# INSECTS AS POULTRY FEED

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## INSECTS AS POULTRY FEED

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### Abstract

The consumption of poultry meat and eggs is expected to increase considerably in the nearest future, which increases the demand for poultry feed ingredients to support a sustainable intensive production. Moreover, the constant improvement of the genetic potential of poultry has resulted in an increased density of the diets, which limits the inclusion of low quality feed compounds. Therefore, the feed industry needs new sources of highly digestible protein with a desirable amino acid composition to substitute other valuable limited protein sources of animal origin such as fishmeal. The phylum of insects includes the largest species variety in the world and suitable species providing high protein and high sulphur containing amino acid concentrations have been identified which can be successfully exploited as feed items for poultry. The aim of this paper is to review the state of the art on the use of insect protein in poultry nutrition and the possibilities of insect mass production for the feed industry. Although, legislative barriers for the inclusion of insect meals still exist, there is no doubt that insects have an enormous potential as feed item for poultry.

### Introduction

The requirement for valuable protein sources of a continuously growing world population and the simultaneously decreasing areas suitable for agricultural production present a serious global challenge. In this context, the global demand for poultry meat and eggs is expected to increase significantly in the future, which is due to the facts that these products have a very high nutritive value, they are relatively cheap and no religious issues are connected to their consumption. Further, compared to other livestock, the production of poultry is considered to be relatively environmentally friendly having a significantly lower $CO_2$ footprint. An increasing intensive poultry production requires increasing amounts of protein to cover the amino acid requirements of the bird for maintenance, plumage development, growth and egg production. Currently available vegetable protein sources for poultry are extraction meals of soya beans, rape seed, legumes, and maize gluten. However, the amino acid composition of plant proteins for poultry is inferior to that of animal based proteins, specifically with respect to their content of essential sulphur containing amino acid in particular methionine. Therefore, fish meal is still used to quite an extend in poultry diets. However, due to overfishing, fish meal has become a very limited resource which is reflected by increasing marked prices over the last decades. Alternative protein sources of comparable value are therefore urgently needed in order to make poultry production a sustainable production form in the future. In this connection, the potential of insect protein in poultry diets has attracted much attention. Chickens with access to outdoor area pick up insects at all life stages and eat them with great pleasure, which indicates that they are evolutionary adapted to insects as natural part of their menu. Therefore, it is seems reasonable to consider the inclusion of insect proteins as raw material to be used in commercial feed manufacturing and to develop intensive farming systems for a new six-legged livestock. In order to ensure a cost effective insect based protein production, the ideal insect candidate should have a short reproduction cycle and should be nutritious providing high concentrations of protein and sulphur containing amino acids. In order to guarantee a constant insect supply, the ideal insect candidate should further be easy to rear in intensive rearing sites.

### Nutrient composition of insects

Insects at all life stages are rich sources of animal protein. Until now, the main research efforts have focussed on the larvae of the Black soldier fly (*Hermetia illucens*), the maggot and pupae of the housefly (*Musca domestica*), the larvae of the mealworm (*Tenebrio molitor*), and insect families belonging to the order Orthoptera including locusts, grasshoppers, crickets and katylids. However, insects of the order Blattodea, like American, German, and Asian cockroach are also interesting candidates. A comprehensive review on the nutrient content of different insects and insect meals including larvae of the Black soldier fly, meals based on housefly maggot meal and pupae meal, mealworms, as well as meals based on locusts, grasshoppers and crickets and silkworm pupae meal is given by Makkar et al. (2014) and Sánchez-Muros et al. (2014).

