PROteINSECT

INSECTS AS SUSTAINABLE SOURCES OF PROTEIN

PROteINSECT Consensus Business Case Report

'Determining the contribution that insects can make to addressing the protein deficit in Europe'

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Report produced by Minerva Health & Care Communications Ltd on behalf of PROteINSECT

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This PROteINSECT Consensus Business Case: 'Determining the contribution that insects can make to addressing the protein deficit in Europe' is endorsed by the organisations represented below.

EURL Animal Proteins

European Union Reference Laboratory for animal proteins in feedingstuffs.

Developed in partnership with
Food Standards Agency food.gov.uk

Food Standards Agency

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Waste and Resources Action Programme

The PROteINSECT project partners are:

Food and Environment Research Agency

CABI

Nutrition Sciences N.V.

KU Leuven

Minerva Communications UK

eutema GmbH

GRANTBAIT

Guangdong Entomological Institute

Huazhong Agricultural University Wuhan

Fish for Africa

Institut D'Economie Rurale

Institute of Aquaculture University of Stirling

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Contributors and Methodology

This Consensus Business Case Report has been developed utilising the knowledge and research materials, available for the public domain at the date of publication, provided by PROteINSECT partners through their research undertakings and reports on insects raised on organic waste streams such as food waste and animal manures to supply protein for animal feed. The report does not cover in detail existing markets for insect derived protein.

Additionally, a significant contribution to this Report has been made by the PROteINSECT Key Opinion Leader (KOL) Group from European stakeholders (membership list below). This contribution most notably includes formal representation at the PROteINSECT Round Table meeting 'Safe and sustainable utilisation of protein from insects for animal feed' which took place on Friday 14th November 2014.

The formal representations from this wide-ranging group of stakeholders on state-of-the-art insect protein production, development and utilisation for animal feed based on organic waste substrate highlighted a number of key challenges and barriers which need to be overcome before the introduction of organic waste reared insect protein into animal feed at scale. The identified challenges and barriers are represented in this report.

Contributing members of the PROteINSECT Key Opinion Leaders Group:

Hanover University of Veterinary Medicine
European Reference Laboratory for Animal Proteins (EURL-AP)
European Feed Manufacturers' Federation (FEFAC)
European Aquaculture Technology Innovation Platform (EATiP)
Waste & Resources Action Programme (Wrap)
International Platform of Insects for Food and Feed (IPIFF)
Metro Group (European Supermarket)
World Wildlife Fund (WWF)
European Commission - Directorate General for Health and Food Safety (DG SANTE)
Association of Poultry Processors and Poultry Trade in the EU (a.v.e.c.)
European Aquaculture Society
European Rural Poultry Association
European Food Safety Authority (EFSA)
Food Standards Agency (UK)
Nutreco Skretting

The PROteINSECT project was represented at the meeting by Elaine Fitches (Co-ordinator), Geert Bruggeman, Adrian Charlton and Rhonda Smith with the Secretariat provided by Minerva (Edward Barnes and Rosie Pryor). The meeting was chaired by Emile Frison. The development of this Consensus Business Case Report has been supported by material generated by all PROteINSECT partners.

Executive Summary

This Consensus Business Case Report provides an evidence base (at this point in time) to support the evolution of a positive and receptive platform in Europe for the utilisation of novel insect based proteins in animal feeds. The document provides a 'stepping stone' to the White Paper to be presented by the PROteINSECT project to the European Parliament in late 2015.

The intended audience for the consensus business case is broad; policy and political circles, feed industry, farmers, retailers, researchers, consumer groups and is freely available via the project's website (www.proteinsect.eu).

Headlines from the PROteINSECT Consensus Business Case Report

The Protein Deficit

> Increasing global populations and changing diets have led to the urgent need for additional supplies of protein from sustainable sources for inclusion in animal feed.

Why Insects?

> Insects are rich in protein and are a natural component of the diets of carnivorous fish and free-range poultry. Fly larvae can be reared on a wide range of wastes and by-products and offer a potential way of recovering value from materials that may be disposed of by agriculture and food industries.

Insect Production

> Commercial insect rearing exists both within and outside Europe and many more systems are being developed. PROteINSECT has identified a need for further development of semi-automated systems more suitable for adoption in Europe; however it should be noted that some European producers are already undertaking this work.

Insect Processing

> Of the processing technologies that PROteINSECT has evaluated to date solvent extraction yielded the highest protein yield and concentrations; however there are a number of existing challenges for solvent extraction processing methodology. Industry reports other favourable processing technologies.

Insect Nutritional Properties and Suitability in Animal Diets

> PROteINSECT is addressing the current need for additional scientifically published nutritional quality data to demonstrate the full potential of the use of insect protein for feed.

Insect Safety

PROteINSECT research on the quality and safety of insect protein will provide data for inclusion in the overall evidence base that is needed for regulatory authorities to assess the potential for the incorporation of insect protein into animal feed in the EU

Environmental Impact and Sustainability

House fly and black soldier fly production systems have showed favourable results in terms of their space requirements but considerable improvement within the systems that PROteINSECT has evaluated is required to improve the heating related energy usage and water consumption.

Waste Management

The supply of organic waste is increasing along with demand for animal products; production of insect protein presents an opportunity to valorise low value waste and produce high value products for inclusion in animal feed.

Legislation and Regulation

In the European Union, the use of insects as a source of protein for animal feed for animals raised for human consumption is currently not possible due to requirements under Regulation EC 999/2001. Insect protein for pet food is not covered by these requirements and is permitted. The European Commission Health and Food Safety (DG SANTE) is aware of the potential for insect protein to make a real contribution to animal feed in the future and has requested a formal scientific opinion on the available safety evidence from the European Food Safety Authority (EFSA). It will base further decisions on the need to make changes to existing regulatory requirements based on this opinion.

Consumer Understanding and Perception

Consumer perception and media monitoring work undertaken by PROteINSECT has demonstrated a high level of support for insects as a protein source in animal feed as well as a desire for more information. PROteINSECT continues to track consumer perception and inform society widely about its research work.

Commercial Potential

There are several existing barriers to full market entry for the use of insect protein within feed, the most significant being the lack of data on the safety and nutritional qualities of insect protein on which regulation change can be based. PROteINSECT continues to address this need for additional data.

The chapters in PROteINSECT's Business Case Report outline the advantages of an additional insect based protein source and highlight current key barriers to its adoption within Europe at scale.

Next steps for PROteINSECT

Over the next 12 months the PROteINSECT project will deliver a number of publications and research outputs including but not limited to:

- Pilot-scale experiments showing extraction yields and compositions of insect proteins.
- Database of the composition (nutrition profile), contaminants, allergenicity and a profile of micro-organisms in insect products for human consumption.
- Risk assessments identifying chemical, allergy and microbiological risks from insect and substrate combinations.
- Database relating to the presence of high value products in insects.
- Life cycle analysis with full results from the economic, social and economic assessments including production scenario analysis and policy and technical recommendations.
- Undertake and report on fish, poultry, and pig feeding trials in Europe.
- Results from the Second Consumer Perception information gathering exercise.

Alongside the delivery of these specific findings the PROteINSECT project is continuing to support the regulatory authorities with quality and safety data to assess the potential for incorporation of insect protein into animal feed in the EU.

This Consensus Business Case is the 'stepping stone' to the PROteINSECT White Paper which will be presented at our European Parliamentary reception in late 2015.

Sign up via PROteINSECT's website www.proteinsect.eu for the Newsletter containing progress reports and updates.

1. The Protein Deficit

Headlines

Population growth

'The global population currently stands at 7 billion and is estimated to reach 9 billion by 2050.' (United Nations, 2009)

Meat demand

'Globally, meat consumption has increased more than 5x since the Second World War and if current trends continue, global meat demand in 2030 will stand at 72% above the 2000 value of 233 million tonnes.' (FAO, 2002; Kanaly et al., 2010)

Feed demand

'Demand for cereals, for both food and animal feed uses, is projected to reach some 3 billion tonnes by 2050, up from today's nearly 2.1 billion tonnes.'(FAO, 2012)

'Demand for coarse grain (predominantly used for feed) is projected to grow by 20% by 2023.' (CAP2020, 2014)

Reliance on imports

'More than 40 million tonnes of crop proteins are imported annually into EU countries.'

'The European Parliament has adopted a resolution to address the EU's protein deficit, stating that urgent action is needed to replace imported protein crops with alternative European sources.'

Food security is a global challenge. Increasing demand for food (particularly meat, fish and eggs) has led to an urgent need for additional supplies of protein from sustainable sources for inclusion in animal feed. More than 40 million tonnes of crop proteins, primarily protein rich soya, are imported annually into EU countries representing up to 80% of the EU's crop protein consumption (Häusling, 2011).

The European Parliament has adopted a resolution to address the EU's protein deficit, stating that urgent action is needed to replace imported protein crops with alternative European sources.

Key facts on the protein deficit from the European Parliament

Supply

- Total EU protein crop production currently occupies only 3% of the Union's arable land and supplies only 30% of the protein crops consumed as animal feed in the EU, with a trend over the past decade towards an increase in this deficit.

- Historically, this significant deficit in protein crop production goes back to previously established international trade agreements, especially with the United States, which allowed the EU to protect its cereal production and in return allowed duty-free imports of protein crops and oilseeds into the EU (GATT and 1992 Blair House Agreement). This was accompanied by significant progress in the efficiency of protein crop production and the use of new technologies outside the EU, leading to a competitive disadvantage for EU farmers who find protein crop production economically unattractive.

Demand

- 70% (42 million tonnes in 2009) of consumed raw materials rich in plant proteins, especially soy flour, are imported mainly from Brazil, Argentina and the USA; approx. 60% of these imports (26 million tonnes) are by-products derived from vegetable oil production and are used as meals, especially soymeal, for animal feed.

- Because the volumes produced are so low, the European compound food industry only uses 2 million tonnes of protein crops each year but estimates that it would be able to use nearly 20 million tonnes per year.

