic acid, and in smaller amounts retinol [9, 16, 43], as well as minerals, mainly iron and zinc [9].

Insect breeding is associated with important aspects of environmental protection, such as lower drinking water consumption than in the case of slaughter animals and reduced use of feed, which can consist of by-products of the agri-food industry that meet food and feed safety requirements, thereby solving the additional problem of their disposal. Insect droppings can be used in agriculture as a fertilizer [7]. Such insect breeding has no negative impact on the environment, in contrast with conventional livestock farming. It entails a relatively low level of carbon dioxide emissions to the environment, and lower emissions of greenhouse gases and ammonia [36]. Another benefit to the environment is the high feed conversion efficiency, which is linked to the poikilothermic physiology of insects [35]. According to the FAO report [15], saving agricultural land, feed and drinking water significantly reduces the costs of insect breeding. Other positive factors that increase the economic potential of insect breeding are the ease of distribution, high fertility rate and short reproductive cycle [45]. Production of larvae is not complicated, owing to the unique reproductive abilities of insects; for example, a female housefly can lay up to 750 eggs a week, and the larvae that hatch from them can increase their weight over 400 times in a few days. Research is currently being conducted on storage of insect meal because, as in the case of other animal meal, the oxidation process and microbiological contamination determine the quality and shelf-life of these products [7].

The purpose of this review is to present current research on the possibility of using insects in various forms as a feed additive for selected livestock species, such as poultry, rabbits and pigs.

The most work on the use of livestock feed containing insects has dealt with meat chickens, and the most commonly used insect has been black soldier fly (*Hermetia illucens*) larvae. Both live insects and meal or oil prepared from them can be successfully used to feed poultry. Newton et al. [33] has found that chickens fed a diet containing dried black soldier fly larvae as a soy substitute grew at a rate of 96% compared to those fed a control diet containing soy, but consumed only 93% of the feed, suggesting more efficient conversion. Pretorious [39] showed that feed for broiler chickens can contain up to 25% housefly larvae without adversely affecting weight gain, feed intake or its conversion rate. He also noted high digestibility of amino acids derived from the larvae of this fly, reaching 91%. Schiavone et al. [46] found that partial (50%) or total (100%) replacement of soybean oil with fat from *Hermetia illucens* larvae had no effect on the growth, blood parameters or health of broiler chickens receiving this feed from days 21 to 48 of life.

Kierończyk et al. [26] conducted research on Ross 308 chicks during their first 28 days of life to demonstrate the possibility of replacing 50 g/kg of the basal diet with mixtures of various oils, i.e. soybean and mealworm or soybean, mealworm and superworm, and their effect on growth, nutrient digestibility, the fatty acid composition of the liver and breast muscles, and the expression of selected genes in the liver. The use of these oils improved growth performance, increased nitrogen retention, and significantly affected the fatty acid composition of the liver and breast tissue. Only the addition of mealworm oil was found to have a positive effect on the PUFA, MUFA, UFA and SFA content of the pectoral muscle and to reduce the IA and IT indices, which is very important for the contemporary consumer. It should be emphasized that both insect oils used in the experiment can be considered to be biologically active compounds that modify the molecular pattern at the mRNA level.

Józefiak et al. [22] evaluated the effect of including insects of the species *Gryllodes sigillatus*, *Shelfordella lateralis*, *Gryllus assimilis*, *Tenebrio molitor* and *Hermetia illucens* in the diet of day-old Ross 308 broiler chickens in amounts from 0.05% to 0.2% on their growth and the composition of the intestinal microbiome. The research was carried out in four different experiments. The use of insect meal in broiler diets did not affect their growth during the experimental period. However, the addition of 0.2% *T. molitor* and *H. illucens* increased feed intake from days 15 to 35 of life and throughout the experiment (from days 1 to 35 of life). Supplementation with 0.2% *S. lateralis* improved weight gain (from days 11 to 21 and from days 1 to 21), feed intake (from days 1 to 10 and 1 to 21) and the feed conversion rate (from days 1 to 21). *H. illucens* supplementation had the most significant effect on the microbiome of the ileum and cecum. The addition of insect meal reduced the pH in the gastrointestinal tract, especially in the amount of 0.1% and 0.2%, which reflects the potential bacteriostatic role of diets with the addition of insects. These results indicate that the use of full-fat insect meal in relatively small amounts can modulate the composition of the gut microbiome of broiler chickens.

Benzertiha et al. [5] have shown that oil from *Tenebrio molitor* can completely replace palm oil and poultry fat in the diet of broilers without adversely affecting weight gain, nutrient digestibility, pancreatic enzyme activity or selected blood parameters. This oil has a positive effect on the composition of fatty acids in the muscle tissues of chicken breasts.

Maurer et al. [31], in a study on laying hens, observed no significant differences in egg production or feed consumption in chickens receiving a diet in which soybean meal was 50% and 100% replaced with partially defatted meal from *Hermetia illucens* larvae. They also did not observe higher mortality or increased incidence of disease. Park et al. [37] obtained higher egg production and weight from laying hens receiving compound feeds with the addition of *Hermetia illucens* larvae.