As shown in Table 1 and 2, insects are a rich source of protein, essential amino acids and fat. The protein content of insect meals varies considerably from below 40% to over 60% even when the meals are based on the same insect species (Table 2). The same holds true for the fat content. However, it is important to note that insect meals compared to fishmeal contain lower concentration of methionine, which has to be considered when formulating diets based on insect proteins. Further, the calcium concentration is usually lower than that of fish meal. Larvae of the Black soldier fly do however provide substantially more calcium than other insects (Table 2). The nutrient concentration of insects depends on the life stage of the insect, the rearing conditions and the composition of the growth media used for insect production. For instance, house fly larvae grown on chicken manure had a lower dry matter content, but a higher methionine content per kg dry matter as compared to larvae grown on a medium providing wheat bran, alfalfa, malt and dried yeast (Engberg et al., unpublished). Mealworm larvae prefer protein based diets rather than starch based diets and they appreciate the inclusion of yeast. The feed conversion ratio of mealworms fed 11.9% crude protein was 6.05 kg/kg and improved significantly to 3.04 kg/kg when feed with a crude protein of 32.7%, was fed. No significant change in protein concentration of the mealworm meal was observed (van Broekhoven et al., 2015). However, the fat content of mealworms fed low protein diets was significantly lower as compared to high protein diets (18.9 *vs* 26.3 %). The live insects contain an average of 30% dry matter, therefore the processing parameters of the insect meal are essential to obtain high quality raw material, which can be used at commercial feed milling operations. For today in the available literature, there are no studies describing the effect of processing on insect protein quality. However, crude protein and crude fat are the main nutrients in dried insect meal. Therefore, similarly to other meals of animal origin, oxidation processes and microbial deterioration during storage (Awoniyi et al., 2004) determine the shelf life quality, and should be taken into consideration.

**Insect protein in poultry production**

For a summary of poultry feeding trials involving diets containing different insect meals, the reader is referred to Makkar et al. (2014) and Sánchez–Muros et al. (2014). Most of the published trials have been carried out with broilers fed housefly larvae meal. The results showed that housefly larvae can be added at approximate dietary levels of 25% (Pretorius, 2011) without any negative effect on weight gain, feed intake and feed efficiency. This suggests that maggot meal can efficiently replace other protein sources, e.g. soy bean meal, fish meal and groundnut cake. With respect to the metabolizable energy (ME) value of maggot meal, only limited data are available, however values of 17.9 MJ/kg DM (Zuidhof et al., 2003) for turkey poults and 14.2 MJ/kg DM (Pretorius, 2011) for broilers have been reported. Due to variations in fat and "fibre"/chitin content of maggot meal, the ME values vary considerably. Both authors observed a high total tract amino acid digestibility (95% and 91%, respectively). Feeding maggot meal at the expense of fish meal at dietary concentrations of 16 % to young pullets in the period from 1- 56 days, did not negatively influence growth and feed intake of the birds (Engberg et al., unpublished).

The feeding of Black soldier fly larvae as a substitute for soymeal resulted in a similar weight gain but a lower feed intake as compared to control indicating an improved feed conversion (Makkar et al. (2014).

High concentrations of chitin present in the exoskeleton of insects influence feed intake negatively and interfere with the use of protein (Longvah et al., 2011). Although chickens have been shown to produce chitinase in the proventriculus and hepatocytes (Suzuki et al., 2002), the digestibility of chitin seems to be limited (Hossain and Blair, 2007), particularly in young birds (Ijaiya and Eko, 2009). Whether chitin may be a substrate for microbial fermentation and therefore may have a positive effect on microbial balance in the gastrointestinal tract similar to a probiotic is at the moment a matter of speculation.

Another interesting aspect of insects considered for poultry feed, is their content of antimicrobial peptides which are highly abundant in several species. In recent studies (Józefiak, unpublished), we used relatively small dietary inclusion levels (up to 0.2%) of low temperature (50$^0$C) dried full fat meals from *Tenebrio molitor, Hermetia illucens* and *Shelfordella lateralis* and observed an improvement of the body weight gain in broilers, when *Shelfordella lateralis* meal was fed. These results may be explained by antimicrobial effects on bacterial populations in the ileum. In contrast, even low inclusion levels of *Hermetia illucens* full-fat meal impaired broiler performance. It may be speculated that the dietary inclusion of *Shelfordella lateralis* meal rich in antimicrobial peptides (defensin) could have beneficial effects on poultry health and welfare. Although the feeding of fresh larvae to poultry includes potential risks primarily in relation to feed hygiene, in particular when organic waste products or even manure is used as medium for larvae growth, there is no doubt that chicken really enjoy the consumption of fresh larvae. In line with this, the supplementation of living maggots as a supplement on top of a balanced diet for young pullets significantly reduced the fearfulness of the birds (Engberg et al., unpublished).

