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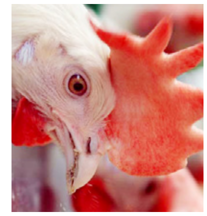
Insects: a protein-rich feed ingredient in pig and poultry diets



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Implications

- The use of insects as a sustainable protein-rich feed ingredient in pig and poultry diets is technically feasible. Insects can turn low-grade biowaste into proteins.
- The amino acid profile of yellow mealworm, common housefly, and black soldier fly is close to the profile of soybean meal with methionine or methionine + cystine, which are generally the most limiting essential amino acids for growing pigs and broilers. Arginine can also become a limiting essential amino acid for broilers fed housefly pupae and mealworm.
- Additional research is recommended on digestibility of (processed) insects, inclusion levels in poultry and pig diets, functional properties, safety when using biowaste as a rearing substrate, extraction of nutrients, shelf life, and use of left-over substrates and residue products of insects.
- To compete with conventional protein sources and become an interesting link in the animal feed chain to fulfil the globally increasing demand for protein, cost price of insect production and processing should be further reduced.

Key words: alternative protein, economics, feasibility, monogastric, nutritional value

Introduction

Insects have been proposed as a high quality, efficient and sustainable alternative protein source. Using insects as a protein source can contribute to global food security via feed or as a direct food source for humans. In 2011, the world compound feed production was an estimated 870 million tonnes, and the turnover of global commercial feed manufacturing generated an estimated annual turnover and sales value equivalent to US$370 billion worldwide (IFIF, 2014). The UN Food and Agricultural Organization (**FAO**) estimates that the world will have to produce ca. 70% more food by 2050. Concerning animal protein production, the International Feed Industry Federation (**IFIF**) believes that the production of meat (poultry, swine, and beef) will even double. This poses severe challenges to the global capacity to provide enough animal feed. Currently, important protein ingredients for animal feed are fish meal, processed animal proteins, and soybean meal. However, in the European Union, the use of processed animal proteins in pig and poultry diets is prohibited due to the transmissible spongiform encephalopathy (**TSE**) legislation while globally, the land availability for soya cultivation is limited and marine overexploitation has reduced the abundance of small pelagic forage fish from which fish meal and fish oil are derived. The growing scarcity of resources to produce these increasingly demanded ingredients has doubled prices during the last 5 yr while already representing 60 to 70% of production costs. So, alternative (animal) protein sources for livestock are urgently needed.

Insects are such an alternative animal protein source because they can sustainably be reared on organic side streams and they have a favorable feed conversion efficiency (Veldkamp et al., 2012), likely because they are cold blooded. Insects identified as most promising for industrial production in the Western world are the black soldier fly (*Hermetia illucens*), common housefly (*Musca domestica*), and yellow mealworm (*Tenebrio molitor*). These three species, discussed in this article, are receiving increasing attention especially because they also have the potential to valorize organic waste. Black soldier fly larvae are naturally found in poultry, pig, and cattle manure but can also be grown on organic wastes such as coffee bean pulp, vegetables, catsup, carrion, and fish offal. Common housefly larvae can also grow on poultry, pig, and cattle manure; they have even been reared on municipal organic waste. Only a limited number of organic waste sources have been described in literature for rearing of yellow mealworm. Mealworms have been grown on dried and cooked waste materials from fruits, vegetables, and cereals in various combinations (Ramos-Elorduy et al., 2002). For future utilization of insects as sustainable animal feed ingredients, it is important to grow them from sources that cannot be included directly in feed for pigs or poultry.

Top to bottom: Black soldier fly larvae; common housefly larvae; yellow mealworm.

This review aims to describe the nutritional value and functional properties of the three insect species described above as well as the performance of pigs and poultry when these insects were used as a feed ingredient. Finally, a short overview of some current insect prices and production costs are discussed as well as potential ways to reduce cost prices.

