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Report 638

Insects as a sustainable feed ingredient in pig and poultry diets - a feasibility study

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Abstract
A feasibility study on the potential feed production chain “biowaste – insects – pig and poultry feed” was performed. Opportunities and challenges were evaluated in a desk study and a workshop with stakeholders and experts, to identify the opportunities and challenges for the industry and scientists for the use of insects as a sustainable feed ingredient in pig and poultry diets.

Keywords
Insects, protein, sustainability, feeding value, safety, legislation, economics

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Title
Insects as a sustainable feed ingredient in pig and poultry diets - a feasibility study

Report 638

Samenvatting
Een haalbaarheidsstudie naar de potentiële diervoederketen “biowaste- insecten- varkens en pluimveehouders” is uitgevoerd. Kansen en belemmeringen zijn geëvalueerd in een deskstudie en een workshop met stakeholders en experts om de kansen en belemmeringen te identificeren voor de industrie en wetenschappers ten aanzien van het gebruik van insecten als duurzame eiwitrijke veevoergrondstof in varkens- en pluimveevoeders.

Rapport 638

Trefwoorden
Insecten, eiwit, duurzaamheid, voederwaarde, veiligheid, wetgeving, economie

Report 638

Insects as a sustainable feed ingredient in pig and poultry diets - a feasibility study

Insecten als duurzame diervoedergrondstof in varkens- en pluimveevoeders - een haalbaarheidsstudie

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October 2012

Preface

Planet earth and its human population are struggling with increasing volumes of bio-waste streams and a growing food demand by an ever increasing number of people. There is a need for innovative solutions to meet these challenges.
This report describes the set-up and results of a feasibility study to explore application of insects, grown on bio-waste and organic by-products, as a sustainable high protein feed ingredient in pig and poultry diets, to be able to produce food of animal origin. This study was conducted by Wageningen UR on request of The Ministry of Economic Affairs, Agriculture and Innovation in The Netherlands.
On behalf of all authors, I thank colleague scientists, consultants, policy makers and industry representatives who provided us with useful information, experiences and recommendations as inputs for this study. I hope that this report will enhance innovations in the valorisation of bio-waste streams and by-products and moreover will contribute to sustainable protein production to meet the future global protein demands.

Dr. Gert van Duinkerken
Project leader

Abstract

A feasibility study to explore application of insects as a sustainable high protein feed ingredient for pig and poultry diets was conducted on request of the Dutch Ministry of Economic Affairs, Agriculture and Innovation. This feasibility study comprised a desk study and a workshop with participants representing the various links in the “insect chain”. The objective of the study was to list, in a joint initiative of industrial stakeholders and scientists, how insects can be used on a large scale as an alternative protein source in feed for pigs and poultry.

The use of insects as a sustainable protein rich feed ingredient in pig and poultry diets is technically feasible. Insects can be reared on low-grade bio-waste and can turn this bio-waste into high quality proteins. Insects therefore can be an interesting link in the animal feed chain to fulfil the globally increasing demand for protein. Results from the workshop indicate that it is feasible to use insects on a large-scale as future feed ingredient. However, opinions differed on whether it would be possible to do it within five years or more. It was generally expected that the use of insects as a feed ingredient in aquaculture is the nearest future application, as well as the use in pet foods. The application of insects in poultry and pig feeding was also considered realistic. Main bottlenecks were identified in the area of legislation and the achievement of a low cost price by an automation of the production process.

To introduce insects as a feed ingredient in the pig and poultry feed chain, additional research is recommended on its feeding value, inclusion levels in poultry and pig diets, functional properties of the feed ingredient, safety when using bio-waste as a rearing substrate, extraction of nutrients, shelf-life, and use of left-over substrates and residue products of insects.

Samenvatting

Insecten kunnen een duurzaam onderdeel zijn van varkens- en pluimveevoeder (Nederlandse samenvatting van de haalbaarheidsstudie)

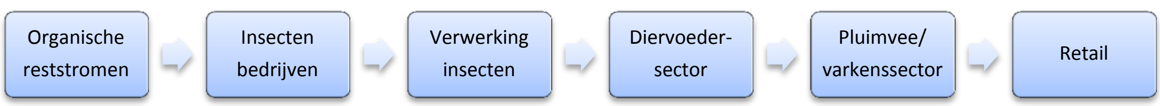
Een haalbaarheidsstudie naar insecten als duurzame eiwitrijke diervoedergrondstof in varkens- en pluimveevoeders is uitgevoerd in opdracht van het Ministerie van Economische Zaken, Landbouw en Innovatie. De haalbaarheidsstudie omvatte een desk-studie en een workshop met stakeholders uit de verschillende schakels van de ‘insectenketen’. De doelstelling van de studie was om in samenwerking met stakeholders uit de ‘insectenketen’ en wetenschappers te onderzoeken of en hoe insecten op grote schaal ingezet kunnen worden als alternatieve eiwitbron in voer voor varkens en pluimvee.

Resultaten van de desk-studie wijzen uit dat het gebruik van insecten als duurzame eiwitrijke grondstof in varkens- en pluimveevoeders technisch haalbaar is. Insecten kunnen laagwaardige biomassa, bijvoorbeeld allerhande rest- en nevenstromen, efficiënt omzetten in hoogwaardig eiwit. Insecten kunnen daarom een interessante schakel vormen in de diervoederketen en voor een deel invulling geven aan de mondiaal stijgende vraag naar eiwitten.

Resultaten van een workshop wijzen uit dat de toepassingen van insecten als grondstof in de visvoeding het dichtst bij liggen, evenals in petfood. Er zijn echter ook reële kansen voor het gebruik van insecten in pluimvee- en varkensvoer. Meningen lopen uiteen over de termijn waarop deze toepassing haalbaar is; reeds binnen vijf jaar of langer dan vijf jaar. De belangrijkste belemmeringen die nog weggenomen moeten worden voordat insecten op grote schaal als diervoedergrondstof kunnen worden gebruikt, liggen op het terrein van wet- en regelgeving en in de snelheid waarmee schaalvergroting van de insectenproductie en kostprijsverlaging gerealiseerd kunnen worden.

Kunnen insecten ingezet worden als duurzame alternatieve eiwitbron in varkens- en pluimveevoeder?
De doelstelling van het project was om in samenwerking met bedrijfsleven en wetenschappers te onderzoeken of en hoe insecten op grote schaal ingezet kunnen worden als alternatieve eiwitbron in voer voor varkens en pluimvee.

De insectenketen is een belangrijke schakel in het sluiten van de voederkringloop
Insecten kunnen een duurzame alternatieve eiwitrijke grondstof zijn, in het bijzonder wanneer de insecten worden gekweekt op substraten van organische afval- en nevenstromen. Insecten zijn koudbloedig en kunnen hierdoor efficiënt laagwaardige biomassa opwaarderen tot hoogwaardig eiwit. Voor deze studie is ervan uitgegaan dat een insectenketen zou kunnen bestaan uit verschillende schakels zoals aangegeven in het volgende processchema:



Organische zijstromen lijken geschikt om als substraat te dienen voor de kweek van insecten. De meest interessante insectensoorten voor grootschalige productie zijn Zwarte Soldatenvlieg (Black Soldier Fly, BSF, *Hermetica illucens*), de huisvlieg (Housefly, *Musca domestica*) en de Gele meelworm (Yellow Mealworm, *Tenebrio molitor*). De voortplantingscyclus van deze insectensoorten is kort en van deze soorten wordt verwacht dat zij laagwaardige organische zijstromen efficiënt kunnen omzetten in hoogwaardig eiwit. De gekweekte insecten dienen daarna verder verwerkt te worden voor toepassing in diervoeders. Het verder verwerken (technologisch bewerken) van insecten kan worden uitgevoerd op insectenbedrijven of op gespecialiseerde verwerkingsbedrijven. Het eindproduct kan een insectenmeel van hele insecten zijn of dat van een water onoplosbare eiwitfractie. Voor deze laatste fractie is het noodzakelijk dat andere eiwitfracties zoals bijvoorbeeld chitine of water oplosbare eiwitten een toepassing krijgen in ‘food’ of ‘pharma’ om voldoende toegevoegde waarde te kunnen realiseren. Voor een brede toepassing van insecteneiwit in mengvoeders zijn grote hoeveelheden nodig. Wanneer bijvoorbeeld 5% van het mengvoeder voor vleeskuikens in Nederland vervangen zou worden door insecten dan is een hoeveelheid van ongeveer 72000 ton insecten nodig per jaar. Een haalbare productie-unit van insecten kan ongeveer 1 ton per dag aan insecten produceren (dit is 365 ton per jaar). In totaal zijn voor dit productievolume van 72000 ton per jaar ongeveer 200 insectenbedrijven nodig.

Voederwaarde van insecten ziet er veelbelovend uit

De chemische samenstelling van de verschillende levensfasen van de zwarte soldatenvlieg, de huisvlieg en de gele meelworm zijn bestudeerd in de literatuur. Er is weinig informatie gevonden over drogestofgehalten. De mediaan van het drogestofgehalte was vergelijkbaar tussen de meeste insectensoorten en was ongeveer 40%; met uitzondering van de zwarte soldatenvlieg die een drogestofgehalte had van 26,8% (dit betrof slechts één studie). Het ruw eiwitgehalte van insecten varieerde aanzienlijk tussen insectensoorten en levensfasen maar ook binnen insectensoorten en levensfasen. Het hoogste ruw eiwitgehalte is gevonden voor de poppen van de huisvlieg (65,7% van de droge stof) en het laagste ruw eiwitgehalte voor larven van de zwarte soldatenvlieg (38,9% van de droge stof). Meelwormen en larven van de huisvlieg hadden vergelijkbare ruw eiwitgehalten van respectievelijk 49,3 en 50,8% van de droge stof. Voor wat betreft het vetgehalte zijn data gevonden voor larven van de meelworm (36,1% van de droge stof) en larven van de huisvlieg (19,5% van de droge stof) maar voor andere insectensoorten en levensfasen zijn nagenoeg geen data gevonden. Het vetgehalte varieerde aanzienlijk tussen verschillende studies. De eiwitkwaliteit van insecten is vergeleken met de eiwitkwaliteit van sojaschroot door vergelijking van de aminozuurprofielen en de essentiële aminozuur index (EAAI). Elk insect en elke levensfase laten zien dat de EAAI waarde hoger dan 1 is wat betekent dat deze eiwitbronnen meer essentiële aminozuren leveren dan de behoefte van de dieren waaraan ze worden gevoerd. Er is weinig informatie gevonden over de nutriëntenverteerbaarheid van de insecten in de doeldieren (varkens en pluimvee). Er zijn drie studies uitgevoerd waarin de fecale verteerbaarheid van insecten is bepaald. In vleesvarkens was de eiwitverteerbaarheid gelijk en de vetverteerbaarheid van de larven hoger dan van sojaschroot. Bij vleeskuikens werd in twee studies de eiwitverteerbaarheid vastgesteld op 69% en 98,5% bij larven van de huisvlieg in vleeskuikens van respectievelijk drie en vier weken oud. De verteerbaarheid van de meeste aminozuren was hoger dan 90%. Aanvullend onderzoek wordt aanbevolen om de voederwaarde van verschillende soorten insecten vast te stellen voor verschillende diersoorten (met name vleeskuikens, leghennen, biggen, vleesvarkens). Deze informatie is essentieel om insecten(producten) op te kunnen nemen in de voerformulering voor varkens en pluimvee.