- Imports represent the equivalent of 20 million hectares cultivated outside the EU, or more than 10% of the EU's arable land, and these producers are not subject to the same environmental, health and GMO regulatory constraints as European producers.

International trade

- The emergence of new customers for South American suppliers, notably China, who are not as demanding as the European Union in regard to production conditions and whose supply strategy is rather opaque, may in the long run weaken the stability of the markets and the EU supply chain.

- The EU livestock sector is vulnerable to price volatility and trade distortions, and depends on affordable and high quality protein imports. Increased weather and climate volatility is likely to drive even greater fluctuations in supply and impact price.

- Shortages of soya and maize imports impose an additional cost burden on the EU livestock and feedstuffs sectors, and put the economic viability of domestic meat production at risk.

- As a consequence of the small volume of leguminous fodder crops (lucerne, clover, sainfoin, etc.) and seed crops (pea, soja, lupin, horse bean, vetch, etc.) produced in the EU, the number of plant protein research programmes in the EU has dropped from 50 in 1980 to 15 in 2010. Training and the acquisition of practical experience in domestic protein crop production have been neglected, leading to a low level of innovation and regionally adapted seed production in the EU.

- The EU is highly dependent on soya beans and maize imported from third countries and any interruption of the supply of these products due to a minute presence of unauthorised GMOs has a costly impact on the European feed industry.

- Advantages of reducing the protein deficit rebalancing the supply and consumption of cereals, proteins and oilseeds in the EU could have major economic benefits for farmers and the food and feed industry and provide a better balance of protein production and contribute to improved global food security,

Link: EU Parliament (http://www.europarl.europa.eu/sides/getDoc.do?type=REPORT&reference=A7-2011-0026&language=EN)

Protein production

The availability of food for human consumption at the global level is heavily affected by the demands that livestock production places on land and water use. It has been estimated that around three-quarters of the world's agricultural area is devoted to producing livestock either directly or indirectly (Foley at al., 2011). Production of feed crops represents 24% of global crop production by mass (Cassidy et al., 2013). Animal protein production is estimated to require 5 to 20 times more water than that required for the production of cereal protein on a per kilogram basis (Chapagain and Hoekstra, 2003), but when the water required for forage and grain production is included in the equation this figure approaches 100 times (Pimentel and Pimentel, 2003), placing considerable stress upon the sustainability of the global water supply.

Aquaculture growth raises similar concern. Aquaculture has in the past been traditionally based on smallholder production integrated with surrounding agriculture (Little, Muir 1987). These production systems had low external demands for feed and were often intended for the purpose of subsistence farming. In the last three decades, aquaculture has grown at rates exceeding all other animal source food categories and has become a worldwide industry that now provides half of the aquatic species consumed by people. Increasingly it has competed for feed inputs, especially protein related, with other forms of livestock. This is particularly pertinent with global fishmeal and fish oil sources; it was estimated that in 2006, 22.85 million tonnes of wild caught fish were processed into fish meal and fish oils, which were then incorporated and used in aquaculture feeds globally (Jackson 2009).

Thus a 'livestock revolution' is taking place, as a result of the rapidly growing world population, income growth, increasing urbanisation, changes in lifestyles and food preferences. With limited potential for increasing the global cultivated land area, and many of the major food crops showing only modest yield gains, it is apparent that an increase in the availability of protein sources for animal feed is required. As the feeding of protein crops to animals results in an approximately seven-fold increase in the land used per unit protein produced, the use of insect protein in animal feed to complement traditional plant sources could contribute to freeing up land to grow crops for direct consumption by the human populace and lead to a concomitant increase in food security.

2. Why insects?

Introduction

Most animals require proteins to compensate for their inability to synthesise certain amino acids. Insects are rich in protein and are a natural component of the diets of carnivorous fish and free-range poultry. Insect species considered most suitable for feed production include silkworms, mealworms, black soldier flies and the common house fly larvae. As fly larvae can be reared on a wide range of wastes they also offer a potential solution to the need to utilise increasing quantities of organic wastes produced by agriculture and food industries. Furthermore, the residual material remaining after larval digestion has economic value as a fertiliser or soil conditioner.

Background

Insects grown specifically with the intention of being fed to domestic animals/fish has been the subject of evaluations for several decades (e.g. Bondary and Sheppard, 1987; Newton et al., 2005; Hem et al., 2008), but has never reached a stage that has led to any significant replacement of traditional plant and fish-based protein used for livestock production with insect-based protein. This is largely due to systems being explored and developed on a local, isolated level with no integration or co-ordinated development of know-how to enable adoption at the national level.

Current land use constraints and the fluctuating cost of plant and fish derived protein provides a critical platform for the development of an approach to fully utilise insects as an additional source of protein for animal feed. The global adoption of insect protein production systems would reduce reliance on crop and fish based protein sources and increase protein availability for animal feed whilst potentially offering reductions in the environmental footprint of livestock production.

Therefore, as any significant switch from meat eating to entomophagy cannot be anticipated at the global level, it is believed that sustainably producing additional protein that can be fed to livestock and fish constitutes a strategy that is not only more realistic, but also one that stands a better chance of increasing food security. It is also likely that the production of ‘generic’ protein extracts from insects for incorporation into foods, in a similar fashion to the generic extracts produced from fish, may be more acceptable and comprise a route whereby insect protein could achieve widespread exploitation directly in human diets in the medium to long term.

Plant based protein

Considerable progress has been made in understanding the importance of protein nutrition (e.g. the significance of amino acid balance and ileal digestibility) for appropriate feed formulation in recent years. The amino acid strengths and weaknesses of different protein feed ingredients, such as the lysine limitation in maize, and methionine and cysteine limitations in soybean, are now well documented. In the light of the 'livestock revolution' and the concomitant growing demands of the feed industry for protein much research has already been conducted to try to identify alternative and enhanced sources of protein for animal feeds. This includes investigating the use of crop residues and co-products produced during the processing of crops for food (e.g. vegetable oil) and industrial uses (e.g. alcohol) and the use of genetic modification (classical breeding and biotechnological approaches) to improve the nutritional value of crops. However, with additional competing demands upon land-use for the production of crops for biofuel, the need to find additional protein sources for animal feed remains paramount. Of the many insects that have been examined, dipteran flies have protein content and amino acid composition that renders them very suitable for use as replacements to traditional plant and fishmeal sources (Newton et al., 2005). Other insect species also have suitable protein composition, for example mealworms, but are not the focus of the PROteINSECT project.

The following chapters provide greater detail about the advantages of an insect based protein source, drawing largely on work undertaken by and currently available for wider dissemination from the EU funded project PROteINSECT, whilst also highlighting current key barriers to its adoption at scale.

3. Insect production

Headlines

- Commercial insect rearing systems for feed production exist both within and outside Europe; however their long-term economic viability remains to be demonstrated.
- Several small and medium-size systems are presently being developed as part of PROteINSECT in UK, China and Africa. Important issues in these systems include production processes that are labour intensive and/or too energy demanding.
- PROteINSECT has identified a need for further development of semi-automated systems more suitable for adoption in Europe; however it should be noted that some European producers are currently undertaking this process.
- Economically viable systems would also need to work with easily accessible and cheap rearing substrates of stable quality and make best use of by-products such as chitin.

Introduction

Historically, insects have been used in many parts of the world as a direct source of human food as well as a complementary food source for animals and fish. However, in most cases, insects were field collected. Exceptions were by-products of the silkworm industry and bee-keeping activities. As such, there is still relatively little expertise in mass production of insects. Until recently European commercial insect rearing was largely limited to the production of biological control agents, pollinators and sterile insects for the agriculture sector and, to a lesser extent, production of insects such as fly larvae for recreational fishing, and crickets and mealworms (the latter on an industrial scale) for pet food. Larger insect production systems exist on other continents. For example in China, HaoCheng Mealworm Inc. exports 200 tonnes of dried mealworms annually to Australia, Europe, North America and South Asia. Growing recognition of the potential value of insects, along with the drive to find new sources of protein for animal feed, has resulted in a growing number of new commercial enterprises over the past decade.

Despite their lack of tradition in direct consumption the insect species considered most suitable for feed production include mealworms, black soldier flies and the common house-fly larvae. As fly larvae can be reared on a wide range of wastes, they also offer a potential solution to the need to utilise increasing quantities of organic wastes produced by agriculture and food industries. Furthermore, the residual material of larval digestion has economic value as a fertiliser or soil conditioner.

Examples of commercial enterprises

Africa

Agriprotein, a South African company established in 2009, is considered the world leader in the mass production of fly larvae. The company is focussed on nutrient recycling using organic wastes to produce insect based protein feed, extruded oil, and fertilisers. While it first focused on house-flies, its commercial products are now based on a black soldier fly production system. Its first industrial scale factory was established in 2014 and has a current capacity of 800 kgs wet larvae per day. The goal is to produce 7 tonnes of insect meal, 3 tonnes of oil and 20 tonnes of fertiliser per day and the company aims to establish 10 similar sites by 2020. Maggots are 'farmed' in a factory that uses a combination of automated and labour intensive processes.

North America

In Canada the Enterra Feed Corporation utilises food processing and distributor wastes to rear black soldier fly. The company produces protein and oil products for aquaculture feed, animal feed and pet food. Like Agriprotein, the digestate from the larvae is processed and sold as a natural fertilizer product.

In the US, Enviroflight is using low-value co-products from breweries, ethanol production, and pre-consumer wastes to rear black soldier fly larvae. The larvae are processed into meal and sold as feed for carnivorous fish such as rainbow trout, perch and bass. Digested feedstock is sold principally as a feed for omnivorous fish, such as Tilapia and catfish as well as freshwater prawns.