Carregal and Takahashi have described the potential use of insects to feed rabbits [10], in a study replacing soybean meal with silkworm larvae. It is worth noting that Liu et al.

[29], who published the results of their research in 1987, treated silkworm larvae not as an experimental factor, but as a permanent component of the rabbit diet, which may indicate their widespread use in China. In the Web of Science database, the Derwent Innovations Index includes Chinese patents on the use of mealworm larvae and silkworm pupae, alongside other components, in the diet of rabbits.

In recent years, Gasco et al. [18, 19, 20], Dalle Zotte et al. [13] and Martins et al. [30] have demonstrated that oil obtained from black soldier fly (*Hermetia illucens*) and mealworm (*Tenebrio molitor*) can be used in rabbit feed.

Positive results of preliminary research by Gasco et al. [18] on the use of insect oils in rabbit feed prompted further research on this issue. Gasco et al. [20] conducted extensive research aimed at assessing the impact of replacing soybean oil with two types of insect fats, extracted from black soldier fly and mealworm larvae, on growth, nutrient digestibility, blood parameters and the health status of growing rabbits. They found no differences in these performance parameters between the control group and the experimental groups. The addition of insect fats did not affect nutrient digestibility coefficients, gastrointestinal morphometric parameters, or the histopathology of internal organs. In another study, Gasco et al. [19] assessed the impact of the same insect oils in the diet of rabbits on the quality of their meat. They found that the addition of insect fat did not affect the carcass characteristics, meat quality parameters or consumer acceptance of the cooked meat, while there was a beneficial change in the profile of selected fatty acids.

Martins et al. [30] studied the effect of two levels of fat from black soldier fly larvae (*Hermetia illucens* L.) or extruded linseed in the diet of growing rabbits on growth and nutrient digestibility, while Dalle Zotte et al. [13] investigated the possibility of replacing extruded linseed with fat from black soldier fly larvae. The authors concluded that insect fat can be considered an alternative source of lipids in the diet of growing meat rabbits. Similar performance results were obtained in animals fed diets with the addition of linseed.

Studies on feeding rabbits diets containing insects have been conducted in Poland as well. Their results are presented in papers that have been accepted for publication, and preliminary results are available in the form of conference reports [21, 27, 28].

Newton et al. [32] conducted research on the use of black soldier fly (*Hermetia illucens* L.) larvae meal in the diet of growing pigs as early as the last century. It seemed particularly valuable due to its high content of amino acids, lipids and calcium. Diets containing this meal were as palatable to pigs as those based on soybean meal. However, due to the relative deficiency of methionine + cystine and threonine, these amino acids had to be included to obtain a balanced diet.

Subsequently, in the 1990s, Ni and Tang [34] studied the possibility of using silkworm pupae in the diet of piglets. In the 21st century, Newton et al. [33] attempted to replace 50% or 100% of dried blood plasma used in the diet of early weaned piglets to increase immunity with dried black soldier fly (*Hermetia illucens* L.) meal, believed to have similar properties. When this feed was not supplemented with amino acids, only 50% replacement resulted in 4% higher weight gain, with 9% lower feed consumption. In the case of 100% replacement of dried blood plasma with black soldier fly meal, the results were lower by 3% and 13%, respectively, compared to the control group.

Xinghao et al. [56] conducted an experiment to study the effect of mealworm (*Tenebrio molitor*) larvae as a feed supplement for weaned pigs on growth, nutrient digestibility and blood profile. Weight gain was shown to be associated with the share of larvae in the diet. Nitrogen retention and digestibility of dry matter and crude protein increased linearly with the amount of insects in the diet. Reduced urea nitrogen levels were observed in the blood profile results. There were no significant differences in IgA and IgG levels resulting from the diet variations.

Spranghers et al. [49], in a study on pigs whose diet included black soldier fly larvae, found that its fat, specifically lauric acid (C12:0), exerted an antimicrobial effect, which may be an important added value enabling a reduction in the amount of antibiotics used in livestock farming. Meal and oil from most insect larvae are a rich source of this acid.

Yoo et al. [58], in one of the latest papers describing research on the use of insects in pig feeding, showed that the addition of mealworm (*Tenebrio molitor*) larvae to diets improves the digestibility of nutrients and amino acids. The authors found that this larva is a valuable source of protein and can constitute up to 10% of compound feed for growing pigs.

It can be concluded from the presented papers on the use of various insects in the diet of poultry, rabbits and pigs that positive results have been obtained in most cases. Thus, the use of insects in animal feed would not only help reduce the global protein deficiency, but would also help reduce the volume of waste. Additional arguments in favour of insect breeding for feed purposes are its simplicity, the high fecundity and short life cycle of insects, the large number of eggs laid, the small area needed for breeding, and low production costs. Moreover, waste from insect production is easily managed as a natural fertilizer. The use of insect protein in feed to supplement traditional plant sources can also contribute to an increase in the area of arable land for crops for direct human consumption, which would improve overall food security.

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