De kostprijs van de kweek van insecten kan en moet omlaag om in aanmerking te komen als grondstof voor diervoeder

Mensen die betrokken zijn bij de insectenketen stellen dat de prijs voor insecten op productbasis om te gebruiken als grondstof voor varkens- en pluimveevoeders maximaal € 1,00 - € 1,50 per kg bij 88% droge stof mag zijn om competitief te zijn als alternatieve eiwitbron. De prijs van vismeel is momenteel ongeveer € 1,24 en de verwachting is dat de prijs van vismeel de komende jaren verder zal stijgen. Wanneer insecten geproduceerd kunnen worden voor een lagere prijs zullen insecten een economisch goed alternatief kunnen zijn voor vismeel.

De huidige kostprijs van insecten ligt een factor 12 hoger dan voor vismeel. Een reductie van de kostprijs is onder meer mogelijk via:

- Een reductie van de voerkosten door enerzijds de voederefficiëntie van insecten te verbeteren en anderzijds het gebruik van goedkope laagwaardige biomassa
- Een reductie van de arbeidskosten door mechanisatie, automatisering en logistiek
- Een reductie van de huisvestingskosten door schaalvergroting en een efficiënter gebruik van bedrijfsgebouwen
- Een reductie van het energieverbruik door gebruik van warmtewisselaars en optimale ventilatie
- Het gebruik van hoog productieve eiwitrijke insectensoorten
- Een toename van de productiviteit door genetische verbetering van insectensoorten
- Verbetering van de efficiëntie van extractie (in het geval van zuiver eiwit)
- Afname in de verwerkingskosten zoals bijvoorbeeld vriesdrogen.

Wetgeving moet deze ontwikkeling beter faciliteren

Er is nog een aantal belemmeringen op het gebied van wetgeving om insecten te kunnen gebruiken als grondstof in de diervoeding. Deze worden veelal veroorzaakt door het feit dat tijdens het maken van deze wetten er geen rekening gehouden is met de mogelijkheid om insecten als diervoedergrondstof te gebruiken. Insecten worden beschouwd als dierlijk eiwit en dierlijk eiwit mag vanwege de BSE wetgeving niet worden gebruikt in voeding voor varkens en pluimvee. De GMP+ certificatie dient te worden aangepast voor insecten. Aanbevolen wordt om in de Wet Dieren, die per 2013 van kracht wordt, rekening te houden met de kweek van insecten. Dierwelzijn en bijvoorbeeld dodingsmethoden zijn op dit moment nog onvoldoende beschreven en onderzocht. Ten aanzien van de Wet Milieubeheer zijn mogelijk slechts in beperkte mate belemmeringen aanwezig omdat bijvoorbeeld de broeikasgas productie van insecten lager is dan van landbouwhuisdieren. Het is wenselijk een levenscyclusanalyse (LCA) uit te voeren voor de insectenketen en een ecologische footprint (o.a. een carbon footprint) vast te stellen voor de kweek en gebruik van insecten als diervoedergrondstof.

Aanbevelingen voor het bedrijfsleven: Opschaling en Kostprijsverlaging

Voor grootschalige toepassing van insecten als grondstof voor varkens- en pluimveevoeders is het volgende van belang

- Er moet verdere opschaling plaatsvinden waarbij kwantiteit en productie met een constante kwaliteit van een voldoende hoog niveau is
- De kostprijs zal verlaagd moeten worden tot een niveau waarbij de alternatieve eiwitbron kan concurreren met bestaande eiwitbronnen.
- De voederwaarde voor insecten moet nauwkeurig worden vastgesteld van bio-waste producten die dienen als substraat voor de groei van insecten
- De voederwaarde moet nauwkeurig worden vastgesteld van verschillende insectensoorten voor verschillende landbouwhuisdieren zoals varkens en pluimvee.
- De houdbaarheid van insectenproducten zal verbeterd moeten worden
- De insectenketen zal verder vormgegeven moeten worden met stakeholders die een bijdrage kunnen leveren in de verschillende schakels zoals: leveranciers organische reststromen, insectenkweek bedrijven, verwerkers van insecten, diervoedersector, varkens- en pluimveesector en Retail
- De efficiëntie op de insectenkweek bedrijven moet worden verhoogd door bijvoorbeeld
    - verlaging van arbeidskosten als gevolg van innovaties in mechanisatie, automatisering en logistiek
    - verlaging van huisvestingskosten door schaalvergroting en een efficiënter gebruik van bedrijfsgebouwen en verlaging van het energieverbruik door het gebruik van warmtewisselaars en optimale ventilatie
    - zoeken naar afnemers van restproducten van de insectenkweek (resten van substraten en resten van insecten)
- Op verwerkingsbedrijven moeten de kosten voor het verwerken worden verlaagd door technologische innovaties
- In een later stadium kan worden onderzocht of uit insecten eventuele functionele stoffen gehaald kunnen worden die geleverd kunnen worden aan industrieën zoals cosmetica, farmaceutica, textiel of papier. Zo kan aan insecten een additionele waarde worden toegevoegd waardoor deze nog interessanter kunnen worden als gevolg van verdere kostprijsdaling
- Onderzoeksresultaten moeten beschikbaar komen om een snelle introductie van insecten als diervoedergrondstof mogelijk te maken. Dit kan onder andere door grootschalige onderzoeksopdrachten uit te zetten. Hiervoor zijn momenteel mogelijkheden op bedrijfsniveau via innovatiesubsidies, via het ‘Topsectorenbeleid’ maar ook internationaal zijn mogelijkheden binnen EU onderzoekprogramma’s.

Aanbevelingen voor de overheid: Wet- en regelgeving

Voor grootschalige toepassing van insecten als grondstof voor varkens- en pluimveevoeders is het volgende van belang

- In bestaande wet- en regelgeving op moet worden nagegaan of insecten als diervoedergrondstof opgenomen kunnen worden. Hiervoor is het wenselijk dat de overheid ook op Europees niveau overleg voert om insecten toe te laten als diervoedergrondstof.
- Ten aanzien van overdracht van contaminanten (bijvoorbeeld zware metalen, dioxines) onderzoeken of vanuit bio-waste producten (substraat voor de kweek van insecten) overdracht naar insecten plaatsvindt en van insectenproducten naar varkens of pluimvee. De overheid kan hierin faciliterend optreden.

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1 Introduction

Insects have been proposed as a high quality, efficient and sustainable alternative protein source. Using insects as a protein source can contribute to global food security via feed or as a direct food source for humans.
The Dutch Ministry of EL&I initiated this study early 2012 in order to explore application of insects as a sustainable source of feed. This initiative identifies specifically the opportunities and limitations for use of insects in feed.

In 2011, the world compound feed production was an estimated 870 million tonnes and the turnover of global commercial feed manufacturing generated an estimated annual turnover and sales value equivalent to US$350 billion worldwide (http://www.ifif.org/).
The UN Food and Agricultural Organisation (FAO) estimates that the world will have to produce ca. 70% more food by 2050. Concerning animal protein production, the International Feed Industry Federation (IFIF) believes that the production of meat (poultry/swine/beef) will even double. This poses severe challenges to the global capacity to provide enough feed.
Currently, important protein ingredients for animal feed are fish meal, processed animal proteins and soybean meal. However, in the European Union the use of processed animal proteins in animal feed is prohibited due to the TSE legislation, globally land availability for soya cultivation is limited, while marine overexploitation has reduced the abundance of small pelagic forage fish from which fish meal and fish oil is derived. The growing scarcity of resources to produce these increasingly demanded ingredients has doubled prices during the last five years, while it already represents 60-70% of production costs. So, alternative (animal) protein sources for livestock and aquaculture are urgently needed. Insects are such an alternative animal protein source, which can sustainably reared on organic side streams. Reasons are that they have a favorable feed conversion efficiency, likely because they are cold-blooded.

Insects contain between 30% and 70% protein on a dry matter basis. Table 1 shows protein and fat composition of larvae for three insect species in comparison to fishmeal and defatted soybean meal. The protein content of the insect species is within the soybean/fish meal range and fat content is higher especially compared to (defatted) soybean meal.

Table 1 Crude protein and fat content (dry matter basis) of larvae of three insect species compared to fish meal and (defatted) soybean meal

Protein source	Crude protein (%)	Crude fat (%)
Hermetia illucens (Black soldier fly[1])	35-57	35
Musca domestica (Common housefly[1])	43-68	4-32
Tenebrio molitor (Yellow mealworm[1])	44-69	23-47
Fishmeal[2]	61-77	11-17
Soybean meal (defatted)[2]	49-56	3

[1]see Chapter 6.
[2]CVB, 2007.

Efficient use of insects can close the loop in a sustainable circular economy, as shown in Figure 1. The figure indicates the possibility of insects to be used in feed as one of the options. A key element in successful introduction of insects in the feed chain is that multiple quality aspects need to be taken into account. In this respect we refer to the extended quality triangle (Luning and Marcelis 2009, modified from Noori and Radford 1995) which identifies three quality dimensions linked to the product itself. These three elements being insect quality as such, insect availability, and costs are all considered to be crucial for a successful introduction of insect protein in feed and are therefore included in this report. The three quality aspects linked to the organisation, namely reliability, flexibility and service are not considered to be critical in this phase and are thus not taken into account.

More in detail, the technical consultation meeting entitled "*Assessing the Potential of Insects as Food and Feed in assuring Food Security"* held from 23-25 January 2012 at FAO Rome (http://www.fao.org/forestry/edibleinsects/74848/en/) considered as major challenges to use insects as feed: selecting suitable insect species and strains, finding cheap rearing substrate (if possible by utilizing organic waste side-streams, but assuring feedstock safety when rearing insects on organic waste and manure), managing diseases and setting up sanitation procedures, producing a constant supply of high quality insects (including quality assurance), developing innovative and cost-effective production systems, increasing automation/mechanization, safeguarding animal welfare (ethical concerns), establishing a regulatory framework, and elaborating an industrial code of practices/standards. All these aspects can be linked to one or more steps in the feed chain and will be worked out further in this document.