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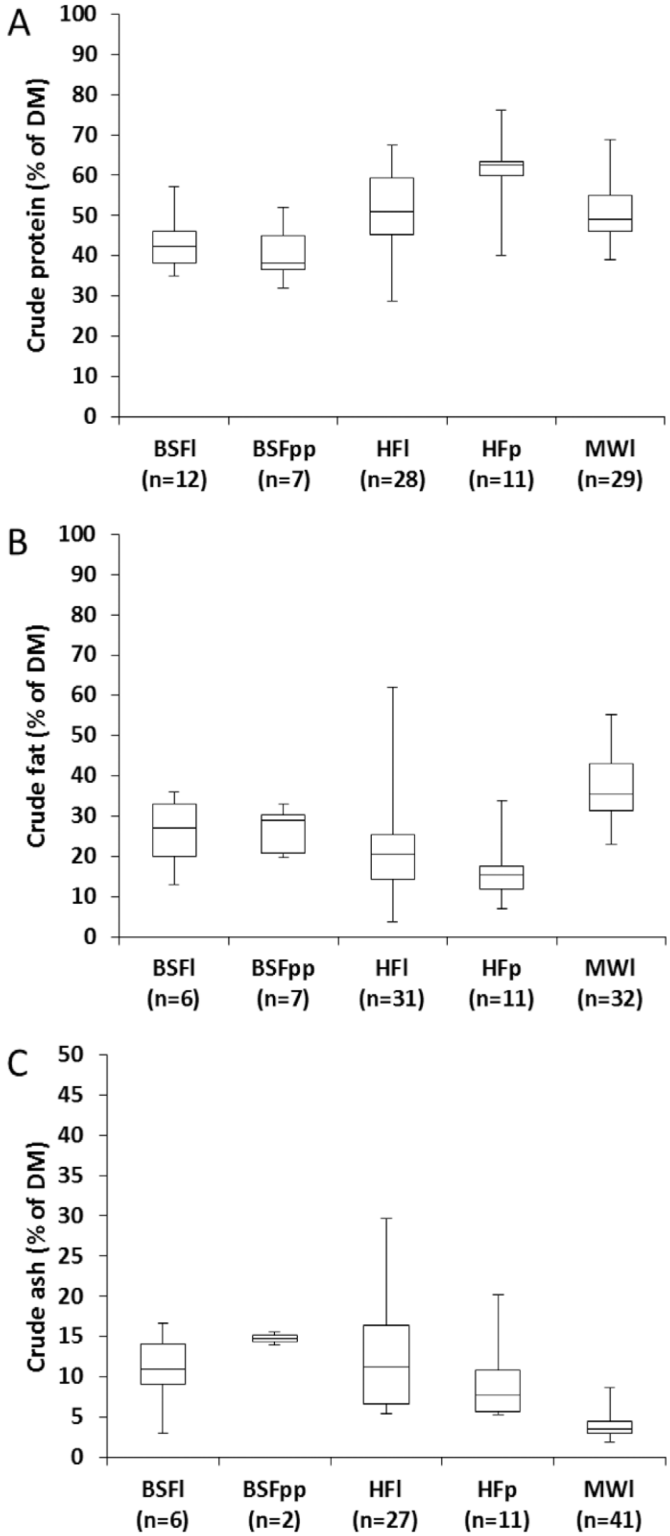

Fig. 1. Variation in crude protein (A), crude fat (B), and crude ash (C) content (percent of DM) in black soldier fly larvae (BSFl) and prepupae (BSFpp), housefly larvae (HFl) and pupae (HFp), and mealworm larvae (MWl) reported in literature. The lower and upper hinges represent the 25th and 75th percentiles of the dataset. The band within the box represents the median, and the whiskers extend to the minimum and maximum values. The n refers to number of data points.

Nutritional Value and Functional Properties of Insects

Nutrient composition and chitin content

The crude protein content varied considerably across insect species and life stages but also within insect species and life stages (Fig. 1A). Growing conditions and sample preparation (e.g., insufficient removal of growing substrates) contribute to the observed variation within insect species and life stage. The highest median crude protein content was found for the common housefly pupae [62.5% of dry matter (**DM**)] and the lowest for the black soldier fly larvae (42.3% of DM) and prepupae (38.1% of DM). Yellow mealworm larvae and housefly larvae had similar crude protein contents (median 49.1 and 50.8% of DM). The main protein source used in pig and poultry feed, soybean meal, has a crude protein content of 49 to 56% DM (CVB, 2007). The soybean meal is, however, the by-product of oil extraction and, consequently, contains only 3% crude fat on a DM basis (CVB, 2007). Defatting insects would also result in meals with greater protein values, likely exceeding those in soybean meals.

The nutritional value of insect proteins was evaluated using data available in the literature 1) by expressing amino acid profiles described in literature as percentage of lysine, 2) by calculation of the essential amino acid index (**EAAI**) (Smith, 2010), and 3) by calculation of the chemical score (**CS**) (Rao et al., 1959). In the present article, requirements for growing pigs with a bodyweight of 3 to 5 kg (NRC, 1998) and for broilers of 0 to 3 wk old (NRC, 1994) were used for calculations of EAAI and CS. The amino acid profiles, EAAI, and the mean of the lowest CS values of insects are compared with those of soybean meal as a reference substrate (Table 1).