Europe

A growing number of companies with similar ambitions are being established in Europe. However, markets are limited by the current legislative landscape that does not permit the use of insects in livestock feed. For example PROtix Biosystems BV in the Netherlands has developed scalable insect production systems using 'end-of-life streams' to produce insect meal and purified oil, as well as chitin as a basis for derivatives like chitosan. The Spanish spin-out, Bioflytech specialises in rearing a range of dipteran species producing biomass for animal feed with additional focus on the use of insects in the development of technologies for waste valorisation. Ynsect, a French company, has attracted €11m of investment to date which is focused on the development of fully automating its insect production and processing facility. Ynsect currently produce over 1 ton of proteins and derivatives, lipids and chitin and derivatives per day. Other companies include Hermetia in Germany and biological control companies, such as Koppert in the Netherlands, which are ideally placed to enter the market owing to their significant expertise in rearing pollinators (including flies) and beneficial insects.

In 2013 the International Platform of Insects for Food and Feed (IPIFF) was formed as a non-profit organisation to represent the interests of private players in the insect industry. The goal of IPIFF is to help the insect industry prosper in Europe and worldwide, which means that:

- The European insect industry will be composed of a collaborative network of local partner companies that will share sustainability as a common value and promote insect industry as an eco-industry
- Insects will be promoted as a top-tier source of animal proteins for both human food and animal feed, thanks to its sustainable and nutritional properties

The European Food Safety Authority (EFSA) has established a working group to assess the safety risks arising from the production and consumption of insects as food and feed. EFSA has made formal requests for supporting data from a number of organisations including IPIFF.

It is noteworthy that the production of insects as feed is in its infancy and the long term economic performance has yet to be tested. However significant investment has been gained within the sector.

Assessing production methods - PROteINSECT

The PROteINSECT project is undertaking the co-ordinated development and optimisation of fly production methods for animal feed production in EU and International Cooperation Partner Countries (ICPC). Insect rearing systems have been established and existing systems modified using the expertise of project partners.

The systems that have been set up or modified are:

- *Musca domestica* in the UK
- *Hermetia illucens* and *M. domestica* in Ghana
- *Musca domestica* and *Hermetia illucens* in Mali
- *Musca domestica* and *Chrysomya megacephala* in China (2 sites)

The systems are smaller than the commercial examples cited above. They range from those suited to mass production at a semi-commercial scale, to systems designed for use by farmers to provide a feed source for their own livestock. Furthermore, optimisation of all trial systems is ongoing. Thus, the present conclusions may not be directly applicable to large, established systems. Importantly the trial systems have also been used to supply larvae for analysis of quality and safety.

All steps of the insect production processes within the PROteINSECT project are being studied for improvement, in particular for finding the most suitable rearing substrates from those tested, the most efficient larvae extraction and drying systems, the best attractants for adult flies, efficient systems to prevent attacks from predators, parasites and accidental release. All PROteINSECT systems and their improvements are being characterised in terms of the technical specifications, insect yield, inputs, energy use, residual flows, economic costs and productivity to provide project data for economic and environmental life cycle assessments (See section 7. Environmental Impact and Sustainability). The biophysical input and output relations are being measured to gain an understanding of the driving factors for performance and the environmental impacts of the PROteINSECT insect production systems. Using the modelled production scenarios from the PROteINSECT systems as templates, a set of trial scenarios, varying single unit processes and input-output relations (e.g. substrates, scale of production, aquaculture species etc.) has been compiled, which will be used to derive recommendations for optimisation of the trial processes and future research activities.

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PROteINSECT: Initial results from production trials

The potential use of waste substrates to yield fly larvae has been demonstrated by the successful establishment of systems with varying production capacities (25-250 kg fresh larvae per week) in China, Africa and the UK. The systems differ in the fly species, methods and purposes and, thus, encounter different problems and presently require different research efforts. The main issues in the PROteINSECT systems so far are:

- Production processes are, in the main, too labour intensive. This is particularly critical for Europe and industrial scale productions. Efforts are needed to develop semi-automated systems to reduce labour cost and reach economic viability. In particular better methods to rapidly extract mature maggots from substrates need to be developed.

- Transport costs and rearing substrate accessibility are clear constraints, in particular in developing countries. Profitability will only be reached in situations where substrates are immediately available at no or low cost. A good example is the house-fly production system attached to a poultry farm and using poultry manure in China. Not only transport, but also other production steps such as heating or larvae drying are still too energy demanding (see section 7, Environmental Impact and Sustainability).

- In some systems, variability in rearing substrate quality can have a very significant impact on yield. Therefore, substrates should not only be cheap and easily accessible but also of a consistent high quality.

- Efforts should be made to make the most of by-products, especially rearing residues that can usually be used as excellent soil conditioner or fertiliser.

The PROteINSECT systems still need improvement along the lines described above before becoming economically viable. Some systems, however, are closer to local economic viability, such as the one based on natural oviposition of house-flies developed in Mali, or the house-fly production system currently being developed in a poultry farm in China. Further work is needed to establish similar trial units both within and outside Europe.

In all cases the employment of trained entomologists and their 'know-how' has been seen to be vital to the successful establishment of larval production systems.

4. Insect Processing

Headlines

A number of challenges exist for the PROteINSECT evaluated insect processing methods including;

- Removal of substrates in the gastrointestinal tract and on the surface of insect larvae feed on organic waste
- Ensuring that the protein extract does not contain solvent residues following the use of solvent extration process
- Establishing appropriate levels of co-extracted chitin
- Removal of parasites in larvae
- Animal welfare issues – determining a suitable killing protocol for insects before extraction such as those developed by Wageningen University (Veldkamp et al, 2012).

Solvent extraction has to date given the highest protein yield of all the protein extraction techniques that have been evaluated by PROteINSECT.

Introduction

PROteINSECT is focussing on insects suitable for animal nutrition so analysis of processing methods has focused on house fly (*M. domestica*) and black soldier fly (*H. illucens*). There is a need for further research for evaluation of their potential as a protein source in animal nutrition (and subsequently also for human nutrition). From Table 4.1, it is clear that both house fly and black soldier fly are rich in proteins at different development stages (despite the significant protein ranges demonstrating the importance of substrate composition) and have clear potential as a protein source in animal nutrition.

Table 4.1 Protein composition of house fly and black soldier fly

Insect	Development stage	Protein content (% of dry insect)
House fly	Larvae	37-66
House fly	Pupa	58-80
Black soldier fly	Larvae	37-48

The PROteINSECT project is analysing (in terms of SWOT: Strengths, Weaknesses, Opportunities and Threats) existing methodologies for protein extraction from the above fly species and their residual substrates (biomasses), for inclusion as a protein source in animal feed applications. The purpose is to define at least two methodologies within each of the following categories: physical, chemical and biotechnological approaches. The aim is to derive some general approaches, but always based on existing literature, patents and practices in participating countries. Claims of patents from Chinese applications were translated by the Chinese partners within the PROteINSECT consortium. In addition to literature on insects (including larvae, pupae and adult insects), literature on biomass was also consulted. This is because most literature on insects was focussed on recombinant protein expression in insect cell lines, showing other characteristics (based on fundamental research activities) compared to conventional protein processing technologies.

PROteINSECT Protein Development Plan

The PROteINSECT Protein Development Plan set up an inventory for possible methods for protein isolation, extraction, enrichment and decontamination. These methods were identified from the literature, patents and daily practices, and screened and reviewed. In addition, the extended expertise of Nutrition Sciences N.V. (and its network) was taken into account. Based on this inventory, a SWOT analysis was performed for each processing step and some leading methods for protein isolation, extraction and enrichment were derived. The methods identified were then tested and fine-tuned at the pilot scale. This method was selected to ensure sufficient protein material can be produced in order to proceed towards the efficacy feeding trials in animals (fish, poultry and pigs).

The *modus operandus* for the SWOT analysis per processing unit is illustrated in the table below (as an example 'pre-(sun) drying'):

Technique	Strength	Weakness	Opportunity	Threat
Pre-(sun) drying	mature technology easy to do easy to upscale manpower and skills large process volume no large investment (even outside, positive in ICPC countries) solar energy high yield	need for surface (land) slow evaporation, long duration less flexibility mixed extracts non-controlled process (seasonal effects) allergenic reaction toxic substances (when dried in sun) denaturation of functionalities limited applications	easy implementation (easy training and application, standard approach) cheap (basic infrastructure)	competition public acceptance (towards deterioration) legislation (towards deterioration and safety)

The SWOT analysis was then applied to the existing literature, patents and daily practices, and the following approaches were identified for protein processing from insect larvae: DESTRUCTION technologies, EXTRACTION technologies, HYDROLYSIS technologies and FERMENTATION technologies, all followed with adequate DOWNSTREAM PROCESSING technologies.

The following PROteINSECT results were obtained:

- Ranking of DESTRUCTION technologies is **mechanical treatment (RTHV 100%) → sieving/filtration (RTHV 84%) → temperature (RTHV 68%) → pre-(sun)drying (RTHV 52%) →** sonification (RTHV 11%) → high pressure (RTHV 0%)
- Ranking of EXTRACTION technologies is **water (RTHV 100%) → salting in = temperature (RTHV 81%) → selective adsorption (RTHV 62%) → solvents = pH (RTHV 56%) →** multi-detergent (RTHV 44%) →extraction aids (RTHV 31%) → ionic fluids (RTHV 25%) → microwave = supercritical CO2 extraction (RTHV 0%)
- Ranking of HYDROLYSIS technologies is **enzymes = acid = alkaline (RTHV 100%)**
- Ranking of FERMENTATION technologies is **lactic acid bacteria = yeast (RTHV 100%)**
- Ranking of DOWNSTREAM PROCESSING technologies is **conventional air drying = conservation agent (when using non-patented conserving agentsa) = precipitation (RTHV 100%) → centrifugation (RTHV 50%)** → drying = membrane technology (RTHV 42%) → Sterilisation/pasteurisation/HTST/radiation (RTHV 0%)

The PROteINSECT consortium agreed that the relative threshold value (RTHV) in the SWOT analyses is set at **50 %** (= 1/2 of the points, see **blue** indications), in order to have been selected for further trials.