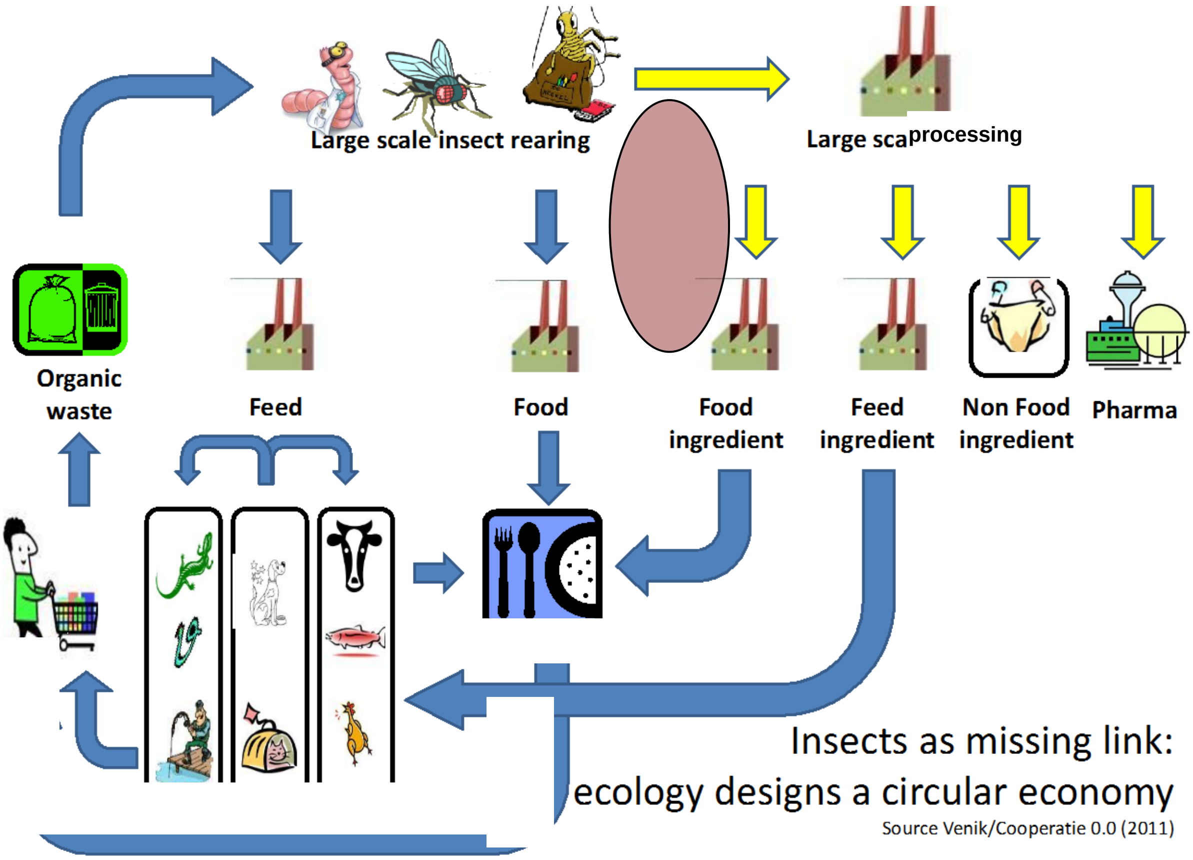

Figure 1 How to use insects in a circular economy

1.1 Aim and approach

The aim of this project is to list, in a joint initiative of industrial stakeholders and scientists, how insects can be used on a large scale as an alternative protein source in animal feed. The focus will be on feed for poultry and pigs. The industrial stakeholders include people from bio-waste industries, insect rearing companies and from the feed, poultry and pig sector. This initiative combines scientists from entomology with food technology and animal nutrition experts.

After consultation of experts in the field, relevant topics were formulated on which a desk study was performed (Chapters 2-6). The results of the desk study were presented in a workshop (June 5th 2012, Wageningen) with 48 participants. The workshop further dealt with visions of several chain players followed by interactive sessions with all participants concerning their view on opportunities and limitations on the use of insect proteins in the feed industry. Outcomes are presented in Chapter 7.

2 Description of the steps in the chain to use insects in feed

To be able to use insects as feed for pigs and poultry the chain and the interactions within the chain will be described in the next paragraphs. Descriptions of the chain starts with bio-waste and insect rearing on organic (processed) side-streams (bio-waste) and descriptions of the chain will end at the poultry/pig sector (Figure 2). Retail/consumer is not included in the descriptions in this Chapter.

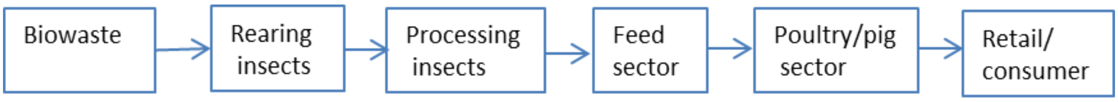

Figure 2 Usage of insects in the animal feed chain

The type of interactions between the different players in the chain will influence whether insects can be successfully implemented as an alternative feed source. Early and extensive supplier involvement in new product development (NPD) projects has the potential to improve its effectiveness and efficiency in term of costs, quality and time to market (Johnson, 2009).

2.1 Bio-waste and rearing insects: *Suitable insect species for large scale rearing*

Until now rearing insects in temperate zones is done by companies on a relatively small scale. To provide insects in sufficient quantities as feed for the poultry and pig sector there is a need to develop large-scale production facilities to establish this. Currently there are about 18 insect rearing companies in the Netherlands. Several of these companies are a member of VENIK[1], the national association for insect rearing companies.

Insects identified as most promising for industrial production in the western world are the Black soldier fly (BSF) (*Hermetica illucens*), Common housefly (*Musca domestica*), and Yellow mealworm (*Tenebrio molitor*). These species receive increasingly attention because potentially they can valorise organic waste, which amounts globally to 1.3 billion tons per year. For example, the European financed Ecodiptera project aimed at reducing the negative environmental impact of pig manure produced on pig farm, by using different fly species.

Ecodiptera project. In 2004, the project co-financed by the European program LIFE was launched to reduce the huge volume of pig manure generated across Europe. Larval flies were used to transform it into fertilisers and protein. In Slovakia, a pilot plant for biodegradation of pig slurry was developed with larvae of flies by adapting existing technology for chicken manure, and the development of methods suitable for the maintenance of colonies of flies and identification of optimal conditions. When the flies reach the pupa stage, they can be used as source for protein rich feed.

Black soldier fly larvae contain a relatively high amount of protein and fat (Table 1), which make them a suitable source of feed for livestock but also for fish. As a component of a complete diet they have been found to support good growth of chickens, swine (Newton, 1977), and also of several commercial fish species (St-Hilaire et al., 2007; Newton et al., 2005; Sheppard et al., 2008). Besides, they can reduce manure pollution potential up to 50-60%, and reduce harmful bacteria and housefly populations. Namely they make manure more liquid and therefore less suitable for house fly larvae. Further, their presence inhibits fly's oviposition (Sheppard 1983; Sheppard et al. 1994). Black soldier flies are naturally found in poultry, pig and cattle manure, but can also occur on organic wastes such as coffee bean pulp, vegetables, catsup, carrion, and fish offal.

[1] Verenigde Nederlandse Insectenkwekers

Housefly larvae (maggots) can provide an excellent source of animal protein for poultry. Also maggots contain a relatively high protein content (Table 1). Maggot production could alleviate the environmental problem of manure accumulation and larvae reduce harmful bacteria. They have even been reared on municipal organic waste as a protein source for poultry. Diets with 25% of fishmeal protein replaced with Maggot Meal Protein was the most efficient in terms of average weekly weight gain and protein efficiency ratio (Awoniyi et al, 2003). From a technical and economic point of view, maggot meal could replace fish meal (Hwangbo et al, 2009).

The company Agriprotein in South Africa (see textbox) already pioneers with large scale fly rearing and processing in order to provide flies as feed for monogastric animals.

Agriprotein: maggots as protein source (http://www.agriprotein.com/)
At the pilot plant of Agroprotein Technologies near Cape Town, the production process starts with rearing stock flies in sterile cages, each holding over 750 000 flies. Two types of waste are used: human waste (faeces) and abattoir blood. A single female fly can lay between 750 to over 1 000 eggs per week, which will then hatch into larvae. Larvae go through three life stages in a 72-hour period, and are harvested just before becoming pupae. The harvested larvae are then dried on a fluidised bed dryer, milled into flake form and packed according to customers' preferences. The product contains 9 essential amino acids with higher Cystine and similar levels of Lysine, Methonine, Threonine and Tryptophan as marine fishmeal. Potential big users would need vast quantities of the product - an estimated 1 000 tons per month. The company now makes two tons per week but aims at improving internal processes to produce 100 tons of larvae per day. A first big factory would require an investment of US$ 10 million, and top countries on the roll-out plan are South Africa, Germany, the UK and the United States.

The Yellow mealworm has been shown to be an acceptable protein source for African catfish and for broiler chickens, and they can be grown on dried and cooked waste materials from fruits, vegetables and cereals in various combinations. HaoChengMealworms Inc., a Chinese company, is a semi-large scale producer and processor of mealworms (see textbox).

Mealworms as feed (http://www.hcmealworm.com/about.php)

HaoCheng Mealworms Inc. at Xiangtan, Hunan province in China produces on 15 companies, 50 tons of living Yellow mealworm (*Tenebrio molitor*) and the superworm (*Zophobas morio*) per month. They are sold alive, dried, canned and as powder for livestock, fish and pets. Two hundred tons dried mealworms are exported each year to North America, Europe, Australia, and Southeast Asia.

