Insect proteins—a new source for animal feed

The use of insect larvae to recycle food waste in high-quality protein for livestock and aquaculture feeds is held back largely owing to regulatory hurdles

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More than 1 billion people already suffer from chronic hunger, and the world population is expected to grow from 6.8 billion people to about 9 billion by 2050 [1]. The Food and Agriculture Organization of the United Nations (FAO) anticipates that food requirements will have to increase by between 70 and 100% to both alleviate existing hunger and malnutrition and feed the additional 2 billion people. If even more land and more natural resources are dedicated to food production, this will have devastating consequences for the Earth's remaining biodiversity. Achieving higher yields from the same land area without severely impacting the environment requires a new way of approaching food production, that is a sustainable intensification, which implies a major improvement in recycling available resources and waste. Indeed, there is huge scope for improving recycling: in the European Union alone, about 90 million tons of foods is discarded each year by private households, retailers and the food industry—the fisheries and agriculture sectors are not included in these figures.

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At present, the increasing use of arable land for the production of bioenergy plants,

rather than crop plants, is leading to a serious reduction in available land for food production worldwide. Similarly, livestock production in the western hemisphere is consuming 85% of global soya production to make concentrated animal feeds (including aquaculture diets), precluding the use of that soya for human consumption. The land used for soya production by just the three major global producers (Brazil, the USA and Argentina) is about 90 million hectares. These areas exhibit the well-known effects of monocultured crops including destroyed biodiversity, decreased soil fertility and depleted water resources.

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Another main feed ingredient, especially for aquaculture diets, is fishmeal (Fig 1). Annual production requires 16–17 million tons of fish caught only for that purpose, in addition to approximately 5 million tons of fish trimmings [2]. More than 90% of the resulting fishmeal and fish oil is used to feed fish that are produced in captivity for human consumption. Bearing in mind the ongoing stagnation of the world captive fisheries—significantly more effort must be made each year to sustain yields for human consumption—this is a prime example of a global vicious

circle. As a result, the fishmeal content of aquaculture diets has been constantly reduced in the last years, but in return, the use of soya, cereals and oils has increased considerably. Thus, the dog bites its own tail as the aquaculture feeds are increasingly in direct competition with human nutrition.

One approach to recycling food waste and producing protein-rich feeds for aquaculture and livestock is to use insects as a source of protein. Both the scientific community and the food and feed's industrial sectors have begun to reconsider the use of insects as feedstuff, based on food-waste recycling. This approach actually has even greater potential, as insects could also be a rich source of protein for direct human consumption. So far, however, eating insects is not very popular in the West, despite the fact that humans in other cultures and regions consume about 1900 different insect species. Using insects to feed animals seems to be much more acceptable for consumers [3]. However, although this strategy holds great promise as a sustainable and environmentally friendly way of generating food and feeds from discarded food, it is severely hampered by existing EU legislation, which strictly bans the feeding of K3-food waste (any meat content) to livestock—including insects—and also bans insect meals in animal feeds other than pet-feed, and which has repercussions far beyond Europe.

Academic and industry research has so far focused on five major species or species groups: the common housefly (*Musca domestica*), the black soldier fly (*Hermetia illucens*; Figs 2 and 3), the mealworm

Figure 1. Typical organic trout farm in Switzerland.

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Figure 2. Adult *Hermetia illucens*.

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(*Tenebrio molitor*), locusts (*Locusta migratoria*, *Schistocerca gregaria*, *Oxya spec.*, etc.) and silkworms (*Bombyx mori*, etc.) [3]. The most promising of these in terms of food-waste recycling is the black soldier fly (BSF), *H. illucens*: it is neither a pest nor a disease

vector and its larvae are omnivorous and very robust against insect diseases. Originating from the southern states of the USA, *Hermetia illucens* now occurs worldwide in all tropical, warm and moderate climate zones—obviously distributed by trade and

shipping from continent to continent. Fully grown larvae produce a biomass that contains 40–45% protein with an advantageous amino acid composition (Tables 1 and 2) and up to 35% fat in dry matter, which makes it suitable as a feed supplement for various livestock [4,5]. *Hermetia illucens* and its use for waste reduction have also been extensively studied since the 1970s [6], which have created a solid knowledge base on which to build recycling applications.