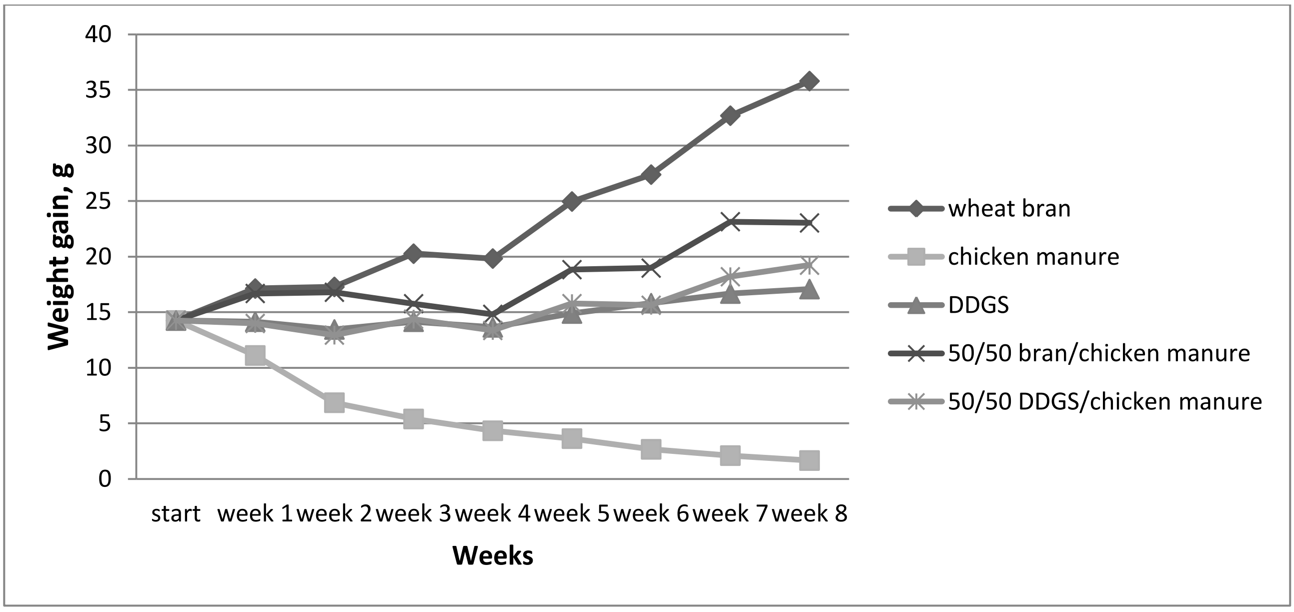
**Nutritional requirements of insects**

Until now, the main research efforts have focussed on the larvae of the Black soldier fly, the maggot and pupae of the housefly, the larvae of the mealworm and insect families belonging to the order Orthoptera including locusts, grasshoppers, crickets and katylids. However, insects of the order Blattodea, like American, German, and Asian cockroach are also interesting candidates. Of special interest is their robustness and ability to grow under extreme conditions (low oxygen, no lighting, high stocking density) as well as their high nutritive value (Table 1and 2). For instance Orthoptera need relatively high amounts of dietary calcium while larvae of the mealworm grow without any calcium supplementation. For today no nutritional recommendations for the different insects exist, but it is obvious that there is a huge variation in the nutrient requirements of different insect species.