2.2 Insect rearing

Black soldier fly (BSF)

In a study the use of substrate by insects has been investigated (Newton et al., 2008). In confined bovine facilities BSF larvae reduced available P by 61-70% and N by 30-50% (Newton et al., 2008). BSF larval digestion of swine manure reduced nutrients as follows: N-71%, P-52%, K-52%, while Al, B, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Na, Ni, Pb, S, and Zn were reduced 38 to 93%. The larvae modify the microflora of manure, potentially reducing harmful bacteria (Erickson, et al., 2004; Liu et al., 2008), e.g. larval activity significantly reduced *Escherichia coli* 0157:H7 and *Salmonella enterica* in hen manure (Erickson et al. 2004). Black soldier fly larvae can be used as animal feed (Newton et al. 1977, Sheppard et al. 1994), as they contain 35-57% protein and 35% fat (Chapter 6). Live larvae contain 27% dry matter and are easily dried for long term storage. As a component of a complete diet they have been found to support good growth of chickens (Hale 1973) and swine (Newton 1977), and a number of commercial fish species (St-Hilaire et al. 2007; Newton et al. 2004; Sheppard et al., 2008). Fish offal (entrails, etc.) can also be fed to the larvae, increasing larval lipid content 30% and omega-3 fatty acids 3% within 24 hours (St-Hilaire et al., 2007).

Swine System 1 (Newton et al., 2005)
Recent developments in rearing BSF allow for waste management in fully enclosed buildings (Figure 3). Swine waste collected by conveyor belt was separated into manure solids and urine plus excess water. Collected manure solids were delivered to the larval culture basin. The larval culture basin contained 85,000 to 100,000 mixed aged larvae/m^2. A 35^o ramp along opposing walls of the manure pit directed the migrating larvae to a gutter at the top. This gutter directed larvae to collection containers. A portion of the larvae was saved and used to support the adult soldier fly colony. Eggs from the adult colony were used to maintain larval densities sufficient to digest the manure. The remaining larvae were dried and processed for rendering or feed preparation. The digested swine manure could undergo further treatment or be land applied as a soil amendment.

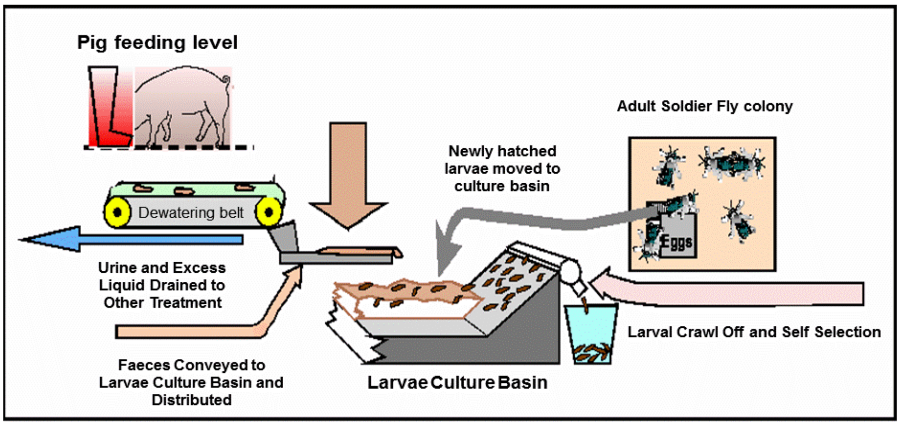

Figure 3 *Hermetia* larvae production away from pigs (Newton et al., 2005)

Swine system 2 (Newton et al., 2005)
If urine and spilled water can be drained or diverted, BSF larvae can be cultured directly beneath pigs housed on slatted floors. Such a system would appear to be readily adaptable to pigs housed in high-rise buildings. A combination of slotted and screened standpipes and laterals within the basin (based on the Ozyboyd Vertical Drainage Bed) has been found to be acceptable for excess liquid removal. These drains are attached to pipes beneath the floor, and can be removed for basin cleaning. The second system for culture on swine manure is illustrated in Figure 4.

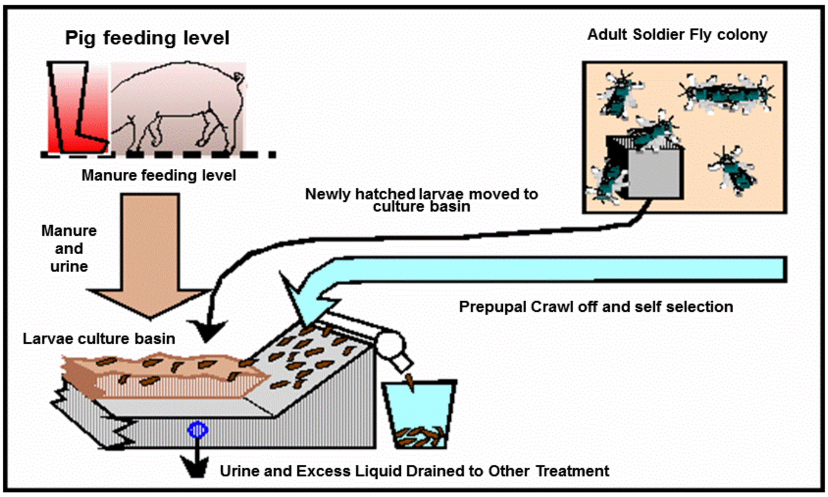

Figure 4 Culture of *Hermetia* larvae directly beneath pigs (Newton et al., 2005)

Conclusion by Newton et al. (2005) for swine systems
During the grow-finish period, larvae collections were 0.214 kg/pig/day for treatment 1 and 0.153 kg/pig/day (P<.03) for treatment 2 (including the first 4-5 weeks when the larvae population was being established and essentially no larvae were collected). This would yield 64,000 kg larvae per year for a house that has 1000 pigs, 2.5 times per year.

A disadvantage of the BSF for biodegradation is that it requires a warm environment, with most of the oviposition occurring at 27.5–37.5°C. Managing high temperatures in temperate regions might prove difficult and energy consuming. Additionally, the developmental period of the BSF under optimum conditions can take from 10–31 days up to 4 months and the pupae stage usually lasts for another 2 weeks, with these times depending on temperatures and the quality and quantity of the larval medium used.

Maggots (housefly larvae)

On a dry matter basis, proximate analysis of house fly larvae meal showed a gross energy value of 20 MJ/kg, 43-68% crude protein and 4-32% crude fat. Looking at the ideal amino acid profile of the diet of broiler chickens, house fly pupae meal was closer to this profile than house fly larvae meal. The content of the essential fatty acid linoleic acid was between 16% (Hwangbo et al. 2009) and 26% (Pretorius, 2011) of the total fat content for the house fly larvae and 15% Calvert et al., 1969), 18% (St-Hilaire et al., 2007) and 36% (Pretorius, 2011) for pupae meal. House fly larvae meal supplementation to broiler diets did not affect gizzard erosion and did not show toxicity in broilers (Pretorius, 2011).

The adult housefly is widely involved in many disease organism transmissions, as the larvae develop in manure and decaying filths. Therefore, maggot meal in diets of livestock raises bacteriological and fungal concerns. However, when separating the rearing of the adult fly from that of the larvae these concerns may be solved. Awoniyi et al. (2004) investigated in Nigeria fresh and 9-month stored samples of freshly harvested dried, milled housefly larvae for the presence of microbes for the determination of its suitability for inclusion in livestock diet. In their studies the moisture in the stored maggot meal (23%) was higher than the peak figure of 12% stipulated by FAO for stored food product, and therefore the stored maggot meal was prone to deterioration by fungi and bacteria.

A facility for the rearing of adult flies was described by Čičková et al. (2012). The text below is cited from this publication:

> Adult flies were kept at 25±2°C with a photoperiod of 12:12(L:D) and relative humidity of 45–60%. In the larval rearing room conditions were kept at 24±2°C, and light and air humidity are identical to the conditions for adult flies. Flies were maintained in two types of cages: experimental cages (30x30x30 cm) at medium densities (1,000–1,500pupae per cage) and production cages (60 cm long, 80 cm wide,145 cm high) which could be loaded with up to 25,000 pupae and were used primarily for egg production. Thus, the volume available for the adults in production cages under these conditions was 2.83 cm^3 and the area available was 2.80 cm^2 per fly. The production cage consisted of two walls of fine gauze (0.2 mm mesh size) covering the wide sides of the cage and two narrow walls made of stainless steel with two gauze sleeves to allow manipulation of the contents of the cage. A U-shaped plastic tube (5 cm diameter) is placed in the middle of the cage through the narrow walls and filled with water. Five longitudinal apertures in the tube are used to insert sponges, which soak up the water and serve as drinking sites. Afterwards, two aluminium trays (4658616.5 cm) are placed inside the cage: the upper one with food (a mixture of powdered milk and sugar in a 1:1 ratio) and the lower one with pupae 2–3 days before expected emergence. Each narrow metal wall features five drawers(13.5 cm long, 18.5 cm wide, 3 cm high), which can be used for egg collection. Cages are provided with food and water ad libitum. Starting from day 5 after emergence, the flies are provided with oviposition substrate (fresh pig manure) offered in special oviposition devices and placed at the bottom of the cage. Flies are allowed to oviposit for 12–14 hours daily for a period of15 days. After egg production, the food and water is removed from the cages and the flies are left to die. The cages are then disinfected and prepared for the next rearing cycle. The Alpuente cages were also described as a way of rearing house flies.

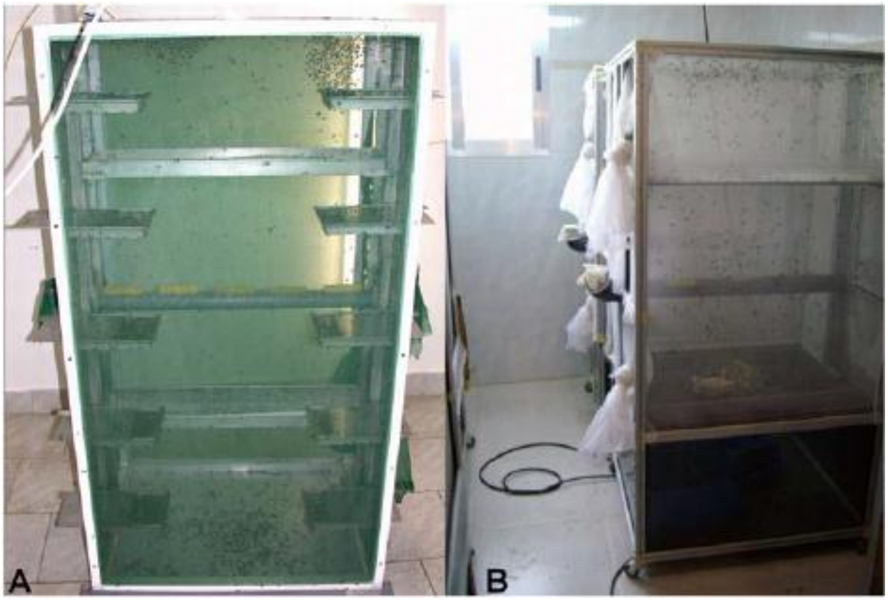

Figure 5 Production cages used to rear adult houseflies. (A) Miloslavov cages, (B) Alpuente cages. doi:10.1371/journal.pone.0032798.g001

Processing of 1 kg of wet manure produced 43.9–74.3 g of housefly pupae and the weight of the residue after biodegradation decreased to 0.18–0.65 kg, with marked differences among manure types (Čičková et al., 2012).