From lab-scale to pilot testing for protein processing

The most promising technologies were selected and tested both at lab and pilot scale. In this context, all insect producing partners within the PROteINSECT consortium, as well as from the international advisory board, were requested to send insect larvae. The characteristics of the insect larvae are:

1. Collected from their best controlled rearing system so far
2. Instar ‘wandering’ development stage or ‘ready-to-feed’ development stage and
3. Killing of the larvae: heat treated for 2 hours at 65°C. In case of cleaning (for removal of dirt), the larvae need to be washed in water after the first heat treatment, and dried again for 2 hours at 65 °C.

PROteINSECT has evaluated all physical, chemical and enzymatic (as part of its biotechnological approach) processing steps and the most promising technique tested to date was solvent extraction. This technology can be summarized as follows:

- Starting material (10% w/v)
    - Insect
- Solubilisation in solvent
- Filtrate
- Freeze-drying of residue

This solvent extraction methodology gave the best protein extraction; however the economic and market viability of this system has not been tested by PROteINSECT.

Summary of PROteINSECT protein processing

From the PROteINSECT evaluated processing technologies, solvent extraction – as a model for EXTRACTION technologies - yielded the highest levels of protein. In addition, a complete recovery of proteins was obtained after solvent extraction. However, a disadvantage is that the fibre fraction (mainly chitin) was co-extracted together with the protein.

The major challenges for the PROteINSECT evaluated processes are:

- Designing generic processing technologies for larvae of different insect species.
- The presence of co-extracted chitin within the solvent extraction method- this will be the basis for further biotechnological processing methods, based on fermentation and enzymatic treatments within PROteINSECT. Chitin itself can be a marketable by-product.
- Solvent residues in the protein extract.
- The presence of residual substrates in the gastrointestinal tract and on the surface of insect larvae.

Animal welfare issues - suitable killing protocol for insects before extraction was raised by some Key Opinion Leaders as a concern.

Next steps for the PROteINSECT Research

In 2015 PROteINSECT will undertake the following work on insect processing:

- Continue to evaluate suitable extraction methodologies for insect proteins.
- Undertake viability testing of the protein extracts and their by-products.
- Report on laboratory-scale experiments showing extraction yields and compositions.
- Report on pilot-scale experiments showing extraction yields and compositions.

5. Insect Nutritional Properties and Suitability in Animal Diets

Headlines

- There is a need for additional nutritional quality data to demonstrate the potential of the use of insect protein for feed.
- Quality data should consider potential changes to the nutritional and taste quality of the feed and food products.
- Consideration should be given to the variability that may occur because of different insect rearing and processing methodologies, as well as variation across a range of feed stocks where inclusion rates for insect derived protein may differ.

Introduction

In animal nutrition, an appropriate available energy and amino acid supply in a balanced diet for efficient protein use by livestock is of critical importance and a high protein to energy ratio is needed to optimise the use of the protein. Different animal species have different protein requirements and these requirements also differ according to age and growth stage. The difference between 'essential', 'semi-essential' and 'conditionally indispensable' amino acids in relation to protein inclusion in the diet is also important. The amino acid strengths and weaknesses of today's protein feed ingredients are well-known, such as methionine and cysteine limitations in soybean, and the lysine limitation in maize. These are key issues for appropriate protein use and feed formulation. However, amino acid composition revealed by chemical analysis may not correctly identify the availability of these amino acids at tissue level in the animal. The significance of 'ileal digestibility' of amino acids for diet formulation, rather than total amino acid content, is important.

Sources of protein for animal feeds are many and varied, with considerable opportunities for further diversification and substitutions in terms of quality and safety. Whilst preliminary studies indicate that insects may be a good source of digestible protein for incorporation into animal feeds, relatively little comprehensive and comparative analysis for suitability for different livestock has been published to date.

The nutritional and economic value of insects in the context of protein substitution is dependent on both the total protein content and the amino acid composition of product. It has been demonstrated that house fly larvae contain relatively high levels of key amino acids such as methionine and lysine, providing an economic incentive for the use of insect protein in animal feed. This is particularly evident when the data are compared to plant based materials that are often low in these growth-limiting compounds. Additional nutritional components that may add value to insect products include fats/oils and vitamins & minerals.

At present the scientific literature around the nutritional value of insects for animal feed is dispersed. Table 5.1 below summarises the data that could be consolidated from the literature coherently. This highlights the wide diversity in the values reported from the study of just two fly species, with the causes of this variation most likely being the different production methods used and, importantly, the lack of data from accredited laboratories.

Table 5.1: A comparison of the reported basic nutritional parameters of the 2 fly species most likely to be used for animal feed a) *M. domestica* b) *H. illucens*

	***Musca domestica* larvae (dry matter)**	***Hermetia illucens* larvae (dry matter)**
Crude Protein %	37-66 (27 articles)	37-48 (9 articles)
Fat %	4-36 (24 articles)	12-46 (9 articles)
Total carbohydrates %	1.3-2.9 (2 articles)	
Total ash (mineral content) %	5-14 (19 articles)	15-16 (4 articles)
Gross energy MJ/Kg	14-25 (8 articles)	21 (1 article)

Amino acids

The nutritional quality of protein is determined by its amino acid composition and digestibility. The ratio between essential and non-essential amino acids is an important factor. To be considered high quality, at least 40% of total amino acid content should consist of essential amino acids (FA0, 1989). A study of 78 species of edible insects found that the essential amino acid score of 46% to 96% whilst protein digestibility varied between 76 and 98% (Ramos-Elorduy et al, 1997). The house fly (*M. domestica*) has a higher percentage of essential amino acids than non-essential amino acids and protein digestibility of 98.5% (Hwangbo et al, 2009).

Fat

Fat content is also an important determinant of overall nutritional quality. The ideal ratio of saturated fatty acid, monounsaturated fatty acid and polyunsaturated fatty acid is 3:4:3 (Belluco et al, 2013). Furthermore, within the category of polyunsaturated fatty acid, the recommended ratio of omega-6 fatty acid to omega-3 fatty acid is 3:1 (Belluco et al 2013). Many edible insects have a high fat content and generally the saturated to unsaturated fatty acid ratio is less than 40%, which compares favourably with fish and poultry (van Huis, 2013). For the housefly, this ratio is 35.89% (Hwangbo et al, 2009).

Micronutrients

Micronutrient content is important when considering the nutritional quality of food and feed. Minerals and vitamins are essential for normal growth and health. For humans, the recommended daily allowances of important vitamins and minerals are listed in EC Directive 2008/100. The majority of edible insect species contain high amounts of the minerals potassium, calcium and magnesium (Schabel, 2010). Insects are a particularly valuable source of iron and most edible insect species contain equal or higher levels of iron content than beef (Bukkens, 2005). Additionally, many species of insect are rich in vitamins. For example, bee pupae is exceptionally rich in vitamins A and D whilst caterpillars are a good source of vitamins B1, B2 and B6 (Schabel, 2010).

There has yet to be a thorough scientifically published assessment of the quality parameters of meat produced from insect-fed livestock, although some industry trials have taken place. Available literature indicates edible insects, including the housefly, are nutritionally well-balanced and meet many important nutritional requirements demonstrating their potential to be a beneficial component of food and feed. Considerations such as taste, texture, odour and colour may be important factors in determining whether insect-fed animals provide high quality meat that can compete with meat produced using conventional feeding regimes. Other parameters such as the fatty acid profiles of the meat/fish will be particularly important in certain sectors, for example in salmon farming.

Initial results from PROteINSECT

Trial production systems have been used to supply larvae for analysis of the nutritional composition of the fly larvae. This work examined the total protein, total lipid and the amino acid and fatty acid composition together with minerals and trace elements quality and safety. Initial results were published in the Journal for Insects as Feed and Feed in February 2015 (Charlton et al, 2015).

Next Steps for PROteINSECT

Fish, poultry, and pig feeding trials are being conducted in 2015 in Europe (Belgium and UK) based on PROteINSECT UK derived insect protein whereas, fish and chicken feeding trials will be conducted in China, Mali and Ghana with insect protein being sourced from PROteINSECT partners within each country. In most cases both crude and refined preparations will be used in feeding trials to enable an evaluation of the benefits of protein refining to be carried out. Where this is not possible and/or appropriate, feeding trials will be conducted solely using crude insect preparations. Data will be collated and used as a basis for comprehensive life cycle analysis to be carried out within the PROteINSECT project.

Aquaculture feeding trials (EU)

Dietary insect protein levels (30%, 50%, and 70%) will be tested and a conventional diet will be used as the control. Fish will be subsequently induced for breeding. The specific growth rate (SGR), feed efficiency (FE), apparent digestibility coefficient (ADC) will be monitored. Protein extracts made by defatting, acid extraction, alkali extraction, salt extraction, and enzymolysis will be tested. Species to be evaluated will include Atlantic salmon and Tlapia. In both cases fully established and validated protocols for the assessment of the performance of fish diets will be employed.

Poultry feeding trials (ICPC)

Chicken trials are being conducted in 2015 and feeding efficacy (daily growth, feed intake and feed conversion ratio) will be monitored. For hens, the egg laying rate and egg nutrition will be tested. Protein extracts made by defatting, acid extraction, alkali extraction, salt extraction, and enzymolysis will be tested and evaluated against conventional protein sources. Protein fractions based on enzymatic processing will be tested as an improved amino acid source for improved digestion and gastrointestinal functioning. Amino acid digestion profiles will be measured in vivo.

Pigs and poultry feeding trials (EU)

These trials will develop the formulation of experimental diets with insect material and their extracts, according to the requirements of weaning pigs and poultry (NRC; net energy, digestible amino acids, minerals and vitamins). In response to these treatments, feed acceptance (intake), growth rates, feed utilisation, and numerous specific parameters illustrating gut health - as constituted by faecal consistency, bacterial numeration/composition, intestinal secretions, mucosal immunity, integrity and functionality - will be monitored. In addition, some responses related to animal welfare will be monitored.

The research on the quality (and safety) of insect protein will provide data needed for regulatory authorities to assess the potential for incorporation of insect protein into animal feed in the EU. This data will also provide valuable information allowing the commercial value of insect meal and insect derived protein to be evaluated. Furthermore this research will also provide a basis for the assessment of the potential use of insect protein in human food.

