Nutrient composition of insects and their potential application in food and feed in Europe

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With the increasing demand for alternative protein sources for food and feed due to a growing global population and changing food habits, insects and insect proteins have attracted attention in Europe as a hitherto unexploited alternative animal protein source for food and feed. The nutrient compositions, amino acid spectra, and mineral compositions of the three exemplary insect species Acheta domesticus (adult house crickets), Tenebrio molitor (mealworm larvae), and Hermetia illucens (black soldier fly larvae) are compared with the two conventional feed components soy bean meal and fish meal as well as with the human amino acid requirement, and the potential and suitability of edible insects as food and feed is discussed.

Keywords: edible insects, food insects, feed insects, alternative protein source, soy bean replacement, fish meal alternative

WITH THE GROWING NEED FOR alternative protein sources for food and feed due to a rising global population and changing food habits including increased meat consumption, insects have attracted attention in Europe as a hitherto unexploited alternative protein source for food and feed. In general, insects are highly nutritious, rich in protein, micronutrients and energy, have high feed conversion efficiencies, and can be used for the conversion and valorization of organic side-streams (van Huis et al., 2013).

In an overview of the nutrient compositions of numerous edible insects as reported in literature, a large variance of nutrient contents has been found even within the same species. It was suggested that this broad range within the nutrient contents of edible insects was not only due to different determination methods but also to differing developmental stages and insect feed. Generally it was observed that the main components of edible insects are protein and fat (Rumpold and Schlüter, 2013a). However, little is known about the quality of insect proteins.

Therefore, the potential of insects as a prospective replacement for fish meal and soy bean meal in feed as well as a meat replacer in food needs to be assessed.

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Insects as food

Since more than 2 billion people worldwide consume insects on a regular basis (van Huis et al., 2013), the overall suitability of insects as food in general is indisputable. They are generally rich in proteins and fat and provide essential amino acids. This is confirmed in Table 1 in which the human requirement for amino acids

Table 1 Nutrient compositions of adult crickets *Acheta domesticus* (AD) mealworm larvae *Tenebrio molitor* (MW), black soldier fly larvae *Hermetia illucens* (BSF), high protein dehulled soy bean meal (SBM), and fish meal (FM), based on dry matter in relation to requirements for human adults (HR)

	AD[1]	*MW*[1]	*BSF*[2]	*SBM*[3]	*FM*[3]	*HR*[4]
Crude protein [%]	66.6	49.1	45.1	53.5	70.6	
Crude fibre [%]				4.9		
NDF [%]	22.1	15.0	9.8	11.0		
ADF [%]	10.4	6.6	7.7	5.9		
Starch [%]						
Ash [%]	3.6	2.4	9.0	7.2	18.4	
Crude fat [%]	22.1	35.2	36.1	1.8	9.9	
Energy [MJ/kg]	19.0	22.6	21.5	19.7	20.4	
Amino acid content [% protein]						
Alanine	8.8	8.2	7.0	4.3	6.3	
Arginine	6.1	5.2	7.0	7.3	6.2	
Aspartic acid			9.4	11.4	9.1	
Cystine	0.8	0.9	0.6	1.6	0.8	0.6
Glutamic acid	10.5	11.3	11.3	17.9	12.6	
Glycine	5.1	5.6	5.2	4.2	6.4	
Histidine	2.3	3.2	3.4	2.7	2.4	1.5
Isoleucine	4.6	5.0	4.4	4.6	4.2	3.0
Leucine	10.0	10.6	6.9	7.7	7.2	5.9
Lysine	5.4	5.5	6.8	6.3	7.5	4.5
Methionine	1.5	1.3	1.9	1.4	2.7	1.6
Phenylalanine	3.2	3.5	4.4	5.1	3.9	
Proline	5.6	7.0	5.8	5.0	4.2	
Serine	5.0	5.1	4.0	4.6	3.9	
Threonine	3.6	4.2	3.9	3.8	4.1	2.3
Tryptophan	0.6	0.8	1.7	1.4	1.0	0.6
Tyrosine	4.9	7.5	6.9	3.5	3.1	
Phenylalanine + tyrosine	8.1	11.0	11.3	8.6	7.0	3.8
Valine	5.2	5.9	7.4	4.8	4.9	3.9
Mineral content						
Calcium [g/kg]	1.3	0.4	24.1	3.6	43.4	
Phosphorus [g/kg]	7.9	7.5	9.2	7.6	27.9	
Potassium [g/kg]	11.3	9.0	11.7	25.0	8.7	
Sodium [g/kg]	4.4	1.4	2.3	0.1	11.3	
Magnesium [g/kg]	1.1	2.1	4.5	3.4	2.3	
Manganese [mg/kg]	37.3	13.6	159.3	40.0	16.0	
Zinc [mg/kg]	217.9	136.5	144.8	57.0	96.0	
Copper [mg/kg]	20.1	16.0	10.4	18.0	7.0	
Iron [mg/kg]	62.7	54.1	171.6	169.0	367.0	