Mealworms

Ramos-Elordoy et al (2002) conducted experiments with growing mealworms on low-nutritive waste products and fed these to broiler chickens. The mealworms were able to transform the low nutritive waste products to a high protein diet.

2.3 Overview of rearing insects in The Netherlands

Dutch companies that currently develop pilots to grow insects as feed for livestock and fish are:

- PROTIX Biosystems B.V. using BSF among others
- Koppert Biological Systems concentrating on BSF
- Jagran B.V. concentrating on the Common housefly

In The Netherlands about 18 companies are producing insects mainly for pet shops and zoos. Production quantity of the current insect rearing companies varies from hundreds of kg per month up to two thousand kg per month. Insect species reared on these companies are: the Yellow mealworm, the Lesser mealworm *(Alphitobius diaperinus),* the Superworm *(Zophobas morio*), house cricket (*Acheta domesticus*), Banded cricket (*Gryllus sigillatus*), the Field cricket (*Gryllus campestris*), the Migratory Locusts (*Locusta mirgatoria*), fruitflies Drosophila spp., Greater wax moths (*Galleria mellonella*), *Pachnoda marginata),* Turkestan cockroach (*Shelfordella tartara***)** and the Dubia cockroach *(Blaptica dubia*). Three companies (Kreca, Meertens and van de Ven), members of VENIK (Vereniging Nederlandse Insecten Kwekers), produce insects for human consumption (marketed through M. Ruig en Zonen B.V. This is a coordinating association which represents the interests of the insect rearing companies. All insect rearing companies in the Netherlands are listed in in Annex 1.

2.4 Processing

After rearing the insects, several processing steps are required in order to get them into a form in which they are usable in the feed industry. Currently, insects are sold in the Netherlands as feed for zoo animals, and as feed in shops for pets such as birds, reptiles, mammals and amphibians. These insects are available in different forms, i.e., alive, freeze-dried and frozen. Freezing and freeze drying enable prolonged storage and shelf life spectacularly. However, these methods are too expensive to be economically feasible for using insects for large scale feeding of poultry and pigs.
Limited attention is given by the industry in temperate zones to the processing of insects. Outside the western world, processing is performed by several companies like Agriprotein Technologies and HaoCheng Mealworms Inc. Agriprotein dries maggot larvae on a fluidised bed dryer, mills them into flake form. HaoCheng Mealworms Inc. (China) sells Yellow mealworm and the Superworm alive, dried, canned and as powder for livestock, fish and pets.

The Insect rearing centre from the Mississippi State University, USA, together with Neptune Industries Inc. (USA) developed a patented production protocol for Ento–Protein TM, a dry protein meal. To our knowledge companies with similar processing activities do not exist in Europe. However, Zetadec in The Netherlands, a consultancy and contract R&D organisation for the feed, food and biomass industry has experience in processing of insects. The textbox below shows three patents on insects as feed.

Patented knowledge of insects as feed:
- Dried silkworm river crab feed as well as preparation method and scale of feeding thereof (Hongqiangpan, L. Patent no: CN101642195 (A)).
- Chicken feedstuff using green yellow mealworm as main protein (Jiangang, S. Patent no: CN101416683 (A)).
- Production and processing of insects for transformation into protein meal for fish and animal diets (Papadoyianis, E. Patent no: US2008/0075818 A1).

2.5 Animal feed industry

The animal feed industry in the Netherlands is largely united in the NEVEDI organisation (Dutch Feed Industry Association). NEVEDI consisted in 2009 and 2010 of 72 companies involved in compound feed production. Five of these companies are responsible for 60% of the total production of compound feed. One third of the production was produced by 18 middle-sized companies and about 10% by 49 small-size companies. The total volume of the feed market in The Netherlands is presented in Table 2.

Table 2 Total overview of the Dutch feed market in 2010

Feed market	Quantity (million tons)
Compound feed	14.3
Milk replacers	0.7
Singular feeds	1.5
Wet feeds	5.0

Source: NEVEDI, 2012.

Compound feed was produced for different categories of animals and the quantities per species in 2009 are presented in Table 3. In 2009 13.3 million tons of compound feed was produced in The Netherlands. The share for cattle, pigs, poultry and others in total compound feed was 26.5, 45.2, 25.0 and 3.3%, respectively.

Table 3 Industrial production of compound feed in The Netherlands in 2009

Types of compound feed	Volume (million tons)	
Cattle	3.522	
Fattening		0.401
Dairy cows		3.105
Others		0.016
Pigs	6.017	
Piglets		0.802
Pigs for fattening		3.926
Breeding pigs		1.289
Poultry	3.333	
Broilers		1.439
Chicks and layers		1.894
Others	0.437	
TOTAL	13.309	

Source: Hoste en Bolhuis, 2010.

The highest requirement of protein is in piglets and broilers. The quantity of compound feed produced in 2009 for fattening pigs was 3.9 million tons and for broilers 1.4 million tons. Soybeans or soybean meal is used as the primary source of protein in pig and broiler diets.
Hoste and Bolhuis (2010) performed a study on the use of soya in The Netherlands with a special focus on soy-products used in compound feed. Results of the seven largest feed companies, responsible for 65% of the total quantity of compound feed in The Netherlands along with average feed formulas in common practice estimated by Schothorst Feed Research over the period from January 2008 to April 2010 provide inclusion levels of soy in compound feed per species as presented in Table 4.

Table 4 Mean inclusion levels (%) of soy-products in compound feed per species, calculated according to usage per species, averaged over the period from January 2008 to April 2010

	Soybean meal	Soybean hulls	Soy oil	Soybeans (heat treated)	Total Soy-protein product
Fattening pigs	7.5	0.1	0.0	0.0	7.7
Broilers	23.9	0.0	0.3	2.3	26.6

Source: Hoste en Bolhuis, 2010.

From the inclusion levels (Table 3) multiplied with the quantity of compound feed produced per species (Table 4) the quantity of soy-products included in compound feed can be calculated. (Table 5).

Table 5 Quantities of soy-products in compound feed per species, calculated according to the usage of feed within a species, averaged over the period from January 2008 to April 2010 (kiloton/year)

	Soybean meal	Soybean hulls	Soy oil	Soybeans (heat treated)	Total Soy-product
Fattening pigs	294	4	0	0	302
Broilers	344	0	4	33	383
Total	638	4	4	33	685

The nutritional value of insects (crude protein and fat content) is at least comparable with the nutritional value in soybean and fishmeal products (see Table 1). Based on the nutritional value as described in Chapter 5 'Nutritional value of insects' it can be concluded the mean crude protein content of the house fly larvae is the highest of all insects varying between 550 en 600 g/kg DM. The crude protein content of the highest quality soybean meal is 555 g/kg DM (CVB, 2007).

In fattening pigs and broilers diets, 302 and 383 kiloton soy-products were included, respectively, in 2009 (Table 8). Hypothetically, to replace all soy-products from fattening pig and broiler diets by insect products import of soy-products can be decreased by 685 kiloton. If 5% of the compound feed ingredients for broiler chickens in the Netherlands would be replaced by mealworms, this would require 72 kiloton of insects. If a feasible insect rearing company would produce 1 ton per day (this is 365 ton per year), then about 200 insect rearing companies would be required.

2.6 Pig and poultry industry

The numbers of available places for animals per species in The Netherlands from 2005 to 2011 are presented in Table 6.

Table 6 Numbers of available places (x 1000) for animals per species on farms in The Netherlands over the period from 2005 to 2011

	Year						
	2005	2006	2007	2008	2009	2010	2011
Pigs, total	11312	11356	11663	12026	12186	12255	12429
Piglets	4563	4647	4837	4966	5068	5124	5297
Breeding pigs	1244	1234	1266	1222	1246	1227	1227
Fattening pigs	5504	5476	5559	5839	5872	5904	5905
Poultry, total	92914	91782	92761	96700	96859	101248	96919
Laying hens	41048	41642	41225	44241	45547	47904	44460
Laying hen breeder	1582	1381	1115	852	1094	1252	1209
Broilers	44496	41914	43352	44358	43285	44748	43912
Broiler breeders	5788	6845	7069	7249	6934	7343	7338
Turkeys	1245	1140	1232	1044	1060	1036	990
Ducks	1031	1043	1134	1064	1157	1087	1016
Other	275	370	584	420	690	250	318

Source: Centraal Bureau voor de Statistiek, 2012.

Over the period from 2005 to 2011 the number of pigs increased from 11.3 to 12.4 million and the number of poultry increased from 92.9 to 96.9 million. With regard to this study the focus is on piglets, fattening pigs and broilers. In piglets and fattening pigs the number increased 16.1 and 7.3%, respectively from 2005 to 2011. The number of broilers decreased 1.3% over this period.

3 Safety, legislation and regulation

In this Chapter different types of organic waste that can be used as substrate for rearing insects are categorized (paragraph 3.1). In this paragraph also different categories of animal by-products are described. In paragraph 3.2 possible risks for contaminations of insects are described. In paragraph 3.3 the currently used quality assessment for animal feed is presented.

3.1 Organic waste

Different categories of organic waste originating from vegetable or animal sources can be distinguished (Table 7).

Table 7 Categories of organic waste (http://www.ecn.nl/phyllis/info.asp)

Group	Subgroup
algae	
char	
grass/plant	
manure	
organic residue/product	side streams of agriculture
organic residue/product	side streams of horticulture
organic residue/product	side streams of auctions
organic residue/product	bagasse
organic residue/product	food industry product
organic residue/product	food industry waste
organic residue/product	Organic domestic waste (GFT)
organic residue/product	organic waste from hotel and catering industry, retail business, public utilities
organic residue/product	swill
organic residue/product	Slaughterhouse residue
organic residue/product	Distillers
organic residue/product	Others
RDF and MSW	Refuse derived fuel and municipal solid waste (usually contains organic components - biodegradable waste).
sludge	

A different category of organic side streams are animal by-products. Animal by-products are classified into three categories, each requiring different grades of treatment (Table 8).