The EAAI for each insect species and target animal (i.e., pig or poultry) was calculated using the following formula:

$$EAAI = \sqrt[n]{\frac{aa_1}{AA_1} \times \frac{aa_2}{AA_2} \times \frac{\dots}{\dots} \times \frac{aa_n}{AA_n}}$$

with *aa* = the amount of an amino acid in the protein source in percent of crude protein, *AA* = the requirement of the target animal for an amino acid in percent of crude protein, and *n* = the total number of amino acids used in the calculation. The EAAI is a calculation taking into account the ratio between the concentration of each amino acid in the studied protein and the requirement of the target animal for these amino acids. For growing pigs and broiler chickens, the highest EAAI values were found for black soldier fly prepupae and yellow mealworm larvae. The lowest values were found for common housefly pupae, which were also lower than the value for soybean meal (Table 1).

If a diet is inadequate in any essential amino acid, protein synthesis cannot proceed beyond the rate at which that essential amino acid is available. That amino acid is called a limiting amino acid. For CS calculation, each essential amino acid in the protein source (in percent of crude protein) was divided by this amino acid requirement of the target animal (in percent of crude protein) and multiplied by 100. The amino acid with the lowest CS value is the first limiting amino acid. Data reported in Table 1 are the mean of the lowest CS values per insect and stage of life calculated based on data available in the literature. The lowest CS in black soldier fly larvae and prepupae as well as in housefly larvae was for methionine or methionine + cystine in pigs and broilers. In housefly pupae the lowest CS was for threonine in pigs and methionine + cystine and arginine in broilers. The lowest CS in yellow mealworm larvae was generally for methionine or methionine + cystine in pigs and broilers and for arginine in broilers. In the soybean meal, the reference substrate, the lowest CS was also for methionine + cystine in pigs and broilers.

Data on the crude fat content of insects are presented in Fig. 1B. More data points were available for yellow mealworm larvae and common housefly larvae than for the other insect species and life stages. Within these two species and specific life stages, considerable variation in crude fat content was noted. Median crude fat content of common housefly larvae was greater for pupae (20.6 vs. 15.5% of DM) whereas black soldier fly larvae and prepupae showed similar values (27.1 vs. 28.8% of DM).

Information on crude ash content was readily available for yellow mealworm larvae (n = 41) and common housefly larvae (n = 27) but limited for other insects (Fig. 1C). Median crude ash contents of yellow mealworm larvae (3.5% of DM) were less than those for common housefly larvae (11.2% of DM) and pupae (7.7% of DM) and for black soldier fly larvae (11.0% of DM) and prepupae (14.7% of DM).

The exoskeleton of insects contains chitin, a linear polymer of β-(1-4) N-acetyl-D-glucosamine units with a chemical structure that is similar to that of cellulose. Few data are available on the amount of chitin in insects discussed in this review. The chitin content of black soldier fly larvae and yellow mealworm larvae was estimated to be 5.4 and 2.8% of DM, respectively (Finke, 2013). There is, however, currently no internationally accepted and validated procedure to quantify or characterize chitin, which is required to gain more insight in the nutritional properties of chitin in insects.

Digestibility

Little information was found about the nutrient digestibility of the selected insects in pigs and broiler chickens. Only three studies determined apparent fecal digestibility of nutrients. Corn-based diets containing either 25.5% soybean meal or 33.0% dried black soldier fly larvae meal were fed to 5-wk old barrows (initial body weight 8.2 kg) for 10 wk in a crossover design (Newton et al., 1977). Compared with the soybean meal diet, apparent fecal digestibility of crude protein was similar (77.2 vs. 76.0%) and digestibility of crude fat greater for the larvae meal diet (73.0 vs. 83.6%).

Apparent fecal digestibility of dried housefly meal was evaluated in broiler chickens in two studies. Hwangbo et al. (2009) fed 4-wk-old broilers a diet with 30% dried housefly larvae meal or soybean meal for 7 d. Pretorius (2011) fed 3-wk-old broilers a corn meal-based diet containing 50% dried housefly larvae meal or dried housefly pupae meal. Hwangbo et al. (2009) reported very high apparent fecal digestibility of crude protein for housefly larvae compared with Pretorius (2011) (98.5% vs. 69%). The latter study also showed that crude protein fecal digestibility was greater for housefly pupae than for the larvae. Digestibility of most amino acids was in both studies around 90% or greater. Surprisingly, Pretorius (2011) reported considerably greater apparent fecal digestibility values for individual amino acids than for crude protein. There is a need for evaluation of nutrient digestibility of (processed) insects as feed ingredients, which is a prerequisite for formulating insect-containing feeds.