Despite this potential, and despite the fact that applied research into transforming organic waste into feed proteins has been going on since the 1970s, industrial-scale methods and technologies are only now being developed. The main reasons for this delay are economic and social factors. In the 1980s and 1990s, fish was a cheap protein source and there seemed to be no need to replace it. Recycling, in particular of organic waste, was also not as popular as it is today. These factors have considerably changed as the price of protein-rich feed bases, such as fishmeal, has multiplied over the past years and recycling is now often mandated and has become popular in many countries. Moreover, new technologies to recycle organic waste, such as biogas plants, were developed during the past 10–15 years. Especially in developing countries, and recently industrialized countries, recycling is now recognized as a sustainable and economic method to deal with waste.

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In addition to food, *H. illucens* larvae could also become a new source for producing biodiesel [7]. Because the fatty acid profile of *Hermetia* meal is suboptimal for feed purposes (Tables 1 and 2), the oil must be extracted from the biomass before it is processed. Insect-based oil is therefore a by-product of insect-meal production, and Chinese researchers have shown that the oil from this extraction meets most of the requirements set by the international standard EN 14214 for biodiesel. Interestingly, the Chinese researchers could document that

Figure 3. Insect larvae as a source for animal feed.

(A) Egg production cages for different strains of adult flies. © FiBL (B) Young larvae of *Hermetia illucens*. © FiBL (C) Larvae L₅ of *H. illucens*, harvestable size. © FiBL (D) Pre-pupae (L₆) of *H. illucens*. © Coop.

bioconversion of complex molecules such as hemicellulose, lignocellulose, cellulose and lignin from rice straw into larval biomass and finally extracted raw oil is possible without elaborate pretreatment via acid hydrolyses and enzymatic hydrolyses. Avoiding these pretreatments was enabled by engaging BSF larvae and an additional premix of bacteria and enzymes on a defined mixture of food waste and rice straw. The raw oil, after petroleum ether extraction, can then be transformed into biodiesel via a two-step esterification/transesterification process. Extraction of the oil fraction from the BSF biomass can also be realized mechanically using modified oil-mill technology, or by using modified fishmeal rendering technology. This might become important in cases where a multiproduct strategy (feed/fuel/chitin) is followed. It might be expected that biofuel production by insect- and microbial-mediated processes will gain greater

importance in the near future; however, there are not yet any large-scale industrial processes for producing insect-diesel.

Research and development projects using *H. illucens* have been started all over the world, including in Africa and Asia. In particular, in tropical and subtropical rural regions, the possibility to produce animal feeds at low costs for small and subsistence farmers is gaining more and more interest. In December 2013, the Swiss Research Institute of Organic Agriculture (FiBL), in cooperation with the University of Ghana and other partners, started a research project that combines waste management, compost research, feed production and aquaculture. The “Insect-based Feed and Fertilizer Production” (IBFFP) via waste transformation for smallholders in Ghana aims to develop practical strategies and technologies to address problems such as

market-waste management and hygienic issues. In addition, it investigates related issues such as income generation for poor rural smallholders, the formulation of insect-based aquaculture feeds, and soil fertility enhancement with accelerated compost production. Socio-economic analysis examines public acceptance and the effectiveness of these new strategies in terms of increasing income and reducing poverty.

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The EU has also begun to explore the potential of insects to produce animal

Table 1. Amino acids profile; feedstock high in carbohydrates.

Amino acids	g/100 g larvae meal
Aspartic acid	6.56
Threonine	2.77
Serine	3.02
Glutamic acid	6.95
Glycine	4.53
Alanine	4.41
Cysteine	0.39
Valine	4.51
Methionine	1.25
Methionine + Cysteine	1.64
Isoleucine	3.15
Leucine	5.07
Tyrosine	4.48
Phenylalanine	2.83
Phenylalanine + Tyrosine	7.31
Histidine	2.08
Lysine	3.63
Arginine	3.33
Proline	4.08

feeds. The EU-cofinanced research project PROteINSECT, together with partners from China and Africa, focuses on safety and quality criteria of insect production processes and products. Environmental impacts and socio-economic performance will also be studied. French academic and industry partners have started another project called DESIRABLE that aims to develop production strategies for different insect meals in the context of biorefinery. DESIRABLE will also focus on the potential use of insects in fish and poultry diets as a substitute for fish-based and soya bean-based meals.