Table 8 Categories of animal by-products as defined in European regulations

Type	*Regulation*	*General Description*	**Main purpose**
Category 1	1069/2009 & 142/2011	High risk material	Destruction
Category 2	1069/2009 & 142/2011	Downgrades, rejections and non-inspected materials	Energy generation, Minks, Fertilizer, Engineering
Category 3	1069/2009 & 142/2011	Originating from healthy animals which are appropriate to slaughter	Feed, Petfood, Minks, Fertilizer, Engineering
Food	853/2004	Food	Food, but can be applied in petfood en feed

Animal by-products may be appropriate to use as a substrate to rear insects. For the development of a sustainable insect chain, low grade sources of animal protein might be used. High-grade sources will be fed directly, without an in-between step with insects, to pigs or poultry. Currently, insect protein may not be used as an ingredient in feed for pigs and poultry. In EU regulation 1069/2009 under article 10 (Category 3 material), paragraph 1, aquatic and terrestrial invertebrates of species which are not pathogenic for humans and animals are included. In EU regulation 142/2011 (in its Appendix 1, bullet 5) processed animal proteins are defined. With this description terrestrial invertebrates (insects) are categorized as processed animal protein and therefore, under the current TSE regulation, it is prohibited for use in the food chain. However, the feed ban on processed animal proteins will be discussed and reintroduction might be possible in the future. Possibly the European Commission is willing to make an exception for insects to accelerate the authorization of insect protein as an ingredient in fish, pig and poultry diets.

A report dealing with development and marketing of new proteins (Wagenberg et al, 2012) indicates major issues to be addressed in regulatory frameworks:

- Close interaction between government and demanders in dossier development.
- Clarification of the authorisation and notification dossiers for marketing.
- Scheduling harmonisation of definitions and procedures.
- Development of specific legislation and regulation of insects.
- Development of voluntary private codes with regard to legislation and regulation.

3.2 Pathogens, heavy metals and toxins

3.2.1 Pathogens

The black soldier fly has been found to reduce *E. coli* in dairy cow manure (Liu 2008). In general the literature seems to indicate that insects themselves do not harbour intrinsically dangerous pathogens for humans. All documented cases of poisoning seems to relate to contamination from the environment. For that reason, hygienic conditions in the rearing of insects need to be respected. Klunder et al. (2012) also pointed out the importance of hygienic handling and correct storage, after studying the microbiological content of reared mealworm larvae and house crickets. Giaccone (2005) also did not exclude that insects could become carriers of micro-organisms pathogenic to humans and therefore cooking or pasteurization was recommended. A PhD student working in the SUPRO2 project (http://www.kennisonline.wur.nl/Project/project-baps-21783) will evaluate how mealworms will deal with diets contaminated with pathogens dangerous to humans. In conclusion, insect rearing companies should be recommended to have a strict hygiene protocol to avoid contamination of insects with pathogens from the environment.

3.2.2 Toxins

Tenebrionid adult beetles can produce carcinogenic quinones, however the larvae do not emit these chemical defence substances, and as only larvae will be used this will not cause a problem (Wirtz, 1984). In general, pesticide use in insect feed can be a serious problem during rearing. The possible presence of toxins that pose a danger to humans needs to be studied further. The effects of the insects‘ feed should be taken into account, particularly when these are organic side streams (FAO, 2012).

3.2.3 Heavy metals

Insects can bio-accumulate heavy metals ingested from the environment in the cells of several organs and although this accumulation of metals may not kill the insects, it can be toxic for their predators. Storage of heavy metals in insects not killing the host may be toxic for consumers. For example, *T. molitor* accumulate cadmium and lead when they are fed with organic matter originating of soils harbouring these metals (Vijver et al., 2003) and selenium when fed an excess of sodium selenite (Hogan & Razniak 1991). However, it all depends whether the feeding substrate contains heavy metals. For rearing insects it is important to guarantee that the substrate does not contain high contents of heavy metals.

3.3 Risk assessment and regulations

The NVWA (Food and Consumer Product Safety Authority) in The Netherlands is the controlling authority to protect human and animal health. It monitors food and consumer products to safeguard public health and animal health and welfare. The Authority controls the whole production chain, from raw materials and processing aids to end products and consumption. An overview of more (international) authorities is presented in Annex 2.

GMP+ certification helps to assess a safe use of ingredients in pig and poultry feed. The GMP+ Feed Safety Assurance scheme (GMP+ FSA) is a scheme for assuring feed safety in all the links in the feed chain. It is also an international scheme, applicable worldwide. The Feed Safety Database (FSD) is an interactive database which is part of the GMP+ FSA Scheme. The FSD comprises various parts of the GMP+ FSA scheme: risk assessments, monitoring results, product standards and fact sheets. All the feed materials in the FSD are considered to be controllable and can therefore be used (safely) in the feed sector. The Feed Safety Database is intended as an aid to all (future) GMP+ companies in the drawing up of their company-specific risk assessments. The FSD is also intended as a reference for the auditors within the framework of GMP+ certification.

In EU regulation 1069/2009 under article 10 (Category 3 material), paragraph l, aquatic and terrestrial invertebrates of species which are not pathogenic for humans and animals are included. Insects might be removed from this EU regulation when proven to be save. Furthermore Directive 2002/32 on undesirable substances in animal feed is applicable to insect products.
Moreover, it is the question how to cope with risks in the production chain. Authorities and business communities may put this on the national and European agenda to complete prescriptions and standards for the use of insects as feed ingredient. Because of the lack of knowledge on food safety, contagious diseases and viruses during the rearing and processing of insects, business communities and authorities may initiate research projects to gain more knowledge in this field.

3.3.1 Health and welfare for animals

The law “Gezondheids- en welzijnswet voor dieren” (Gwwd) is principally also applicable to invertebrates. For example, in the ‘resolution for production indicated animals’ a number of insect species is mentioned. The Gwwd is currently under construction. Probably, this law will be changed in 2013 into the Animal Law (‘Wet Dieren’). The accompanying implementing order will be completed in 2012. The content and planning are politics dependent. Animal welfare aspects of methods of killing insects are not described properly at this moment. Insects should be able to behave naturally, such as mealworms having the ability to hide for light. It is not completely clear how to guarantee animal welfare for insects. More welfare criteria are required per insect species to determine whether they are reared in proper conditions. Insects are mostly killed by cooling followed by freezing. This seems to be a proper method considering that insects are poikilothermic/cold-blooded. It is not clear if this method is sufficient to realise unconsciousness. The Dutch Society for the Protection of Animals does not recognise the rearing of insects as a priority at this moment but they are interested to review proposals.

3.3.2 Ammonia en Greenhouse Gas emission from insect rearing

Oonincx et al. (2010) performed a study to quantify production of carbon dioxide (CO_2) and average daily gain (ADG) as a measure of feed conversion efficiency and to quantify the production of greenhouse gas (GHG) methane (CH_4) and nitrous oxide (N_2O) as well as NH_3 by five insect species of which the first three are considered edible: Yellow mealworm, House cricket, Migratory Locust, Sun beetle and Dubia cockroach. Insects used in this study had a higher relative growth rate and emitted comparable or lower amounts of GHG than described in literature for pigs and much lower amounts of GHG than cattle (Table 9). The same was true for CO_2 production per kg of metabolic weight per kg of mass gain. Furthermore, also the production of NH_3 by insects was lower than for conventional livestock.

Table 9 CH_4, N_2O, CO_2 eq. and NH_3 production (average ± standard deviation) per kilogram of mass gain for five insect species, pigs and beef cattle (Oonincx et al, 2010)

Species	CH_4 (g/kg mass gain)	N_2O (mg/kg mass gain)	CO_2 eq. (g/kg mass gain)	NH_3 (mg/day/kg mass gain
Pachnoda marginata	4.9 ± 1.96 [a]	1.03 ± 1.06 [a]	121.86 ± 49.09 [a]	3 ± 4.8 [a]
Tenebrio molitor	0.1 ± 0.03 [b]	25.5 ± 7.70 [b]	7.58 ± 2.29 [b]	1 ± 2.0 [a]
Blaptica dubia	1.4 ± 0.30 [c]	5.7 ± 4.05 [a]	37.54 ± 8.01 [c]	54 ± 31.1 [a]
Acheta domesticus	0.0 ± 0.09 [b]	5.3 ± 6.05 [a]	1.57 ± 1.80 [d]	142 ± 184.5 [b]
Locusta migratoria	0.0 ± 0.11 [b]	59.5 ± 104.8 [c]	17.72 ± 31.22 [e]	36 ± 10.8 [a]
Pigs	1.92 – 3.98	106 – 3,457	79.59 – 1,130	1,140 – 1,920
Beef cattle	114	N/A	2,850	N/A

N/A = Not Available.
Reported values for pigs and beef cattle were obtained from Aarnink et al., 1995, Groot Koerkamp et al., 1998, Demmers et al., 2001, Nicks et al., 2003, Beauchemin and McGin, 2005, Cabaraux et al., 2009, Harper et al., 2009.
Mean values bearing different superscripts in a column differ significantly ($P<0.05$).

It should be noticed that this comparison is interesting when insects will be used directly as human food. However, when insects will be used as a feed ingredient a comparison with the footprint of feed ingredients such as soybean meal, rapeseed meal and fish meal would be of more interest.

4 Processing insects: opportunities and limitations

In analogy to fish meal and soybean meal, insects need to undergo a number of processing steps to make them suitable for application in the feed industry. A literature search (using search engine "web of science") was performed to find relevant information on this topic. Key words used as single search terms or in combinations were: insects; milling; drying; heating; processing; mealworm; *Tenebrio molitor*; *Musca domestica*; *Hermetia illucens*; protein; extraction; solubility; grinding; feed; food; meal. The literature search made clear that scientific publications on this topic are scarce or even absent. The vast majority of articles found dealt with pest control, insect infestations and sometimes with processing methods to prepare insects for, e.g., electron microscopy, which is completely out of scope.

4.1 Meal of whole insects

After rearing insects the first processing steps include cleaning of insect biomass and harvesting. The organic materials on which the insects grow and their excreta need to be easily separated from the insects themselves. Sieving is an option that is mentioned in the materials and methods section of some articles that prepare insects for feeding chickens (Gawaad and Brune, 1979; Ramos-Elorduy et al. 2002). For harvesting, different options can be used, which are cold treatment (freezing), hot treatment (e.g. cooking), and possibly use of controlled atmosphere, but the exact method is not addressed specifically in literature. Although there is a lack of literature, industrial knowledge and experience in on-going research projects exists on the issues of cleaning and harvesting.