Whilst the primary aim of the PROteINSECT project is to produce high volumes of protein, the insects produced may also yield additional compounds (e.g. chitin, vitamins, minerals, etc.) which could be isolated from the crude insect extracts and used for other high-value applications.

6. Insect Safety

Headlines

- There is a potential risk that insects will contain natural metabolites or proteins which are toxic to humans or animals when eaten.
- The potential for insects to bio-accumulate chemical substances and pathogens present in waste streams has yet to be explored to the standards required to fulfil regulatory requirements.
- The persistence of chemical residues, such as antibiotics and pesticides through the food chain, is of particular concern where, for example, manure or anaerobic digestate made from manure or slurry is used as feedstock.
- The use of food waste as feedstock raises concerns over microbiological safety and the formation of natural toxins produced during food spoilage such as mycotoxins.
- There is currently a potential risk for livestock of allergenic proteins in insects.
- Microbiological risks may be effectively managed through the heat and pressure treatments that are already used in the animal feed industry.

Introduction

A major consideration in the use or applicability of any novel feed product is to demonstrate its safety, in particular if the initial substrate used for its production is a waste product. Information on the safety of the use of insect protein is very scarce in the literature. The safety of insects for food and feed has recently been reviewed (Belluco et al., 2013; van der Spiegel et al., 2013) but little data is available to support risk analysis, particularly for the use of insects as feed as only a small number of safety related studies has been published (e.g. Awoniyi et al., 2004). Only isolated information in relation to the chemical risks of insects has been published (e.g. Diener et al., 2011) with inferences to food/feed use sometimes made.

Safety and legislation

In the European Union, the use of insects as a source of protein for animal feed is currently prohibited for animals raised for human consumption under regulation EC 999/2001, which prohibits all processed animal protein (PAP) -with the exception of hydrolysed proteins and in some cases fishmeal (e.g. fishmeal in milk replacers for young ruminants) - being used in animal feed. A recent amendment to this legislation (EU Regulation 56/2013) allows the use of non-ruminant PAP in fish feed: however insect proteins are not authorised. Further proposed amendments, such as the use of non-ruminant PAP (possibly including insects) for feeding to non-ruminants, are currently difficult to implement owing to the lack of a clear method for species origin determination in PAP. Identification methods for insect PAP in feed are currently not yet available, these methods will largely depend on the type of insect PAP that will be proposed on the market (e.g. insect meals, protein extracts). It is PROteINSECT's view that it is therefore highly unlikely that insects will be permitted in animal diets until thorough consideration of the safety of their use has been made, and diagnostic methods for the detection of processed insect protein in animal feed are available.

A key consideration for feed suppliers is the safety of raw materials. Potential risks from the use of insect protein include chemical contaminants, parasites, microbiological threats, allergens and prions, these potential risks vary depending on the rearing/feeding substrate, production and processing methods. Prions are a particularly emotive area epitomised by the bovine spongiform encephalopathy (BSE) or 'mad cow disease' crisis, associated with the feeding of meat and bone meal (MBM) or PAP to ruminants. Whilst there is no evidence to suggest *infective* forms of prion proteins are present in insects, there may be a greater risk that prion protein transmission occurs through the use of meat-based food waste or slaughterhouse waste as a feed stock for insects, which may then act as disease vectors by retaining residual specified risk materials (SRM), such as undigested spinal cord or brain in their digestive track. There are existing controls on the routes of disposal for SRM and the potential risk of prion transfer from Category 3 food waste to insect protein is significantly reduced.

Safety considerations of insect species that can be used in food and feed are species-specific. For example, there is a potential risk that insects will contain natural metabolites or proteins which are toxic to humans or animals when eaten. This may extend beyond known venoms, in, for example, bees and wasps. A safe history of human consumption of several insect species has recently been reported (van Huis et al., 2013).

Current regulations that limit undesirable substances in animal feed for animals raised for human consumption are described in EC Directive 2002/32. This covers a range of contaminants and residues including heavy metals, pesticides, veterinary medicines, and environmental contaminants. The potential for insects to bio-accumulate chemical substances and pathogens present in feed substrate waste streams has yet to be explored to the standards required to fulfil regulatory requirements for the use of insects as food or feed, raising significant concerns about the safe use of insects in the human food chain. PROteINSECT is evaluating the hazards associated with using organic waste streams.

Chemical residues

The persistence of chemical residues, such as antibiotics and pesticides through the food chain, is of particular concern where, for example, manure or anaerobic digestate made from manure or slurry is used as feedstock possibly leading to longer term issues such as antibiotic resistance in livestock. The use of food waste as feedstock generates further concerns over microbiological safety and the formation of natural toxins produced during food spoilage such as mycotoxins. Industrial toxins such as dioxins may also be important depending on insect rearing and preservation processes. To some extent, processing insects into a protein meal will reduce the chemical risk of using insects as a protein source for animal feed. For example, highly toxic lipophilic endocrine disruptors such as dioxins could be removed as a potential issue by defatting the insects before feeding. Care should be taken to ensure that processing does not create new risks by adding chemicals or creating, for example, acrolein through processing methods.

Metals

Research to assess the potential effects of the presence of some metals (cadmium, lead and zinc) and to determine possible bioaccumulation revealed accumulation patterns according to metal type and concentration; cadmium was accumulated, lead suppressed and zinc remained constant (Diener et al., 2011, 2009). In addition, it was observed during field experiments that high concentrations of zinc in the growth substrate led to problems with the fly populations. The authors recommended developing a process that allows separation of heavy metals from pre-pupae and residue.

Allergens

The presence of allergenic proteins in insect feeds has the potential to pose a risk to livestock health. Tropomyosin, an allergen responsible for shellfish allergy, is also present in many insect species. For example, tropomyosins from house dust mites and cockroach have sequence identities to shellfish tropomyosin of around 80% (Ayuso et al., 2002; Santos et al., 1999). Cross-reactivity of insect proteins to crustacean allergic individuals has been demonstrated (Leung et al., 1996; Reese et al., 1999; Ayuso et al, 2011; Verhoeckx et al., 2013). Whilst this is clearly important in making choices in relation to entomophagy, it is also a major consideration in relation to insects for use as animal feed because any potential allergenic response in farm animals, such as watering eyes, will result in animal welfare concerns, in addition to economic and nutritional implications in relation to, for example, weight gain and meat yield.

Microbiological risks

Microbiological risks may be effectively managed through the heat and pressure treatments that are already used in the animal feed industry. One persistent concern is Salmonella, which is routinely screened for in animal feed. Other persistent microbiological risks are likely to be viral and may include hepatitis E. Initial data from PROteINSECT has also shown that manure grown fly larvae will carry a high volume of Enterobacter.

PROteINSECT – safety evaluation outputs

PROteINSECT is advancing the state-of-the-art by undertaking a full safety evaluation of the products intended for animal feed produced as a result of this project to ensure they comply with current regulations that limit undesirable substances in foodstuffs (EC Directive 2002/32). A broad range of contaminants, determined by current regulatory requirements, is being analysed by using a range of modern state-of-the-art analytical methods. In addition testing for nutritional composition, taints, allergenicity and microbiological safety is also being carried out in.

PROteINSECT has made progress (Charlton et al, 2015) in determining the levels of chemical and biological hazards in insect larvae. Samples produced in the UK, Ghana, Mali and China (by PROteINSECT and reared on organic wastes) using different production methodologies have analysed for the presence of potentially hazardous chemicals. Chemical safety data has been collected in accordance with EC directive 2002/32/EC resulting in the analysis of five subclasses of chemical risks: veterinary medicines, pesticides, metals, dioxins and polychlorinated biphenols (PCBs), polyaromatic hydrocarbons (PAHs) and mycotoxins. All larvae analysed possessed levels of potential toxins (over 500 tested) that were below recommended maximum amounts. However, the toxic heavy metal cadmium was found to be of concern in three of the *M. domestica* samples analysed. Further studies are required to determine the source of the cadmium.

PROteINSECT next steps

PROteINSECT will be developing three key outputs over the next 12 months:

- A robust database of the composition (nutrition profile), contaminants, allergenicity and a profile of micro-organisms in insect products for human consumption (including meat/fish from insect reared animals),
- A risk assessment identifying chemical, allergy and microbiological risks from insect /substrate combinations
- A database relating to the presence of high value products in insects studied

The research being undertaken by PROteINSECT on the quality and safety of insect protein is providing supporting data to EFSA and DG SANTE to aid the assessment of the potential for incorporation of insect protein in animal feed in the EU. For more information on the current EFSA position please see section 9. Legislation and Regulation. The data will also provide valuable additional information allowing the commercial value of insect meal and insect derived protein to be evaluated.

7. Environmental Impact and Sustainability

Headlines from research by PROteINSECT

- House fly and black soldier fly production systems showed favourable results in terms of their space requirements.
- Considerable improvement potential for heating related energy usage (fossil energy depletion potential) and water consumption has been identified.
- Alternative cleaning measures and/or rearing vessels with more favourable volume/surface ratio are required to lower water consumption.
- PROteINSECT recommends the design of suitable automated separation devices, as manual separation of larvae and residue substrates requires substantial labour input.

Introduction

The largest portion of a product's environmental impacts and costs of manufacturing and use results from decisions taken in the conceptual design phase long before its market entry. In order to foster sustainable production patterns, an application of Life Cycle Assessment in the very early product development stage, called Life Cycle Design, has proven most effective. The concept of Life Cycle Assessment is based on an evaluation of impacts of products and services over their complete lifecycle, which is from extraction of raw materials, transport, processing and assembly to distribution, end use, and waste disposal.

To address all the sustainability dimensions within insect protein production, PROteINSECT has employed a life cycle methodology that includes environmental Life Cycle Assessment (Env. LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA).