Note: ADF, acid detergent fibre; NDF, neutral detergent fibre
[1] Finke, 2002; [2] Finke, 2013; [3] Feedipedia website; [4] WHO, 2007

and the amino acid spectra of the three exemplary insect species *Acheta domesticus* (adult house crickets), *Tenebrio molitor* (mealworm larvae), and *Hermetia illucens* (black soldier fly larvae) are given. All three species contain sufficient amounts of the amino acids required for humans as stated by WHO (2007).

However, before insects can be successfully marketed in the European Union (EU), there are several aspects that need to be addressed such as regulatory frameworks, safety and health issues, and consumer acceptance. At present, the marketing of edible insects and insect ingredients is limited to species and their ingredients that have been marketed in the EU and have a history of significant consumption before 15 May 1997 according to the Novel Food legislation (Regulation (EC) No 258/97). Even if there is a long-term history of safe consumption outside of Europe for certain insect species, their safety must be verified in order to be authorized by the Novel Food legislation for marketing. To date, the majority of insects intended for consumption are still collected in the wild (Codex Alimentarius Commission, 2010). Besides aspects concerning overexploitation and biodiversity as well as environmental issues, safe insect rearing under controlled conditions is to be preferred to gathering insects in the wild, to ensure food and feed safety. Therefore, reliable rearing, conservation, and processing methods need to be developed and food safety regulations for edible insects need to be established (Rumpold and Schlüter, 2013b). Consumer acceptance is another barrier that needs to be overcome. Up to now in Europe, entomophagy, the consumption of edible insects, is mostly associated with disgust, dares such as in reality TV shows, spoiled food, and poverty.

Furthermore, the impact of insect consumption on human health needs to be considered. It was discovered that insects have the potential to cause allergic reactions upon consumption just like other arthropods (e.g. crustaceans). For example, in an assessment of the allergenic potency of proteins of the yellow mealworm, *Tenebrio molitor*, allergens such as tropomyosin and arginine kinase have been found and it was indicated that patients allergic to house dust mites and crustaceans might also show allergic cross-reactions to the yellow mealworm (Verhoeckx et al., 2014).

Potential of insects as feed

At present, the application of insects in feed in Europe is hindered by current European legislation, mostly due to the so-called feed ban (Regulation (EC) No 999/2001 on transmissible spongiform encephalopathies; among others amended by Commission Regulation (EU) No 56/2013) that prohibit the use of processed animal proteins (PAP) in feed for farmed animals with the exception of the use of non-ruminant PAPs in feed for aquaculture. In order to legitimize the use of insects as feed, particular safety issues need to be addressed and ecological, economic, and/or nutritional benefits in comparison to traditionally applied feed stuff need to be evaluated. In addition, the potential of insects as a replacement for fish meal and soy bean meal in feed needs to be assessed.

From an ecological point of view, the benefit of insect proteins as feed is debatable when compared with plant proteins. Although insects have higher food conversion efficiencies and lower greenhouse gas emissions than conventional livestock (Oonincx et al., 2010), and could be used to valorize organic waste, they generally cannot compete with the nitrogen efficiency and ecological footprint of plant proteins since plants metabolize CO_2 and emit O_2 and can be fed directly to livestock. However, with regard to fish meal and soy, insects could offer an alternative. Fish meal is produced from by-catch, trimmings, and wild small fish that are not suitable for human consumption. The use of wild fish in particular raises concerns, for example, regarding overfishing and aquatic biodiversity (The Fish Site, 2008). Global fish meal production ranges from 5 to 6 million tonnes per year. Owing to the intensification of aquaculture, especially in Asia, the demand for fish meal is increasing without the corresponding growth potential to supply the increasing demand (see Feedipedia website). The EU is one of the main consumers of fish meal at 1.2 million tonnes per year (including the candidate countries). In 2002, 33 per cent of fish meal was used in aquaculture, 32 per cent as pig feed, and 29 per cent for poultry production in the EU. Between 1997 and 2001 the EU was the fourth largest producer, producing 9 per cent of the world's fish meal and approximately 442,000 tonnes of additional fish meal were imported into the EU each year. The world price of fish meal is mostly dependent on the availability in South America and the demand in the Far East (Oliveira-Goumas, 2004). In December 2013 the price of fish meal was USS$1,800 per tonne. Between December 2004 and December 2013 the price for fish meal increased by 175 per cent (Globefish, 2014), which strongly affects the cost of aquaculture production and leads to the search for alternatives.