In a few articles that do not study processing as such, some basic steps are mentioned in the M&M section. For example, Gawaad and Brune (1979) washed two types of fly larvae three times with water of 40-50°C and dried them afterwards during 24 hours at 60°C, which is similar to the temperature used by Calvert (1969) for housefly larvae. Ramos-Elorduy et al. (2002) dried mealworm larvae at 50°C for three days. The drying step can be followed by a grinding step to obtain a (full fat) insect meal (Calvert, 1969; Gawaad and Brune, 1979; Ramos Elorduy et al. 2002).
The drying step, performed to remove moisture, can be seen as an efficient preservation step to obtain a material that is stable enough to be stored for long periods. The mild heat treatment step, mentioned in articles above, supports the preservation effect of the drying step. Another aspect of heating is that it causes denaturation of proteins and also induces Maillard reactions. Although the effect of heat treatment can be beneficial from a safety point of view, denaturation and Maillard reactions could have adverse effects in terms of solubility and availability of essential amino acids. Apart from heat treatment, other preservation or drying methods could prolong shelf life, such as freeze drying, using UV, pH and high pressure treatment (although this is currently too expensive for feed).

Grinding of unheated fresh mealworms leads to extensive browning or blackening, likely to be the result of enzymatic browning due to the presence of polyphenols in the insects. This is reminiscent of cut fruits and vegetables, and also occurs in some crustaceans like shrimps. For potato tuber, this process results into covalent attachment of phenolics to proteins (Narváez-Cuenca, unpublished results), thereby decreasing protein solubility and possibly also protein digestibility. Enzymatic browning can be prevented by heat treatment or addition of processing aids like vitamin C, sulphite and activated carbon. Similar to the enzymatic browning process, the presence of digestive enzymes in insects (Lwalaba, 2010) could also influence protein properties after grinding.

To our knowledge the effects of heat treatment and other preservation treatments on feed quality have not been studied systematically. However basic knowledge seems to exist on how to obtain meals of whole dried insects. Usage of whole insects is seen as directly applicable in the feed industry from a technological point of view, although we expect space for optimization. The costs of the technological processes will play a major role in reaching commercial viability.

4.2 Fractionation of insects

After harvesting and grinding-type procedures to come from whole insects to smaller particles, apart from using the whole grinded insects for feed, another option is open:
composition wise fractionation of insects (Figure 6).

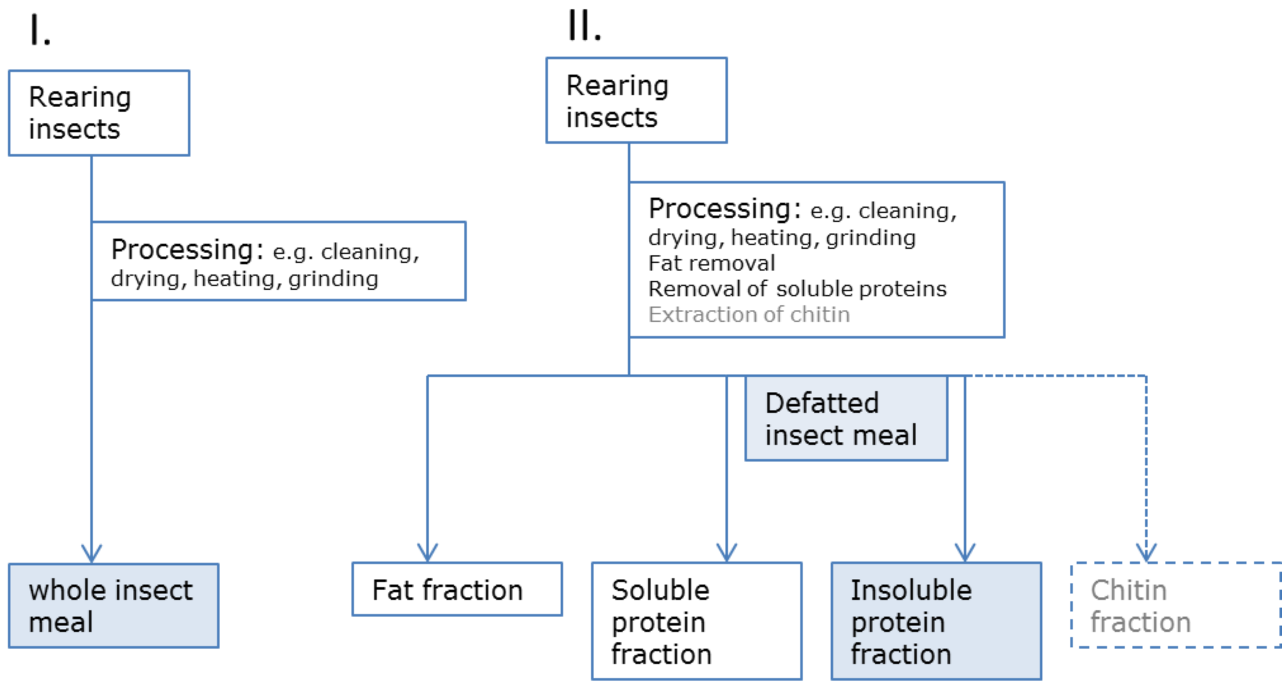

Figure 6 Schematic presentation of possible processing strategies for insects I. Use of processing to obtain whole insect meal. II. Composition wise fractionation by fat removal, removal of soluble proteins, and possibly chitin extraction. In blue fractions potentially suitable for the feed industry

In literature detailed information is available on composition of several insect species, as well on macro-(see Chapter 5) but also on micronutrient composition (e.g. Bukkens, 1997; Finke 2002). The most important constituents of insects in terms of quantity are moisture, proteins and lipids. Chitin, a polysaccharide that constitutes the exoskeleton of the insects is present in smaller quantities, but is also important from a processing point of view.

For feed use protein-rich fractions are interesting. Protein content is increased by fat removal, which is thought to be a logical first step in the fractionation process. Insect fat could possibly be valorised for other purposes than usage in feed. In analogy with the soybean meal defatting, fat removal could possibly be carried out using organic solvents such as hexane. Then defatting steps need to be preceded with a drying step to remove the moisture. Also alternative methods could be used for fat removal, thereby omitting environmental unfriendly use of organic solvents. In the fish industry, for example, oil is extracted by cooking to coagulate the protein followed by pressing (e.g. Opstvedt, 2003). Insect fat is prone to fat oxidation reactions due to relative high amounts of unsaturated fatty acids in some species. Fat oxidation can be reduced by adding anti-oxidants like Butylated

Hydroxytolune (BHT). Removal of fat probably affects stability of the obtained fraction positively. It also facilitates large scale handling of insect meal (less sticky).
Ichhponani and Malik (1971) used successfully defatted silkworm pupae meal as a substitute for fish meal in chick rations. It is unknown what procedure for fat removal was used since no experimental details on processing steps to obtain defatted meals were given.

The proteins within the insect body are present all over the insect body, although a distinction can be made into muscle protein, haemolymph protein and protein incorporated in the exoskeleton. The properties (e.g. solubility) of the insect proteins are largely unknown in contrast to the commonly used proteins from other animal and plant sources, like other meat, milk, and plant proteins. The few data on protein composition of insects (protein content and amino-acid composition) are obtained for whole insects, not for isolated proteins (Finke 2002, Renault et al. 2006, Bukkens 1997).
For the food industry obtaining high quality protein concentrates and isolates using several extraction procedures is very relevant in terms of obtaining the specifically required functional properties, as foaming, emulsification, and gelation properties. These properties require protein to be soluble. So next to defatting, it could be relevant to engage in further protein purification procedures. A possible result could be to obtain soluble protein fractions to be used for the food industry and usage of the insoluble fractions also for the feed industry. Basically, fractionation knowledge exists for other type of protein sources, but research is needed to translate this knowledge for insect processing from a technological point of view but also in terms of economic feasibility. Up to date only Valle et al. (1982) studied a procedure to obtain concentrates and isolates from Mexican fruit fly larvae. Experience of extraction and purification procedures has been obtained through the SUPRO2 project at Wageningen University (see text box) in which one of the tasks is to explore methods to extract and purify proteins from several insect species.

SUPRO 2

The SUPRO 2 project is a research project within Wageningen University, being a co-operation of the Entomology group and the Product Design and Quality Management group and Food and Biobased research. The project is financed by the ministry of EL&I. It studies how insects can grow in a sustainable way on bio-waste materials and how the insect feed influences insect composition. It is further investigated how to extract and purify proteins from insects for usage in food. Proteins are characterized and functional properties relevant for food uses are studied, such as emulsifying, foaming and gelling capacities.

Apart from (soluble) protein, insects can deliver another very valuable product that is chitin. Chitin is the main constituent of the insect exoskeleton. It is a non-toxic, biodegradable linear polymer. Recent studies demonstrated that chitin has complex and size-dependent effects on innate and adaptive immune responses (Lee et al., 2008). Chitin has immune-system stimulating properties and ingestion of chitin, being part of insoluble insect fraction, could improve the immune status of the animals. It needs to be investigated whether or not chitin consumption could potentially contribute to a reduction of the use of antibiotics in the feed industry.

Chitin consists mainly of β-(1→4)-linked 2-acetamido-2-deoxy-β-D-glucopyranose units and partially of β-(1→4)-linked 2-amino-2-deoxy-β-D-glucopyranose. It is the second most abundant polymer in the world after cellulose. Chitin is insoluble in water, diluted mineral acids and most organic solvents. It has a low reactivity and low processability.
Currently sea foods like crabs or shrimps are the main industrial source of chitin. Evaluation of the potential uses of insect chitin is worth to consider as a high value side product. Chitin can be processed into chitosan. For chitosan many applications are possible. For instance it is used in the cosmetic, pharmaceutical, textile, paper or waste water industries. Chitin production from insect waste after protein extraction is a new area.

Chitin extraction can be performed using two methods. A first option is demineralisation followed by deproteinisation using NaOH and HCl. Also biological extraction procedures are possible, being fermentation or enzyme assisted extraction. The use of purified enzymes could result in a high yield and selectivity, but is expensive.

Conclusion
From a processing point of view insects could be used for feed as a whole or as the water insoluble protein fraction. The last option requires other fractions (water soluble proteins and/or chitin) to be used in food or other cost effective options.
For developing both options systematic research would add to the quality of the obtained feed powders. Important topics are preservation and shelf life issues, processing methodologies, fractionation procedures, and safety issues. Standard practises can be translated from meat, fish, soybean, and crustacean processing practises. Furthermore, the optimal level of inclusion of whole insects or insect fractions in feed, thus the percentage of insect ingredient in the final feed, will determine typical requirements on the insect meal.
The economics of the processing steps in combinations with legal requirements imposed on insects derived products will play a major role in which form insects can be used in future feed.