The industrial, large-scale production of fly meals is already being pushed forward worldwide by some companies, the most prominent of which are AgriProtein from South Africa and Enterra from Canada. These companies produce *Hermetia*, *Musca* or *Calliphora* flies on a base of organic wastes with the intention to produce several thousand tons of meal per year. In addition, both companies offer the residues of the insects as fertilizer or soil conditioner. For now, AgriProtein and Enterra serve only non-EU, non-US and local markets, but both companies are planning to franchise with European partners to expand their business

Table 2. Fatty acids profile; feedstock high in carbohydrates; hexane extraction.

Fatty acids Trivial name	International nomenclature	g/100 g fatty acids
Lauric acid	12:0	52.08
Myristic acid	14:0	7.94
Palmitic acid	16:0	10.95
Palmitoleic acid	c9-16:1	2.46
Stearic acid	18:0	1.28
Oleic acid	c9-18:1	13.80
Linoleic acid	c9,c12-18:2	5.74
Arachidonic acid	20:4n-6	0.27
Alpha-linolenic acid	18:3(n-3)	0.81
Eicosapentaenoic acid	20:5n-3	0.12

once the legal constraints for animal-based feed change. Both companies seem to be optimistic about waiting for the EU and USA to relax regulation on insect-based feeds, particularly as they can rely on non-EU and non-US markets for now. AgriProtein also produces insect oil, marketed as Magoil, and some smaller companies in Europe also offer insect meals and insect larvae for the pet-food market.

Among the academic players in this area, the University of Wageningen in the Netherlands has been one of the most important places for research into the use of insects as feeds and for human consumption. In May 2014, more than 600 scientists and professionals from all over the world attended the conference “Insects to feed the world”, organized by Wageningen entomologists, to discuss all aspects and problems of the sector. The greatest concern of all researchers in the field—as discussed at the Wageningen congress in 2014—is to find ways to use existing resources for insect biomass production in order to avoid competition with human nutrition. However, existing legislation in the EU and other parts of Europe hampers sustainable approaches, especially those that make use of recycling food waste. Mainly as a result of the BSE scandal in the 1990s, EU legislation on food-waste recycling and the use of animal by-products is very strict. Regulation (EC) No 1069/2009 (see Sidebar A) states that materials that are not suitable for direct

human consumption must also not be incorporated into the feed chain. They can only be processed into technical or industrial products, provided that the processing follows specific health-related provisions.

Under EU legislation, animal by-products are classified into three risk categories, of which K3, the lowest category, is the one of interest for recycling organic waste. It comprises carcasses, slaughterhouse by-products, other products of animal origin and food made from animals that is no longer suitable for human consumption and that does not bear any risk for human and animal health. Importantly, category K3 also includes any other organic food waste that bears no such risks. However, EU legislation prohibits feeding any K3 materials, including kitchen and food waste, to livestock, and insect larvae are categorized to livestock. Conversely, insect larvae are not allowed to be fed to livestock because they are regarded as secondary products of food-waste usage. There are only a few exemptions that allow the use of insects and insect-based feed in the pet sector and the biorefinery of technical products. In the meantime, the European Food Safety Authority (EFSA) is investigating the issue, and there is some reason to hope that the EU will lift the ban in the next years and will define protocols for safely using non-animal organic waste. However, this will most likely still exclude any food waste containing meat or other animal-based materials.

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Although there is a general feeling of enthusiasm among researchers for the potential of technologies that make use of insects for feed, food and biofuels, many technical and legislative problems remain and there are still economic risks involved in developing this technology. In particular, it is not yet clear whether insect production and insect meal processing can attract investment from the private sector, as their economic viability is mostly untested. Most important in this context is the existing legislation in the EU, which is one of the

Sidebar A: Further reading

EU (2009) Regulation (EC) No 1069/2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Reg. (EC) No 1774/2002 (Animal by-products Regulation) <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:300:0001:0033:EN:PDF>.

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most important and largest markets in the world. Without a legal framework in the EU that clearly defines permissible feedstock for insect larvae and that allows insect meals to be used as feed ingredients, academic and private enterprises will have little incentive

to invest into research, development and production.

Conflict of interest

The author declares that he has no conflict of interest.

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