Pilot Production Systems

In order to design sustainable insect production systems that are suitable for adoption by small and large-scale operations in different regions of the world, PROteINSECT has examined different pilot-production systems in different biophysical and socio-economic environments. With a focus on applications of the house fly [*M. domestica*] and the black soldier fly [*H. illucens*], PROteINSECT has surveyed insect pilot-production systems in Europe (Spain), Asia (China) and Africa (Ghana, Mali). The systems under research show variation in production orientation (e.g. application in waste management, production of protein feed for monogastric livestock and aquaculture), substrates (e.g. manure, residues from the food and feed industry), and technological set-up, ranging from simple labour-intensive process organisation to intensive, partially-automated production flows. The collected, site-specific biophysical and socio-economic input and output data is being used to build ex-ante modelled industrial scale rearing systems.

Environmental impact

At the current stage of research, PROteINSECT has assessed the driving factors of performance and the environmentally sensitive aspects of two distinguished, up-scaled rearing processes in Spain: the rearing of house flies (HF) on fresh and dewatered pig manure and the rearing of black soldier flies (BSF) on brewery waste, and two different harvesting techniques. For both systems, PROteINSECT has assessed the environmental impacts with regard to agricultural land occupation, water use and fossil energy depletion.

The preliminary research findings have identified a number of current process inefficiencies and environmentally-burdensome production characteristics. Although different in their production orientation, i.e. manure reduction and protein production, the HF systems as well as the BSF systems showed favourable results in terms of their space requirements and considerable improvement potential for heating-related energy usage (fossil energy depletion potential) and water consumption.

The house fly system, designed to facilitate a maximum of pig manure dry matter (DM) reduction, showed a fossil energy depletion potential of 3.0 $kg_{oil\ eq}$ attributed to the reduction of 1 kg DM from fresh manure (fm), respectively 1.7 $kg_{oil\ eq}$ per reduction of 1 kg DM from dewatered manure (dm). The water depletion potential was estimated 31 m^3 (fm) and 57 m^3 (dm). Regarding the space requirements, per kg manure DM reduction the modelled manure treatment systems were estimated to occupy 1.4 m^2yr (fm) and 2.6 m^2yr (dm) agricultural land.

The black soldier fly system, designed to facilitate a maximum output of insect (pre-pupa) DM, showed a fossil energy depletion potential of 2,9 $kg_{oil\ eq}$ per kg insect DM assuming a manual harvest (mh) process, respectively 0,6 $kg_{oil\ eq}$ per kg insect DM in conjunction with a semi-automated harvest (sah) process. The water depletion potential per kg insect DM was estimated 9.7 m^3 (mh) and 1.9 m^3 (sah). The space requirements per kg insect DM in the different BSF production models were estimated 0.09 m^2yr (mh) and 0.02 m^2yr (sah).

Recommendations

PROteINSECT recommends more efficient heating devices and adequate insulation at production facilities to lower the fossil energy depletion. To lower the water use, future research should look to design alternative cleaning measures and/or rearing vessels with more favourable volume/surface ratio. PROteINSECT also recommends the design of suitable automated separation devices to reduce the labour costs of manual separation. As each of the processes above included cumulative cleaning and labour efforts, it is advisable to aggregate rearing steps and minimise the technological setup to benefit from economy of scale effects.

It has been further established that the application potential of these novel manure treatment and protein production concepts is subject to site-specific geographical and socio-economic circumstances. Regions with year-round high temperatures, high density of concentrated animal operations and presence of food processing industry facilities appear most suitable. The geographical context and the utility of the co-products, i.e. residue substrates and insect products, were determined as influential variables to the application potential. However, to find the appropriate point of reference, further research is required to evaluate the value of the co-products from insect production.

The initial results from the PROteINSECT studies, applied at the earliest stages of the design of these processes, assist evaluation of the feasibility of such systems and provide guidance for future research and development activities.

Next Steps for PROteINSECT

The life cycle analysis work within the PROteINSECT project is ongoing, with full results from the economic, social and economic assessments expected later in 2015. These outputs will include production scenario analysis and policy and technical recommendations. Such technical recommendations will include insect rearing station integration options for farms in Europe, Africa and China.

8. Waste Management

Headlines

- Supply of organic wastes is increasing along with demand for animal products.
- Insect larvae are excellent organisms for the extraction of protein from waste materials.
- Larvae can reduce the mass of organic waste by up to 60% in 10 days.
- Residual insect digestate can be exploited for added value products including fertilizer.

Organic waste

'The European Union generates 88 million tonnes per year of biodegradable organic waste (BOW) material (food waste, garden and public parks waste)' (EC NOW Project, 2011)

Food Waste

'In the EU, food waste along the supply chain has been estimated at approximately 89 million tonnes or 180 kg per capita per year, and is expected to rise to about 126 million tonnes a year by 2020, unless action is taken.' (EPRS, Jan 2014)

Manure

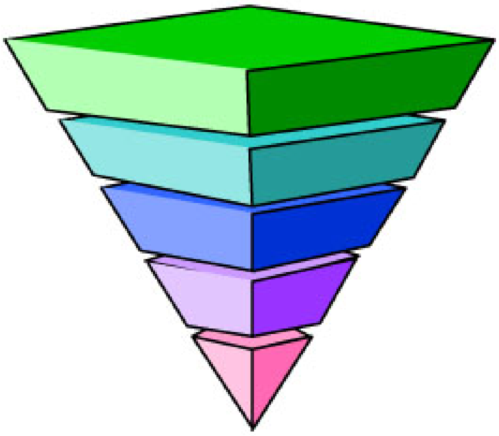
'It is estimated that as much as 1.4 billion tonnes of manure is produced by EU member states annually.' (Foged, 2011)

EU Waste Framework Directive

The EU Waste Framework Directive (http://ec.europa.eu/environment/waste/framework/) provides the legislative framework for the collection, transport, recovery and disposal of waste, and includes a common definition of waste. The directive requires all member states to take the necessary measures to ensure waste is recovered or disposed of without endangering human health, or causing harm to the environment and includes permitting, registration and inspection requirements.

The directive also requires member states to take appropriate measures to encourage firstly, the prevention or reduction of waste production and its harmfulness and secondly the recovery of waste by means of recycling, re-use or reclamation or any other process with a view to extracting secondary raw materials, or the use of waste as a source of energy. This is known as the waste hierarchy (See Figure 8.1).

Figure 8.1 The Waste Hierarchy



Specific information on the legislation for the use of organic wastes as a substrate can be found in section 9. Legislation.

Insects as waste managers

The biological reprocessing of organic waste is a key concept underpinning the use of insect protein in animal feed. The potential for insects to be used to exploit waste streams to produce useful products was proposed over 40 years ago, primarily as a means of reducing animal manure volumes and the generation of insects that could be fed to appropriate livestock.

The predicted increases in livestock production that are likely to occur over the next 30-40 years will of course be mirrored by increases in waste mass. Whilst some uses are found for these wastes, such as compost and biogas generation, insects have the potential to utilise these wastes as food and effectively convert it into high value materials, including protein. Many may be suitable developmental substrates for a number of dipteran fly species, and as such constitute an unexploited resource for the production of protein.

Insects are not only able to provide the potential to extract protein from waste material but also facilitate significant reductions in waste volume. It has been shown that Dipteran larvae can reduce the mass of organic waste by up to 60% in 10 days (Miller et al., 1975, Sheppard, 1983).

There is evidence that the remaining digestate can be exploited for added value in a number of ways. This is based on the fact that fly digestion only reduces the values of key elements (N, P, K, C) within the substrate by 40-60% (Newton et al., 2005). Such potential uses for residual material include compost, fertiliser, soil remediation material, and as a substrate for biogas generation (anaerobic digestion).

To date little research has been conducted to enable a thorough evaluation of the potential added value to be gained from insect digestate, either at a local or national level and exploiting these materials will add significant value to the process of protein generation.

It is desirable to rear flies on organic waste substrates produced by the agriculture and food industries for two important reasons.

1. It would enable low value waste products such as manure and catering waste to be converted into a high value source of protein.

2. It would simultaneously facilitate significant reductions in waste volume.

88 million tonnes of garden and kitchen waste is produced in the EU with 40% ending up in landfill sites (European Union, 2010) thus waste management is a serious issue. Fly larvae have the potential to drastically lower this volume of waste as they are capable of reducing the mass of organic waste by up to 60% over a period of ten days (Sheppard, 1983).

Developing economic uses for residues

The potential exploitation of residual materials is a secondary goal of the PROteINSECT project. PROteINSECT is aiming to ascertain the most economically viable end-use of the materials that remain following digestion by insect larvae. The use of residues as fertiliser is particularly attractive given the recent variations in global prices of chemical fertilisers, with prices fluctuating by more than 400% for particular blends over the last 10 years (Index Mundi).

Preliminary studies have suggested that residues can be utilised as an agricultural fertiliser (unpublished results). However, the sporadic and localised occurrence of insect production systems has, to date, prevented any systematic evaluation or analyses of the potential values of residual flows. PROteINSECT is advancing the state of the art by carrying out a comprehensive evaluation of residues derived from a number of different insect/substrate combinations under a range of climatic conditions. A combination of chemical analyses and laboratory and field scale studies is enabling the added value of residual flows to be ascertained. Other potential down-stream uses, such as anaerobic digestion for the production of biogas, are also being assessed.

Supporting the circular economy

A circular economy is one in which resources are kept in use for as long as possible. This is made achievable by extracting the maximum value from each resource whilst in use, then recovering and regenerating products and materials. The use of organic waste and manures as a feed substrate for the production of protein for feed, and a digestate product for use as a fertilizer (for example), matches the requirements of such an economy as it reduces waste, drives greater resource productivity and reduces the environmental impacts of current waste disposal.