Functional properties

To our knowledge, there is no study on functional properties of insects as feed or food constituents. Insects may produce antimicrobial peptides (Ratcliffe et al., 2014). As black soldier fly larvae and common housefly

Table 1 Amino acid profile (in % of crude protein and in % relative to lysine) and mean essential amino acid index and chemical score of processed and unprocessed insects and soybean meal used as the reference protein source

	BSF		HF		MW	SBM
	larvae	prepupae	larvae	pupae	larvae	
Amino acid	n=5	n=2	n=9	n=5	n=13	CVB, 2007
% of crude protein						
Arginine	5.2	5.1	4.9	4.7	5.8	7.5
Cystine	ND	ND	0.7	0.4	5.8	1.5
Histidine	3.6	3.7	2.8	2.4	3.6	2.7
Isoleucine	4.4	4.5	3.2	3.5	6.7	4.6
Leucine	7.2	6.8	5.7	5.3	10.7	7.7
Lysine	6.5	5.7	6.9	5.5	6.4	6.2
Methionine	1.9	1.7	2.2	2.1	2.1	1.4
Phenylalanine	4.0	3.9	5.0	4.4	5.4	5.2
Threonine	3.3	3.9	3.3	3.2	5.1	3.9
Tryptophan	1.22	ND	3.2	ND	1.6	1.3
Tyrosine	ND	ND	5.1	5.2	7.8	3.7
Valine	6.7	6.1	4.4	4.2	8.2	4.8
Total	44.0	41.4	47.5	40.9	69.0	50.5
% relative to lysine						
Lysine	100	100	100	100	100	100
Arginine	80	90	74	84	88	121
Cystine	ND	ND	10	8	34	24
Histidine	55	64	42	45	67	44
Isoleucine	67	78	49	64	95	74
Leucine	111	119	86	98	168	124
Methionine	29	30	32	38	28	23
Phenylalanine	61	69	74	79	72	84
Threonine	51	67	49	61	86	63
Tryptophan	18	ND	41	ND	34	21
Tyrosine	ND	ND	77	93	120	60
Valine	103	106	65	75	126	77
Essential amino acid index[1]						
Growing pig	1.24	1.43	1.25	1.19	1.72	1.29
Broiler chicken	1.18	1.35	1.18	1.11	1.68	1.23
Chemical score[2]						
Growing pig	78	73	75	88	66	86
Broiler chicken	68	76	64	75	56	64

Abbreviations: BSF = Black soldier fly, HF = Housefly, MW = Mealworm, SBM = soybean meal, ND = not determined.

[1]The EAAI is the adequacy between the concentration of all the essential amino acids in the dietary protein and the requirement of the target animal.

[2]For chemical score each amino acid in the protein source (in % of crude protein) was divided by this amino acid requirement of the target animal (in % of crude protein) and multiplied by 100. The lowest CS was determined for each study and the mean of all the lowest CS values per insect was calculated.

larvae can thrive in manure and organic waste, they likely produce antimicrobial peptides to protect themselves from microbial infections. These peptides might also be functional in pigs or poultry. Furthermore, non-insect chitin or chitin derivatives can enhance the immune response in kelp groupers (*Epinephelus bruneus*) (Harikrishnan et al., 2012) and act as an antibiotic/prebiotic in rats and chickens (Chen et al., 1999, 2002, cited by Khempaka et al., 2011). Potential functional properties (beneficial or detrimental) of insects remain to be investigated.

Performance of Animals Fed Insects as Feed Ingredient

Growing pigs

Black soldier larvae meal was found to be a suitable ingredient in growing pig diets, being especially valuable for its amino acid, lipid, and Ca contents (Makkar et al., 2014). The relative deficiency in methionine + cystine and threonine should be taken into account for the preparation of balanced diets. Dried black soldier fly prepupae meal was fed to early weaned pigs as a replacement (0, 50, or 100%) for dried plasma meal (proportions of dry plasma meal in diets: 5% during phase 1, 2.5% during phase 2, and 0% during phase 3), with or without amino acid supplementation. Performance was slightly better with the 50% replacement diet without amino acid supplementation during phase 1 (+4% gain, +9% feed efficiency). However, full replacement of 5% dried plasma in the diet (phase 1) did not perform as well as the control (overall performance reduced by 3 to 13%). Additional refinement (cuticle removal and rendering) may be necessary to make black soldier fly prepupae meal suitable for early weaned pigs (Newton et al., 2005).