Approximately 38 million tonnes of soy beans and soy bean meal are imported into the EU as feed each year. Those imported soy products are usually not sustainably produced and concerns are being voiced with regard to forest clearance for soy cultivation (BMELV, 2012). Therefore, there is also the need to find adequate and sustainable replacements for soy protein in feed as well as for fish meal. Insects could have potential as adequate alternatives to fish and soy bean meal in feed. This would require the sustainable, large-scale production of feed insects in order to meet the demand for insect proteins or insect-based feed at comparable prices in relation to protein quality and performance.

Comparing the protein content of acridids (family of grasshoppers) of 60–66 per cent with conventional protein supplements for feed such as soy bean meal and fish meal, acridids appear to be a superior protein supplement in feed (Anand et al., 2008). This is contradicted by higher values for the protein content of fish meal of 70 per cent (based on dry matter) that have been reported (see Feedipedia website). However, protein contents of up to 77 per cent (based on dry matter) have been observed for the grasshopper *Sphenarium histrio* (Ramos-Elorduy et al., 1998) and protein contents of species of the order Orthoptera (grasshoppers, locusts, crickets) average approximately 61 per cent (based on dry matter) (Rumpold and Schlüter, 2013a) which highlights the high protein content and the potential of orthopterans as a valuable protein source in feed.

Comparing soy bean meal and different cricket meals as rat feed, Finke et al. (1989) observed that house cricket meal was superior to soy bean meal, whereas mormon cricket meal was equivalent and Eastern tent cricket meal was inferior. This supports the potential of orthopterans as an alternative protein source and further illustrates that the choice of insect species is crucial.

Table 1 summarizes the nutrient compositions, amino acid spectra, and mineral contents of the three insect species and of the animal feed soy bean meal and fish meal. Comparing the nutrient contents, the lower protein contents and considerably higher fat contents of the three insect species become obvious. Therefore, a defattening step could be necessary if meals of whole insects were applied in the feed. When comparing the amino acid spectra of the three insects and the two traditional feed components soy bean meal and fish meal, the insects had lower glutamic acid contents especially compared with soy bean meal, lower lysine contents, lower methionine contents especially when compared with fish meal, and lower tryptophan contents, except for black soldier fly larvae. For a thorough assessment of the suitability of insect proteins as feed, more knowledge on their protein quality (e.g. protein digestibility) is required. With regard to mineral composition, the three insect species have lower iron contents, phosphorus contents comparable to soy bean meal but considerably lower than fish meal, and lower magnesium contents except for the black soldier fly larvae which have even higher magnesium contents than soy bean and fish meal. The black soldier fly larvae also have the highest calcium content of the three insects, but not as high as fish meal. Furthermore, all three exemplary insect species have higher zinc contents than soy bean and fish meal. This especially has to be taken into consideration for feed since it has been shown that high dietary zinc influences the intestinal microbiota in weaned piglets (Starke et al., 2014).

Insects as poultry feed

Insects are naturally consumed by wild birds and free-range poultry and thus form an ordinary part of bird diets (Hwangbo et al., 2009). Several investigations regarding the suitability of insects, for example, from the orders Lepidoptera, Diptera, Coleoptera, and Orthoptera, in farmed poultry feed have been undertaken. For example, Ijaiya and Eko (2009) showed that meal consisting of silkworm larvae (*Anaphe infracta*) could be applied for the complete replacement of fish meal in starter broiler chickens in Nigeria without performance or economic loss. They observed an increased protein efficiency ratio and reduced average daily intake with a similar mean daily weight gain and lower feed costs when fish meal was completely replaced by silkworm larvae meal. The higher protein efficiency ratio of the larvae meal was attributed to a better amino acid spectrum, and the reduced daily intake to the higher fibre and fat content of the larvae meal. This was in accordance with a study of the dietary potential of *Cirina forda* (Westwood) larvae as a fish meal replacement in poultry feed. It was shown that a complete replacement of fish meal by caterpillar meal resulted in no significant differences in growth performance of broiler chicks (Oyegoke et al., 2006).