The ability of house fly larvae and Black solder fly larvae to feed on organic waste material Čičkova, et al., 2015) including manure (Newton et al., 2005; Zhu et al., 2015); with high moisture content (60-80%) and convert it to valuable insect protein. This sounds immediately attractive because the production of these larvae can be used as a biological tool to solve environmental problems. Black soldier fly larvae can reduce the accumulation of poultry manure by 50% and more in the process Newton et al., 2005). Moreover, the feeding of larvae reduce the available phosphorous in the manure by 61-70% and nitrogen by 30-50% (Makkar et al., 2014). A further advantage of larvae is their ability to reduce bacterial growth in the manure which consequently results in a reduced odour development and the growth suppression of significant pathogens, e.g. Salmonella (Erickson et al., 2004). As a further co-product, the waste residue of manure can be recycled and used as fertilizer. Even though fly larvae are capable of utilizing animal waste product, e.g. manure and slaughter house offal, it may be doubted whether these feed items will be approved in the diets for a six-legged livestock and may give rise to biosecurity issues. However, fly larvae particularly the Black soldier fly can also easily grow on plant material. In contrast to fly larvae, mealworms and members of the Orthoptera are unable to utilize chicken manure even when dried (FIG.1) and prefer feeds of plant origin.

The great advantage of insect production is that no additional drinking water has to be applied. As compared to other livestock species, insects utilize water very effectively and in most cases the feed is the main source of water. As the feed supplies both nutrients and water, feed optimization is a very important part of insect production and should be addressed in future research. In our laboratory, work is going on to identify different substrates that are preferred by different insects. In a choice feeding test it was clearly shown that mealworms prefer different roughages rather than wheat middlings or DDGS. However, we are only at the beginning to understand the special requirements of different insect species under intensive production conditions and much work has to be done to optimize the diets to support their optimal performance and their nutrient composition.

**Figure 1** Weight gain (g) of mealworm larvae fed on different media (88% dry matter)



**Intensive insect production**

Considering insects as a new six-legged livestock, the prerequisite for any commercial production is knowledge on optimal housing conditions (temperature, humidity and ventilation), and feeding both regarding feed composition and structure. Further, it is important to gain knowledge of insect diseases and biosecurity standards for this production form. In contrast to most of the livestock species (excluding fish), insects can be produced in 3D dimension systems, which allows a very effective usage of the buildings. Taking the life cycle and growth rate of insects into consideration, the most effective are larvae. It is for instance possible to produce more than 180 kg of live weight of Black soldier fly larvae in 42 days from 1m$^2$ whereas only 30 kg of adult crickets can be produced on the same area. Finally insects are capable to utilize some poor quality raw materials as by-products from food industry for example apple or potato pulps.

The growth rate as well as feed utilization is highly depended on temperature, which for most insects is optimal in the range of 27-30$^0$C. Insects are durable to temperature changes for instance for mealworms optimal rearing temperature is 28$^0$C but they easily survive -15$^0$C for 48h. However under high humidity conditions (>70%) they die very quickly.

Another important issue of insect production is farm biosecurity. Due to size and activity of invertebrates, a very efficient control of the buildings has to be applied. For instance, the usage of plastic nets is effective in the production of Black soldier flies but not in cockroach or cricket rearing. The latter species can easily force most plastic materials. Therefore aluminium or copper nets should be used. Finally intensive insect production should also consider invasive species, which can interfere with the natural environment. This is why insect farming should be considered as “all in all out” system with a separate hatching-brooding area.

**Barriers for the inclusion of insect protein in poultry feed**

There is no doubt that insect meals from a nutritional perspective are suitable for the feeding of poultry. However, a barrier for the inclusion of insects in feed for livestock is the present EU legislation (Regulation (EC) No. 1069/2009), where insect meals are defined as processed animal protein (PAP). Insects and other invertebrates are classified as Category 3 material (fit but not intended for human food chains). As such, they are suitable as feed for livestock in particular for fish, poultry and pigs. However, despite Regulation (EC) No. 1069/2009, Regulation (EC) No. 999/2001 (“BSE” regulation) prohibits the feeding of farmed animals with PAPs, with the exception of hydrolysed proteins. The feeding of insect meals to aquaculture species is going to be allowed and a re-authorization of these PAPs for pig and poultry feed is expected in the near future.