Limited information was found on the use of maggot meal in pig diets. In Thailand, a soybean-based diet supplemented with 10% maggot meal to replace fish meal (isonitrogenous and isocaloric) was fed to weaned pigs. This diet had no negative effect on body weight gain or feed conversion efficiency (Viroje and Malin, 1989).

Broiler chickens

For poultry under intensive rearing conditions, common housefly larvae (maggots) should be used in a dry form. Most trials indicate that partial replacement of fish meal by maggot meal in broiler diets is possible. Inclusion rates greater than 10% in the diet decreased intake and performance, perhaps due to the darker color of the meal, which may be less appealing to chickens (Atteh and Ologbenla, 1993; Bamgbose, 1999). An imbalanced amino acid profile may also explain the negative effects observed when the inclusion levels are greater than 10% (Makkar et al., 2014); methionine supplementation might enhance performance.

Diets containing 5, 10, 15, or 20% maggots were fed to broilers, and effects on growth performance and carcass quality were studied. Feeding diets containing 10 to 15% maggots improved carcass quality and growth performance of broiler chickens (Hwangbo et al., 2009). Awoniyi et al. (2003) conducted a performance study with 3- to 9-wk-old broiler chickens that were fed five isonitrogenous and isocaloric diets in which maggot meal replaced 0, 25, 50, 75 and 100% of 4% fish meal in the diet. The diet with 25% of fish meal protein replaced with maggot meal was the most efficient in terms of average weekly body weight gain and protein efficiency ratio. At 9 wk of age, however, live, dressed, and eviscerated weights as well as relative length, breadth, and weights of the pectoral and gastrocnemius muscles were not significantly influenced by the diets (Awonyi et al., 2003). House fly larvae meal supplementation in a three-phase feeding system significantly increased average broiler live weights at slaughter, total feed intake, cumulative feed intake, and average daily gain when compared with commercial corn-soy oil cake meal diet (Pretorius, 2011). Pretorius (2011) also conducted a performance study with broilers using seven dietary treatments consisting of a commercial diet (corn-soy) and diets supplemented with 10% housefly larvae meal, 10% fish meal, 25% housefly larvae meal, 25% fish meal, 50% housefly larvae meal, and 50% fish meal. The diets were formulated according to nutrient specifications as provided by Ross International (2009), but for the 25 and 50% larvae and fish meal diets, protein supply was greater than the requirement. No significant differences in performance results were observed between a 10% housefly larvae meal and a 10% fish meal supplementation. Broilers fed the 10% larvae meal or 10% fish meal diets had significantly greater breast muscle portions relative to carcass weight than the chicks that received the commercial corn-soy based diet. The 25% housefly larvae meal supplementation significantly improved broiler live weights, feed intake, and cumulative feed intake when compared with the 25% fish meal supplementation diet in the growth phases. Based on these results, it seems that maggot meal could be an inexpensive replacement for fish meal in broiler-chick feeding. Téguia et al. (2002) also concluded that maggot meal could replace fish meal in broiler diets based on technical and economic criteria.

Ramos-Elorduy et al. (2002) reduced the level of inclusion of soybean meal (protein content of 55%) to 31, 26, and 20% of the diet and replaced it by 0, 5, and 10% of dried yellow mealworm, respectively. Sorghum (with 9% protein) represented 61 to 64% of the diet (by weight) and did not differ among the three treatments. Performance results after 15 d showed no significant dif-

2010 piglets in the farrowing pen in the company of Guus and Lian Daamen.

ferences among treatments. These data indicate that the yellow mealworm has the potential to be used as protein source for raising broilers.