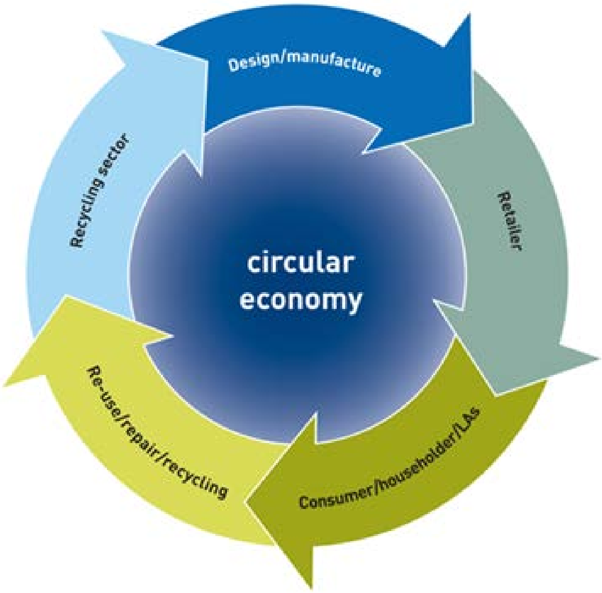


Figure 8.2 Supporting the Circular Economy
Source: **WRAP and the Circular Economy**

9. Legislation and Regulation

Headlines

- In the European Union, the use of insects as a source of protein for animal feed for animals raised for human consumption is currently not possible due to requirements under Regulation EC 999/2001. Insect protein reared on plant based material for pets is not covered by these requirements and is permitted in pet food.
- Under the current regulations, it would not be possible to rear flies on manure or catering waste.
- PROteINSECT believes it is unlikely that insects will be permitted in Europe for animal feed until thorough consideration of the safety of their use has been made and diagnostic methods for the detection of processed insect protein in animal feed are available to ensure species origin detection.

Introduction

At present, conservative European laws concerning the use of insects in feed and food are seen as a major barrier to potential investors and thus market entry for insect-derived protein. In order to support and encourage the development of industrial-scale insect-rearing plants, appropriate safety and quality data must be available so that the relevant current legislation and regulation can be reviewed.

PROteINSECT undertook a review of existing legislation and regulation relevant to the use of PAP (processed animal protein) from insects in animal feed, primarily from a European perspective but also in Ghana, Mali, and China. The report 'PROteINSECT Mapping Exercise Report Legislation & Regulation: Europe and Africa & China' is freely available to download here.
(http://www.proteinsect.eu/index.php?id=37.)

Legislation specific to the use of insects in animal feed

Within the Catalogue of Feed Materials (EC 68/2013), there is no specific entry for 'insect meal' although there is a listing for 'whole or parts of terrestrial invertebrates' suggesting that the use of insect protein in animal feed may be possible providing insects are not pathogenic to humans or animals. If they are to be used for feed, insects must meet the requirements of Directive EC 2002/32 on Undesirable Substances in Animal Feed. This sets the maximum permitted levels of contaminants such as heavy metals. Additionally, in any case where the insects are not fed live but processed, all requirements as laid down in the EU Animal By-Products Regulation 1069/2009 - and its implementing regulation EC 142/2011 - to become processed animal protein (PAP) have to be complied with before they can be fed to animals. Imported insect material from non-EU countries must also be processed in accordance with this regulation. Furthermore, under this regulation, non-pathogenic insects are classed as category 3 material and are therefore deemed suitable for feeding to farmed animals.

However, in response to the BSE outbreak, regulation EC 999/2001 prohibited all PAP, with the exception of hydrolysed proteins, from being used in animal feed. This ban has now been partly lifted and under regulation EC 56/2013, PAP derived from non-ruminants is allowed to be fed to aquaculture species.

Importantly, regulation EC 56/2013 does not apply to processed insect protein. This is because the regulation concerns slaughterhouse processing procedures and thus is not applicable to the production of animal protein. Ultimately, this means that the feeding of insect protein to aquaculture or any other farmed animals is not currently permitted under EU law.

Legislation relevant to substrates used to rear insects

It would be desirable to rear flies on organic substrates currently considered as waste produced by the agriculture and food industries for two important reasons.

Under EC regulation 1069/2009, insects reared for the production of PAP would currently be considered 'farmed animals' and therefore would be subject to the relevant regulation. The same regulation states that manure is classed as category 2 material and only category 3 material can be used as feed for farmed animals. Catering waste is classed as category 3 material; however, currently it is prohibited to feed catering waste to farmed animals, other than fur animals (DEFRA 2013).

If insect rearing is confined to category 3 materials there will be a missed additional economic and environmental opportunity of using organic wastes for protein production.

Additionally, EC regulation 767/2009 provides a list of materials that cannot be placed on the market or used for animal feed. There is an entry for 'Faeces, urine and separated digestive tract content resulting from the emptying or removal of digestive tract, irrespective of any form of treatment or admixture'. Therefore it appears that under the current regulations, it would not be possible to rear flies on manure or catering waste.

In contrast, by-products from bioethanol production such as wheat protein and barley hulls are listed in the Catalogue of Feed Materials (EC 68/2013) and thus could be used as a substrate on which to rear flies.

Summary of areas that need to be addressed

The PROteINSECT mapping report highlights several areas that need to be addressed from a regulatory perspective before the large-scale production of insect protein reared on organic waste substrates for animal feed and food can take place in Europe.

(1) Firstly, although PAP from non-ruminant origin is currently permitted in aquaculture feed and will likely be permitted in pig and poultry feed in the future (provided interspecies recycling remains prohibited), these legislative changes do not apply to insect protein. Therefore, legislation that

specifically addresses the use of insect PAP in animal feed needs to be developed, provided that it is demonstrated to be safe. Encouragingly, this is a topic which is under discussion at a European level (see below).

(2) Secondly, following a thorough safety analysis (including the safety of those employed in the industry), consideration should be given to adjusting current legislation to permit the rearing of insects on organic waste substances such as manure. This would facilitate a significant reduction in waste volume.

(3) Thirdly, it is necessary to address new issues that will accompany the mass production of insect protein and implement the appropriate regulatory measures. Specifically the associated environmental impact and animal welfare concerns should be taken into account.

Finally, clarification of the status of insects as a novel food is required so that a consistent approach can be taken across the EU with regards to placing insects on the market for human consumption. It is believed that the forthcoming novel food regulation (COM (2007) 872 final) will address the current ambiguities.

Current situation regarding potential changes to EU legislation concerning insect protein

The cumulative impact of this evidence of the potential of insect protein is that discussions are currently underway within the Safety of the Food Chain Committee of European Commission Health and Food Safety Directorate Central (DG SANTE) to consider changing EC Regulation 999/2001 to allow the feeding of insect protein (PAP) to non-ruminant animals. Also an amendment of Regulation EC 142/2011 is in discussion to expand the potential feed materials for farmed insects.

In May 2014 DG SANCO (now DG SANTE) requested 'an initial scientific opinion on the safety risks arising from the production and consumption of insects as food and feed' be made by the European Food Safety Authority (EFSA). The European Commission has asked EFSA to assess the microbiological, chemical and environmental risks arising from production and consumption of insects as food and feed. The assessment of those risks will cover the main steps from production to consumption:

1. Production (farming of insects): production process including substrates (feedstock) for the insects;
2. Processing: manufacturing of insects to insect products;
3. Consumption of the products by pets, food producing animals and humans considering the composition of the products and potential microbial and chemical contamination.

In addition, EFSA was requested to provide an overall conclusion based on the above assessments, on the risks posed by the use of insects in food and feed, *relative to such risks* posed by the use of other proteins sources used in food or feed.

The list of insect species to be covered by the assessment is as follows:

- *Musca domestica*: Common housefly
- *Hermetia illucens*: Black soldier fly
- *Tenebrio molitor*: Mealworm
- *Zophobas atratus*: Giant mealworm
- *Alphitobus diaperinus*: Lesser mealworm
- *Galleria mellonella*: Greater wax moth
- *Achroia grisella*: Lesser wax moth
- *Bombyx mori*: Silkworm
- *Acheta domesticus*: House cricket
- *Gryllodes sigillatus*: Banded cricket
- *Locusta migratora migratorioides*: African migratory locust
- *Schistocerca americana*: American grasshopper

EFSA has formally accepted the request to develop an opinion to assess the microbiological, chemical and environmental risks arising from production to consumption of insects as food and feed in collaboration with national risk assessment bodies. To date, EFSA has established a working group composed of experts from the EFSA Scientific Committee and Panels and external experts and is progressing the development of its scientific opinion. EFSA proposes a deadline for finalisation of the scientific opinion of September 2015.

If EFSA has access to enough robust data to reach a favourable scientific opinion and amendments to the legislation are recommended, this will be a positive enabling step to the production and use of insect protein reared on organic waste as animal feed. If insects are to be reared on organic waste other areas of legislation and regulation will need to be changed (EC regulation 1069/2009), and standards established concerning the methods of production and processing.

10. Consumer understanding and perception

Headlines

- Over 70% of people completing PROteINSECT's first benchmark survey stated they would be willing to eat fish, chicken or pork from animals fed on a diet containing insect protein.
- Two thirds of survey respondents said that the larvae of flies are a suitable source of protein for use in animal feed.
- There is a desire for more information on the use of insect protein in animal feed to be made available to the public.
- The tone of the media coverage in both consumer and trade publications tracked and analysed by PROteINSECT is overwhelmingly neutral or positive.

Introduction

One of the major challenges facing the use of insect protein in animal feed is public acceptance. In Western society, the use of insects in animal feed and food is rarely practiced. A lack of a cultural history of entomophagy means that insects are associated with a 'yuck factor' and are commonly viewed as vectors of disease or pests. Moreover, a number of high profile food scandals in recent decades means that consumers are becoming increasingly interested in how the food they eat is produced. Thus, if insect protein is to be introduced into animal feed, it is important that this is carried out in a transparent manner with consumers consulted and informed throughout the process.

Ultimately, public acceptance of the use of insect protein in animal feed will be vital to the success of the development of a successful insect protein market within Europe.

PROteINSECT consumer perception survey

"

If the practice is safe, then I have no problems with it"

"I don't feel ready to eat insects even though it is food, but I really like the idea of using larvae or insects to raise chicken or fish or pork, or even shrimps"

"It seems like a very "natural" way to go about this, which is appealing"

"If meat fed on insects did not taste any different, then I would not have a problem eating meat raised on insect feed".