At the moment, a significant obstacle for the use of insects in animal feed is the limited quantity of produced insects in particular shortcomings in breeding, which does not guarantee a constant supply. The prices for insects and insect meals are presently very high, and cannot compete with other protein sources in this respect. To overcome this problem, the identification of the most suitable insect species giving rise to a cost efficient protein production at an industrial scale is a prerequisite. For mass production, it is necessary to develop automated process technologies for the rearing, harvest and post-harvest procedures, which certainly include the monitoring of product safety and quality (Rumpold and Schlüter, 2013).

The general acceptance of the inclusion of insects in animal feed has been frequently discussed to be a barrier. However, in a recent study from Belgium, cross sectional data were collected among farmers, agriculture sector stakeholders and citizens (Verbeke et al., 2015). The results of this study indicate a broad acceptance. The perceived benefits such as improved sustainability of livestock production, lower dependence on imported protein sources and lower environmental impact, outweighed the perceived risks, such as microbiological contamination, chemical residues in the food chain and lower consumer acceptance of animal products.

At the moment, significant knowledge gaps in the field of insect production exist, particularly in Europe, where insects are not considered as traditional food item (Vantomme et al., 2012, Van der Huis et al., 2013, Veldkamp et al., 2012). However, most signals seem to be set at green for the use of insect proteins in animal feed, so it is all about pulling on the work gloves.

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Table 1. Amino acid composition of different insect and fish meal

| Amino acid | Mealworm (*Tenebrio molitor*) Larvae | Tropical house cricket (*Gryllodes silligatus*) Subimago | Field cricket (*Gryllus assimilis*) Imago | Black soldier fly (*Hermetia illucens*) Larvae | Turkish cockroach (*Shelfordella lateralis*) Subimago | Housefly (*Musca domestica*) Larvae | Fish meal |
|---|---|---|---|---|---|---|---|
| % of crude protein | | | | | | | |
| Histidine | 2.7 | 2.2 | 2.1 | 2.6 | 2.5 | 2.8 | 2.6 |
| Arginine | 4.5 | 5.7 | 5.8 | 4.8 | 5.6 | 4.9 | 5.8 |
| Threonine | 3.6 | 3.5 | 3.3 | 3.6 | 3.3 | 3.3 | 4.3 |
| Tyrosine | 5.4 | 4.2 | 4.5 | 6.0 | 5.6 | 5.1 | 3.1 |
| Valine | 5.9 | 5.2 | 5.3 | 5.6 | 5.1 | 4.4 | 4.8 |
| Methionine | 1.2 | 1.6 | 1.2 | 1.4 | 1.3 | 2.2 | 2.9 |
| Cysteine | 0.6 | 0.9 | 0.5 | 0.7 | 0.7 | 0.4 | 1.2 |
| Isoleucine | 4.0 | 3.7 | 3.4 | 4.0 | 3.1 | 3.2 | 4.0 |
| Leucine | 6.9 | 6.9 | 6.6 | 6.6 | 5.8 | 5.7 | 7.4 |
| Phenylalanine | 3.2 | 3.1 | 2.9 | 3.8 | 3.0 | 5.0 | 3.6 |
| Lysine | 4.9 | 5.3 | 5.0 | 5.6 | 4.9 | 6.9 | 7.8 |
| Tryptophan | 1.0 | 0.9 | 0.7 | 1.1 | 0.8 | 3.2 | 1.2 |
| Total | 43.9 | 43.2 | 41.3 | 45.8 | 41.7 | 47.1 | 48.7 |
| % relative to lysine | | | | | | | |
| Lysine | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Histidine | 55 | 42 | 42 | 46 | 51 | 41 | 33 |
| Arginine | 92 | 108 | 116 | 86 | 114 | 71 | 74 |
| Threonine | 73 | 66 | 66 | 64 | 67 | 48 | 55 |
| Tyrosine | 110 | 79 | 90 | 107 | 114 | 74 | 40 |
| Valine | 120 | 98 | 106 | 100 | 104 | 64 | 62 |
| Methionine | 24 | 30 | 24 | 25 | 27 | 32 | 37 |
| Cysteine | 12 | 17 | 10 | 13 | 14 | 6 | 15 |
| Isoleucine | 82 | 70 | 68 | 71 | 63 | 46 | 51 |
| Leucine | 141 | 130 | 132 | 118 | 118 | 83 | 95 |
| Phenylalanine | 65 | 58 | 58 | 68 | 61 | 72 | 46 |
| Tryptophan | 20 | 17 | 15 | 20 | 17 | 46 | 15 |