Laying hens

In a performance study with 50-wk-old laying hens, all the diets contained whole-cassava root meal (390.2 to 424.6 g/kg) as source of energy with soybean meal and cassava leaf meal (plant protein sources) supplying 50 and 25% of the total dietary protein, respectively. The experimental treatment consisted of fish meal and maggot meal as animal protein sources supplying the remaining 25% of the total dietary protein. In Diet 1, fish meal and maggot meal supplied 25.0 and 0% of dietary animal protein, respectively. They supplied, respectively, 18.75 and 6.25% in Diet 2, 12.50 and 12.50% in Diet 3, 6.25 and 18.75% in Diet 4, and 0 and 25.0% in Diet 5. The results of this experiment indicated that maggot meal can replace fish meal in diets based on cassava roots and leaves; it could replace 50% of the dietary animal protein supplied by fish meal without deleterious effects on egg production and shell strength (Agunbiade et al., 2007).

Laying hens at the feed trough..

Current Prices of Insects

Cost price varies per insect species and insect producers are currently optimizing and upscaling production, which will greatly impact the cost prices. To be competitive, the price of insect protein products has to be about €0.40 per kilogram live weight based on a 35% DM content. The current prices of freeze-dried yellow mealworms for reptiles or ornamental fish is at this moment €3.70/kg (Kreca, The Netherlands, 2014), and high-grade protein meal from black soldier fly larvae for testing purposes is offered on the internet for €20/kg (Protix Biosystems, The Netherlands, 2014). Furthermore, the market price of a commercially available maggot meal is €1.08/kg (AgriProtein, South Africa, 2014). Compared with the most frequently used protein-rich feed ingredients, insect protein is the most competitive with fish meal whose actual price per kilogram is €1.24 and is expected to increase in the near future. The current price for soybean meal (crude protein > 480 g/kg) is approximately €0.57. However, in order to make a good comparison between insects and conventional protein sources, the price has to be adjusted for nutritional value, e.g., on a digestible protein or digestible amino acid basis.

To become competitive, insect producers aim to reduce the cost price. The level of automation/mechanization of the insect rearing companies is generally low, and as a consequence, the labor productivity is low (Veldkamp et al., 2012). Increasing the size of the insect-rearing companies will further increase efficiency and decrease the cost price of insects. Other possibilities to reduce the cost price are (Veldkamp et al., 2012):

- Reduction of feed costs by increasing the efficiency of converting biowaste products
- Reduction of housing costs by increasing the size of insect-rearing companies and efficient use of the buildings, for example, by reducing energy use and improving heat exchange and ventilation
- Increase of productivity by upgrading breeding and rearing methods
- Improvement in efficiency of extraction (insect protein and insect fat)

Besides a reduction in costs, an increase of product value would contribute to the competitiveness of insects. Beneficial functional properties of insects (see above) have the potential to increase the value of insects as feed ingredients. Organic farmers may also be interested in feeding insects to the animals to increase sustainability on their farms. Insects are originally present in the natural habitat of domesticated animals. Therefore, for welfare reasons, whole insects can be fed to animals as a way to change behavioral patterns during the day.

Summary, Actions, and Recommendations

Use of insects as a sustainable protein-rich ingredient in pig and poultry feed is technically feasible. Insects can be reared on low-grade organic waste. It is evident that insects, like other feed ingredients, should be safe for pigs and poultry and result in animal products that are also safe for consumption. The overall variation in nutrient composition (e.g., protein and fat) observed in the literature indicates that insect composition can be engineered using rearing methods.

The ratio of essential amino acids to lysine is important, and the amino acid profile of yellow mealworm, common housefly and black soldier fly is close to the profile of soybean meal used as a reference. The EAAI, an indicator of the adequacy between the concentration of all the essential amino acids in the dietary protein and the requirement of the target animal, is above 1 for the three insects described in this study although this does not give information on the first limiting essential amino acid. Insects have a relatively good amino acid profile, but CS calculations indicate that methionine or methionine + cystine and sometimes arginine are the more frequent limiting essential amino acids for growing pigs and broilers. The feeding value of (processed) insects, in particular nutrient digestibility, should be further evaluated for pigs and poultry in order to obtain accurate matrix values for different insect products for feed formulation. Optimal inclusion levels of insect products in diets for pigs and poultry should also be further evaluated. Most published animal performance data originate from studies conducted in Africa and Asia. Studies in other regions using different pig and poultry husbandry systems are required to further explore the potential of insect ingredients as well as to evaluate the effect on quality of animal products. Potential beneficial functional properties of insect products need to be further investigated, which could create a potential added value for insect protein.

The insect-rearing companies will continue to explore ways to increase production efficiency to reduce the current cost price of insects and to compete with conventional protein sources. Production of insect protein-rich feed ingredients is now rapidly evolving and can be a promising link in the animal feed chain to fulfil the globally increasing demand for protein in a sustainable way.

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