"I don't like interfering with our food chain in this way"

"The costs of processing and making 'safe' may be prohibitive"

"Does not seem ethical"

"I personally think the idea is disgusting"

PROteINSECT conducted a baseline survey in 2013/14 in order to achieve an initial benchmark of public opinion. A consumer survey of such scale and topic had not previously been undertaken within Europe. The survey aimed at finding out whether people would be willing to eat chicken, pork or fish derived from animals fed with insect protein and to gain an understanding of what types of substrate people think are suitable on which to rear insects if they are to be used in animal feed. The survey also looked to gain an understanding of how many people have eaten insects and what species are the most popular.

The survey consisted of 16 questions and was made publicly available in English, French and German for a period of 6 months. The survey was completed by 1302 people from 71 countries with the top five responses from the UK (27.3%), Mali (8.5%), China (8.2%), Poland (6.7%) and France (6.3%). The majority of respondents (56.4%) identified themselves as consumers with the second largest group being researchers (29.0%). Finally, 86.5% of people said that they had no dietary restrictions.

The full results of the survey can be found here (http://www.proteinsect.eu/index.php?id=37).

Key findings

Insects in animal feed

- 72.6% of people who responded would be willing to eat fish, chicken or pork from animals fed on a diet containing insect protein. Only 6.5% said that they would not.
- 65.8% of respondents said that the larvae of flies are a suitable source of protein for use in animal feed and only 6.1% saying no.
- When asked whether chicken, fish and pork, for sale for humans, and fed on protein from insects should state that clearly on the food label, 57.2% said yes, whilst 30.1% said no. The remaining 12.7% of people replied that they don't know. No assessment was made as to the how often consumers read food labels.

The substrate used to produce insects for animal feed

- The survey was used to evaluate the public's acceptance of manure substrate compared to other potential waste materials. The following options were available: vegetable waste, food waste e.g. from supermarkets, chicken manure, other animal manure, abattoir waste, all of the above or I don't know.
  - 30.3% of respondents believed that all of the waste materials were suitable
  - The most popular single answer was vegetable waste with 64.0% and was followed by food waste from supermarkets accounting for 51.0% of replies
  - Abattoir waste was the least popular option with 22.4%

Need for more information

One of the key findings from the survey is a desire for more information on the use of insect protein in animal feed to be made available to the public. A total of 88.2% of respondents answered that more information should be made available on the use of insects as a food source for animals and humans.

Media coverage of insects as food and feed

During the last 12 months PROteINSECT has monitored hundreds of pieces of media on the topic of insects in food and feed. The majority of media coverage identified consisted of online articles with a smaller number of television and radio items.

The tone of the media coverage tracked was overwhelmingly neutral or positive when discussing the use of insects as an ingredient for food or animal feed with just 1% of coverage being negative. Many articles chose to mention environmental and nutritional benefits associated with entomophagy. The use of insects for human food was the most popular subject matter in the media, with two-thirds of articles about insect consumption and less than one-third about insects for feed. 70% of media coverage to date has come from sources aimed at the general public, whilst 30% was found in specialist publications – mostly trade magazines aimed at the agricultural or feed industries.

Next steps

PROteINSECT is conducting an additional information gathering exercise on consumer understanding and perceptions throughout 2015. The focus of this work is to:

- Benchmark attitudes about the use of insect protein against existing and other novel sources.
- Measure current levels of understanding of animal feed content and perceptions as to how much information consumers require.
- Gauge perception and understanding of the 'greenness' (sustainability) of existing and other novel protein sources (including insects).
- Target the section of the European population which recorded low response rates previously (particularly 14-18yrs)

The information gathering exercise is available in multiple European languages on the PROteINSECT website (www.proteinsect.eu).

PROteINSECT will also continue to monitor and analyse media activity for insects as food and feed until 2016.

Conclusion

The PROteINSECT survey provided a benchmark overview of the current levels of public opinion regarding the use of insect protein in animal feed and other related issues. The results suggest that people are generally accepting of the idea of insect protein in feed and food; however, one of the clearest messages resulting from the survey is that there is a strong desire for more information to be made available to the public.

Continued public engagement and the sharing of information are vital in order to increase public awareness of the potential of insect protein in animal feed.

PROteINSECT will continue to map and evaluate acceptance of the use of insects as a protein source for feed throughout the life of the project.

11. Commercial potential

Introduction

The development of alternative and additional protein sources to feed the growing global demand is not a new concept and consumer acceptance can be demonstrated. In 1985 a joint venture between a food company (Rank Hovis McDougall) and a chemicals company (ICI) launched a Mycoprotein derived from *Fusarium venenatum* fungus under the brand name Quorn. Over subsequent years this 'novel' business has grown in value at the following rates:

- 2003 Quorn sold for £72m
- 2005 Quorn sold for £172m
- 2011 Quorn sold for £205m

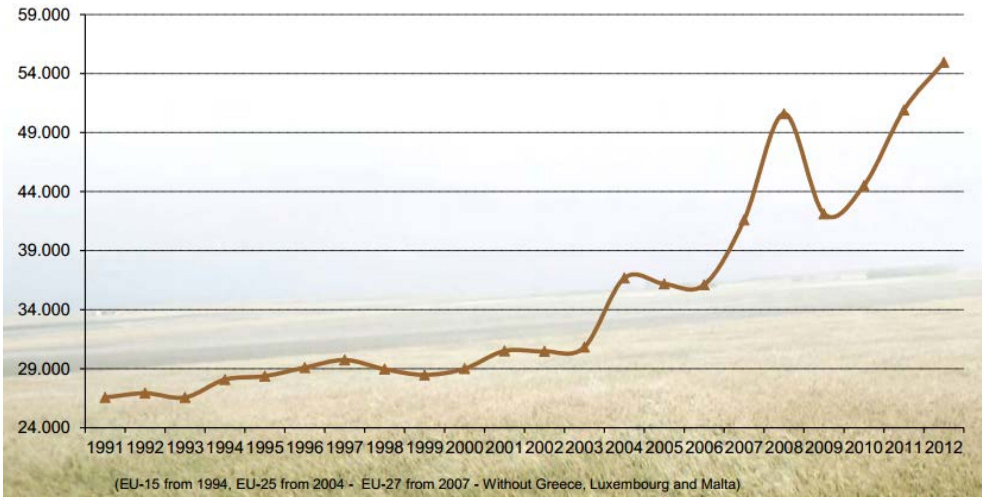
Although Quorn offers a direct meat substitute, rather than a feed supplement such as insect derived protein sources, it is clear that market development of 'novel' protein sources is both possible and proven.

Current scale of feed market

Livestock

In 2013 the value of livestock production in the 28 European Union Member States (EU-28) amounted to €169.5 billion; this accounts for 41% of the overall agricultural output to €415.5 billion (FEFAC, 2013). Purchases of compound feed have risen significantly over the last 10 years to €55 billion (FEFAC, 2012) in 2012. Figure 11.1 (below) shows the compound feed industry turnover since 1991.

Figure 11.1 Compound feed industry turnover (Million Euros), FEFAC.



Source: The compound feed industry in the EU livestock economy, 2012

Aquaculture

Aquaculture production by the EU-28 reached 1.108 million tonnes and a value of €3.365 billion in 2012 and showed growth of 3.4% and 3.8% respectively on the previous year (Eurostat). EU aquaculture production is mainly concentrated in 4 countries: Spain, United Kingdom, France and Greece, making up 71% in volume and 70% in value of EU28 totals. Of the main aquaculture species produced, in weight terms the carnivorous Atlantic salmon and Rainbow trout accounted for 14% and 11% respectively. The most important costs of the EU salmon aquaculture sector are the feed costs, which represented 42% of the total costs in the combined segment and 27% of the costs in the cages segment in 2012 (EU Aquiculture Report, 2014).

Future demand

The global population is estimated to grow by 2 billion by 2050 (United Nations, 2009). The demand for meat has already increased fivefold since the Second World War (FAO, 2002) and it is estimated that global meat demand in 2030 will stand at 72% above the 2000 value of 233 million tonnes (Kanaly et al., 2010). The global production of aquaculture products has increased rapidly from about 3 million tonnes in 1970 to 90 million tonnes in 2012 and is the fastest growing animal food producing sector in the world (Asche and Bjørndal 2011). Fish production is expected to grow by 23.6% during the 2010–30 period (Word Bank, 2013).

Changing consumption patterns are associated with income growth, increasing urbanisation, changes in lifestyles and food preferences. The demand for feed to maintain this meat consumption growth is demonstrated by coarse grain production (predominantly used for feed) which is projected to grow by 20% by 2023 (CAP2020, July 2014).

Production

Commercial insect rearing already exists both within and outside Europe. Agriprotein, a South African company established in 2009, is considered the world leader in the mass production of fly larvae. The company is focussed on nutrient recycling using organic wastes to produce insect based protein feed, extruded oil, and fertilisers. While it first focused on house-flies, its commercial products are now based on a black soldier fly production system. Its first industrial scale factory was established in 2014 and has a current capacity of 800 kgs wet larvae per day. The goal is to produce 7 tonnes of insect meal, 3 tonnes of oil and 20 tonnes of fertiliser per day and the company aims to establish 10 similar sites by 2020. Maggots are 'farmed' in a factory that uses a combination of automated and labour intensive processes.

For more information on current production systems and suppliers of insect protein within and outside of Europe see section 3. Insect Production.

Barriers to market

There are currently several barriers to market entry:

- The current lack of robust safety data is holding up progress on the development and discussion of appropriate legislation within Europe. See section 9. Legislation and Regulation.
- Additional nutritional quality data is required to show the potential of the use of insect protein for feed and added value products. See section 5. Insect Nutritional Properties and Suitability in Animal Diets
- Consumer acceptance of insect protein in animal feed has not been fully evaluated. See section 10. Consumer Understanding and Perception.
- The current production processes are labour intensive and require further development of a semi-automated system to ensure their long term economic viability. See section 3. Insect Production.

It is worthy of note that the EC-funded PROteINSECT project is working to address the shortfalls in safety and quality data and to assess the current state of both consumer perceptions and production systems. PROteINSECT will be releasing results throughout 2015.

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