Table 2 Nutrient composition of different insect meals

| | Field cricket (*Gryllus assimilis*) | | Housefly (*Musca domestica*) | | Black soldier fly (*Hermetia illucens*) | Mealworm (*Tenebrio molitor*) | Turkestan cockroach (*Blatta lateralis*) |
|---|---|---|---|---|---|---|---|
| | Imago | Subimago | Pupae | Larvae | Larvae | Larvae | Nymph |
| **Item** | | | | | | | |
| *per kg DM* | | | | | | | |
| Gross energy, MJ | 21.5 | 19.3 | 20.1 | 20-24 | 22.1 | 26.8-27.3 | - |
| Crude fibre, g | 70 | 94 | 157 | 16 - 86 | 70 | 51-88 | 86-89 |
| Ash, g | 64 | 54 | 55-98 | 31-173 | 146-284 | 10-45 | 46-54 |
| Phosphorus | 8.0 | 8.6 | - | 9.2-24.0 | 6.4-15.0 | 4.4-14.2 | 0.6-0.7 |
| Calcium | 9.9 | 3.1 | - | 3.1-8.0 | 50.0-86.0 | 0.3-6.2 | 0.2 |
| Crude protein, g | 564 | 638 | 630-762 | 380-604 | 411-450 | 451-603 | 543-734 |
| Crude fat, g | 238 | 168 | 144-161 | 90-260 | 150-350 | 250-431 | 176-261 |
| *Amino acids per16 g N* | | | | | | | |
| Glycine, g | 3.0 | 2.7 | 3.9-4.3 | 3.7-5.1 | 5.1 | 3.9-5.6 | 4.6-4.8 |
| Arginine, g | 3.7 | 3.3 | 4.2-5.9 | 3.7-5.8 | 4.8-8.0 | 3.8-5.6 | 3.8-5.6 |
| Threonine, g | 2.1 | 1.9 | 3.0-3.4 | 2.0-4.4 | 1.3-4.8 | 3.5-4.4 | 2.5-3.3 |
| Valine, g | 3.4 | 3.0 | 3.4-4.6 | 1.3-5.1 | 5.6-9.1 | 5.5-6.6 | 4.4-5.1 |
| Methionine, g | 0.8 | 0.8 | 1.5-2.6 | 1.3-4.6 | 1.4-2.4 | 1.1-2.0 | 1.1-1.2 |
| Cysteine, g | - | - | 0.4 | 0.5 - 1.0 | 0.1 | 0.8 - 0.9 | - |
| Leucine, g | 4.2 | 3.6 | 4.9-5.4 | 4.5-7.8 | 6.6-8.4 | 6.7-10.6 | 4.7-5.8 |
| Lysine, g | 3.2 | 2.9 | 4.8-6.5 | 5.0-8.2 | 5.5-8.0 | 4.6-6.1 | 4.0-4.9 |
| *Fatty acids per kg fat* | | | | | | | |
| SFAs, g | 351 | 352 | 476 | 417 | 749 | 229-334 | 28.7 |
| MUFAs, g | 298 | 261 | 307 | 314 | 155 | 407-536 | 46.3-50.2 |
| PUFAs, g | 336 | 369 | 291 | 399 | 74 | 254-323 | 138-219 |
| Total Omega 3, g | 22 | 17 | - | - | 2 | 2-4 | 1-11 |
| Total Omega 6, g | 314 | 352 | - | - | 23 | 81-93 | 35-207 |