An investigation of the use of up to 15 per cent dried house fly (*Musca domestica*) larvae, together with yellow corn replacing soy bean meal and corn gluten meal in feed formulae for broiler chicks, led to an increased weight gain and to enhanced tryptophan and lysine contents in the breast muscles. The improved performance was attributed to the beneficial nutrient composition, in particular, the amino acid composition of the larvae. The enrichment of amino acids in the chicken meat was explained by the high protein digestibility of the house fly larvae (Hwangbo et al., 2009). Furthermore an inclusion of up to 10 per cent of ground mealworm larvae (*Tenebrio molitor*), replacing soy bean meal in chick feed, resulted in no significant differences in weight gain, feed intake, or feed conversion values and it was concluded that mealworm larvae provide protein quality comparable to soy bean meal and can be utilized as a protein source for broiler feed and a soy bean meal replacement (Ramos-Elorduy et al., 2002).

Up to 15 per cent of fish meal and soy bean meal in a poultry diet could be replaced with cricket meal from the field cricket *Gryllus testaceus* Walker without any adverse effects on weight gain, feed intake or gain/feed ratio of broilers (Wang et al., 2005). It was also suggested that the application of insects in poultry feed has the potential to enhance the meat quality with regard to fatty acid composition. An investigation of free-range broilers fed on grasshoppers, (approximately 60–70 per cent (based on dry matter) of the diet) in comparison with intensively reared broilers fed on a typical maize-soy bean diet, was feasible and showed an increased content of polyunsaturated acid in the chicken meat (Sun et al., 2012).

Although highly dependent on the insect species and its nutrient composition, as well as its amino acid spectrum, it was shown that fish meal can be completely replaced by insect meal and up to 15 per cent of soy bean meal can be replaced by insects in poultry feed.

Insects as fish feed

Fish meal is the prevalent feed and protein source in fish diets. Since the main cost factor in aquaculture is attributed to feed costs, research has been undertaken to develop substitutes for fish meal (and oil). But especially for carnivorous fish, unsuitable amino acid spectra and poor digestibility of vegetable proteins are limiting factors and necessitate supplementation with meat by-products, for example (Naylor et al., 2000). Here insects could function as animal protein sources in fish, feed to supplement vegetable proteins. It is common knowledge that insects are naturally consumed by wild fish, which is exploited by fisherman using insects as bait or mimicking insects by applying fishing methods such as fly fishing.

Several studies have been undertaken to investigate the potential of insects as potential fish meal replacement in fish feed. In agreement with the nutrient compositions in Table 1, insects generally have a higher fat and lower protein content than fish meal (Barroso et al., 2014). In comparison with the amino acid spectrum of fish meal, the three example insect species are lacking in lysine, methionine, glycine, and glutamic acid. This is only partly in accordance with findings made by Barroso et al. (2014) who determined a lack in lysine, threonine, and histidine in an examination of 16 different insect species, including the three species mentioned above, and their potential as a fish meal replacer. However, the majority of the species analysed also lacked in methionine and only dipterans (flies) showed comparable methionine contents.

It was shown that a replacement of 25 per cent of fish meal with meal of the grasshopper *Zonocerus variegatus* L. was feasible, without losses in growth performance or nutrient utilization (Alegbeleye et al., 2012).

Several studies have been undertaken investigating the potential of dipterans – specifically the black soldier fly larvae or prepupae – as a potential ingredient in fish diets as well as a fish meal replacement. For example, Bondari and Sheppard (1981) replaced up to 75 per cent of commercial diets with chopped black soldier fly larvae in the feed of tilapia (*Tilapia aurea*) and channel catfish (*Ictalurus punctatus*) which resulted in similar body weights and total lengths. Additional taste tests revealed that larvae-fed fish had an acceptable taste for the consumer with slightly lower ratings than fish fed the commercial diets. Although the content of fish meal in the commercial diets is unknown, the potential of black soldier fly larvae as fish feed was nonetheless shown. However, this was not observed replacing 10 per cent fish meal with dried meal of black soldier fly larvae in the feed of channel catfish (*Ictalurus punctatus* (Rafinesque)), where larvae meal resulted in slower growth (Bondari and Sheppard, 1987). It was concluded that the growth was also influenced by the culturing systems (cage vs. tank). A feeding trial of juvenile turbot (*Psetta maxima*) for 56 days, where up to 76 per cent of the diet contained meal of the black soldier fly prepupae (*Hermetia illucens*), indicated that the application of *Hermetia* meal in fish feed as a fish meal replacer is feasible but limited based on, among other things, feed intake, growth performance, specific growth rate, feed conversion ratio, and food composition of the turbot (Kroeckel et al., 2012). This was in accordance with results obtained by Stamer et al. (2014) who observed reduced growth rate as well as body weight gain, feed conversion ratio and protein efficiency ratio upon replacing fish meal with 50 and 75 per cent, respectively, of black soldier fly larvae meal in iso-nitrogenous diets of rainbow trout. They concluded that up to 50 per cent of fish meal could be replaced by *Hermetia* meal without considerable losses in body weight gain, food conversion ratio, and protein retention ratio. A sensory analysis of the rainbow trout fillets resulted in no significant preference for one of the three diets (control without larvae meal, 50 per cent *Hermetia* meal, 75 per cent *Hermetia* meal).

A substitution of 25 per cent of fish meal with domestic house fly (*Musca domestica*) pupae and 50 per cent of fish meal with black soldier fly (*Hermetia illucens*) prepupae, based on protein content in diets of rainbow trout (*Oncorhynchus mykiss*), resulted in reduced growth, respectively. However, no adverse effects on growth were observed by a replacement of fish meal with 25 per cent black soldier fly prepupae (based on protein content) after a 9 week feeding trial, which demonstrates the potential of black soldier fly as a partial fish meal replacer. However, the lipid content and composition of the prepupae-fed fish was inferior (St Hilaire et al., 2007b). While the amino acid profiles of dipterans – especially of the black soldier fly prepupae – are similar to fish meal, they have lower levels of omega-3 and omega-6 fatty acids (Barroso et al., 2014).

Rearing black soldier fly larvae on fish offal 24 h before their pupation resulted in higher fat contents (43 per cent higher than larvae fed on cow manure alone) and an enrichment in the three omega-3 fatty acids eicosapentaenoic acid, docosahexaenoic acid, and α-linolenic acid. And it was suggested that fish offal enriched prepupae could function as fish meal as well as fish oil replacer (St Hilaire et al., 2007a). This was in accordance with results obtained by Sealey et al. (2011) where a substitution of 25 and 50 per cent of fish meal with black soldier fly prepupae in the diet of rainbow trout resulted in significantly reduced growth, respectively, whereas no differences in growth had been observed when a substitution of 25 per cent and 50 per cent of fish meal with fish offal enriched black soldier fly prepupae was performed. A sensory analysis by a panel showed no differences in the rainbow trout fed insect-based and normal diets (Sealey et al., 2011). These results indicate that the nutritive value of insect meal could be enhanced, that the lipid composition of the black soldier fly and possibly other insects could be manipulated by targeted feeding shortly before the harvest of the insect, and that the fatty acid profiles of insects most likely reflects the fatty acid composition of their food (Barroso et al., 2014).

It can be concluded that depending on the insect (and fish) species, a partial replacement of fish meal in fish diets is feasible. Comparison of nutrient compositions as well as the results obtained by Sealey et al. (2011) and St Hilaire et al. (2007a) rearing black soldier fly larvae on fish offal before being fed to rainbow trout suggest that further research on insects as fish feed and as a potential fish meal replacer ought to focus not only on the amino acid spectra and protein quality but also on the fat content as well as fatty acid composition of the insects. More research is required including long-term feeding trials and identification of appropriate insect species for use in fish feed.

Summary and conclusions

In general, insects are a valuable alternative protein source for food and could provide humans with the required amino acids. Several barriers need to be overcome, however, before entomophagy will be established in Europe including regulatory frameworks and consumer acceptance.

In addition, insects have shown particular promise as a protein source in feed. It was shown that insects could effectively be utilized as poultry feed. Several studies on the utilization of insects as poultry feed suggest that insects could replace up to 15 per cent of soy bean meal in a poultry diet and that fish meal could be completely replaced by insect meal in poultry feed. Insects examined as poultry feed included caterpillars (Lepidoptera), fly larvae (Diptera), beetle larvae (Coleoptera) and crickets (Orthoptera) which leads to the conclusion that no insect order stands out or excelled and insects in general have potential as an efficient poultry feedstuff.

Concerning fish feed, several feeding trials indicated the potential but also the limitations of insects as a fish meal replacement. In the studies undertaken to assess the potential of insect as fish feed, dipterans and especially the black soldier fly *Hermetia illucens* predominated. It was suggested that the amino acid profile of *Hermetia* was similar to the one of fish meal and therefore had the highest potential as a fish meal replacement. Its application appeared to be limited by its inferior fatty acid composition. It was also shown that this limitation could be diminished by enrichment with omega-3 fatty acids via fish offal.

More extensive research is required for the identification of ideal insect species that are most qualified as feed.

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