5 Nutritional value and functional properties

A literature study was conducted to evaluate the nutritional value (i.e. nutrient composition and chitin content, digestibility and protein quality) and functional properties of insect proteins. Target species and life-stages were Yellow mealworm larvae and pupae, Lesser mealworm larvae, Superworm larvae, Common housefly larvae and pupae, and Black soldier fly larvae and prepupae. All data were collected by electronic literature searches conducted in SciVerse, Scopus and OvidSP and by screening of the literature database of the Laboratory of Entomology (Wageningen University). These initial searches were supplemented by reference and citation tracking. The nutritional value of insect proteins was evaluated by expressing amino acids as percentage of lysine and by calculation of the essential amino acid index (EAAI) (Smith, 2010). The EAAI for each insect species and target animal (i.e. pig or poultry) was calculated using the following formula:

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

with *aa* = the amount of an amino acid in the protein source in % of crude protein; *AA* = the requirement of the target animal for an amino acid in % of crude protein; and *n* = the total number of amino acids used in the calculation. In case the amino acid profile of an insect is completely in agreement with the requirement of the target animal the EAAI will be 1. For each amino acid that is more available than required the EAAI value will be larger than 1 and if it is less available than required the value will be smaller than 1. If data on one of the essential amino acids was missing, it was not included in the calculation resulting in a smaller *n* and a less accurate calculated EAAI. For each amino acid profile that was found in literature the EAAI was calculated and the mean EAAI is presented.

5.1 Nutritional value

Information on the nutritional composition was found for all selected insect species but not for each age class within insect species. In total 42 studies were used in this review of which some are not peer-reviewed. Most studies have information about house fly larvae and mealworm larvae (n=14). For the Common housefly, information was found for the larval and the pupae stadium whereas for the Black soldier fly information was found for the larval and the prepupae. For the Yellow mealworm information was available for the larval and the pupae stadium. For the Lesser mealworm and Superworm information was available only about the larval stadium. In this chapter the data are presented in boxplots, more elaborate data can be found in tables in MSc thesis of Else Ottevanger (Ottevanger, 2012). Defatted soybean meal is used as a reference substrate. It should be noted that, similar to soybeans, in the future insects may be fractionated into a fat-rich fraction and protein-rich fraction.

5.1.1 Nutrient composition and chitin content

In Figure 7A the dry matter (DM) content is shown for specifically unprocessed insects. Information on DM content was scarce. Multiple data points were available for mealworm larvae (n=28, median 40.4% DM) but only few or no data points for other insect species and life stages. The median DM content was relatively comparable between most insects and around 40% with the exception of Black soldier fly larvae (26.8%, n=1). Dry matter content of processed insects (mostly dried and ground) was around 90% (data not shown).
The crude protein content varied considerably across insect species and life stages and also within insect species and life stages (Figure 7B). Highest median crude protein content was found for Common housefly pupae (65.7% of DM) and lowest for Black soldier fly larvae (38.9% of DM) and prepupae (37.4% of DM). Yellow mealworm larvae and housefly larvae were comparable in crude protein content (median 49.3 and 50.8% of DM). Few data were available for Yellow mealworm pupae

(n=2, 53.4% crude protein of DM), Lesser mealworm larvae (n=1, 67.9% of DM) and Superworm larvae (n=2, 45.0% of DM).

Data on the crude fat content of insects are presented in Figure 7C. Multiple data points were available for Yellow mealworm larvae (n=22, median 36.1% crude fat of DM) and Common housefly larvae (n=26, 19.5% of DM) but only few or no data points were available for other insect species and life stages. Within these two species and specific life stages, considerable variation in crude fat content was noted. Compared to larvae, Yellow mealworm pupae showed a similar median crude fat content (33.8%, n=2) whereas that of Lesser mealworm larvae was lower (20.7% of DM, n=1) and of Superworm larvae somewhat higher (41.4% of DM, n=2). Compared to Common housefly larvae, crude fat content of pupae were somewhat lower (15.8% of DM, n=5) and that of Black soldier fly larvae and prepupae higher (34.8% of DM, n=1; 33.1% of DM, n=1, respectively).

Information on crude ash content was readily available for Yellow mealworm larvae (n=35) and Common housefly larvae (n=26) but limited or lacking for other insects (Figure 7D). Median crude ash contents of Yellow mealworm larvae (4.4% of DM) and pupae (5.1% of DM) were lower than those for Common housefly larvae (11.2% of DM) and pupae (12.4% of DM) and for Black soldier fly larvae (14.6% of DM) and prepupae (15.5% of DM). For application of insect products as feed ingredient in pig and poultry feed, the calcium en phosphorus contents and ratio are important. The Ca:P ratio of all insects lied between 0.02 (Yellow mealworm larvae) and 5.68 (Common housefly larvae) (data not shown). The values for Common housefly larvae had a relatively large range in comparison with the other insects. The insects with the highest Ca:P ratio were Black soldier fly larvae (median ratio of 3.33) and Common housefly larvae (1.52) while the other insects had a median Ca:P ratio of 0.54 or lower.

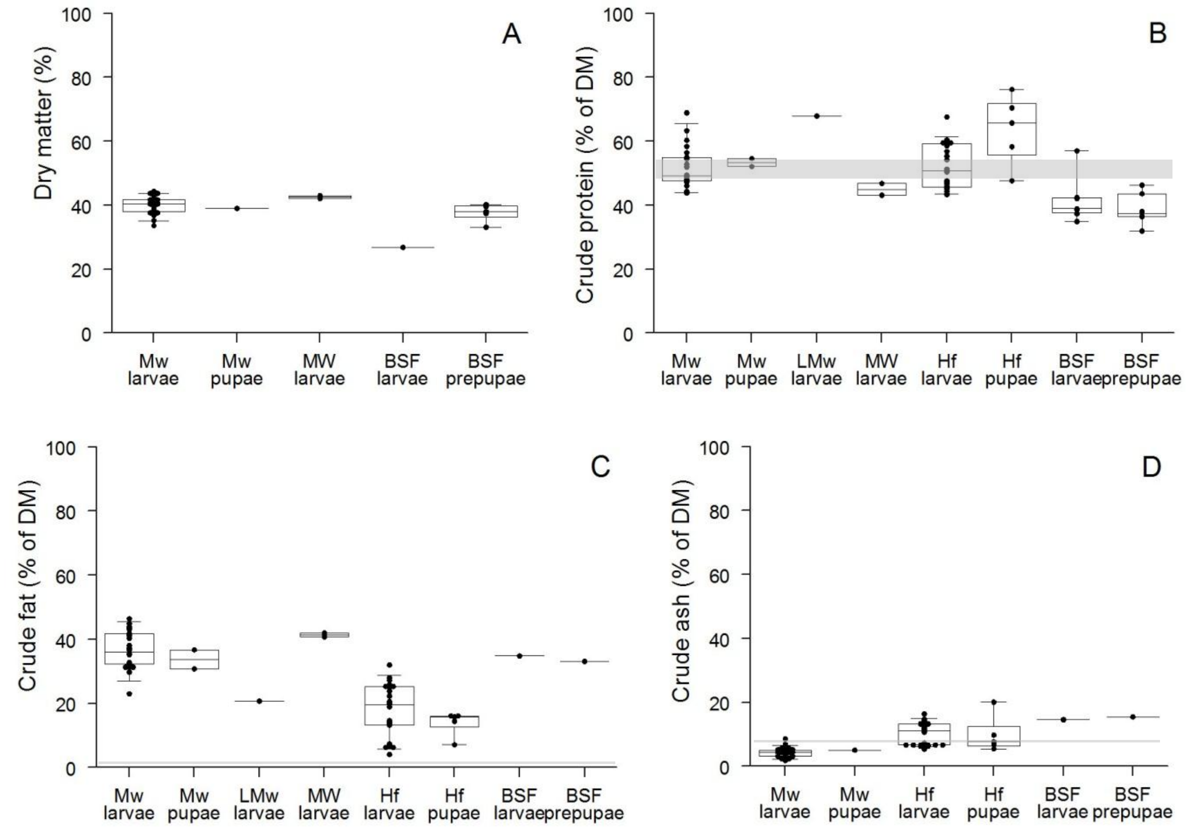

Figure 7A-D. Dry matter (A, DM) of unprocessed insect species in different life stages and crude protein (B), crude fat (C) and crude ash (D) contents of processed insect species in different life stages. Abbreviations: Mw = Yellow Mealworm, LMw = Lesser mealworm, MW = Superworm, Hf = Common housefly, BSF = Black soldier fly. Grey transparent horizontal bars indicate variation in composition between five soybean meals according to CVB (2008), i.e. 48.6-55.7% crude protein of DM, 2.7-3.4% crude fat of DM, 6.9-7.4% crude ash of DM

The amount of chitin may vary between different species and on the method used to determine these amounts. The chitin content of target insect species and life-stages has not been estimated yet. Finke (2007) estimated chitin contents in raw whole insects to be low: 137.2 mg/kg for adult Yellow mealworms (dry matter basis) and 67.6 mg/kg for House crickets (dry matter basis).

5.1.2 Protein quality

The amino acid profiles and EAAI values of insects are presented in Annex 3. The profile and EAAI value of soybean meal is also shown as a reference substrate. Multiple data on amino acid composition of insect proteins were available for Yellow mealworm larvae and Common housefly larvae and pupae. For the other insects only one reference was found.
Compared to soybean meal, insect proteins are generally lower in arginine and cysteine (except mealworm larvae) and higher in methionine and tyrosine. Yellow mealworm larvae proteins are in particular high in essential amino acids.
Each insect and life stage showed EAAI values higher than 1 indicating that these protein sources provided in general more of the essential amino acids than required. For growing pigs and for broiler chickens, highest EAAI values were found for Black soldier fly prepupae, Yellow mealworm larvae and Lesser mealworm larvae. Lowest values were found for superworm larvae and Common housefly pupae, which were also lower than the value for soybean meal. Note that most reference did not provide information about all essential amino acids so EAAI values were not based on all essential amino acids (22 of 31 data points).

5.1.3 Digestibility

Little information was found about the nutrient digestibility of the selected insects in combination with the target animals (i.e. pigs and broiler chickens). Only three studies were found that determined apparent faecal digestibility of nutrients. Apparent faecal digestibility of dried Black soldier fly larvae meal and soybean meal were evaluated in 5-week old barrows (initial body weight 8.2 kg) (Newton et al., 1977). Corn-based diets contained either 25.5% soybean meal or 33.0% dried Black soldier fly larvae meal and were fed for 10 weeks in a cross-over design. Compared to the soybean meal diet, apparent faecal digestibility of crude protein was similar and digestibility of crude fat was higher for the larvae meal diet (Table 10).

Table 10 Apparent faecal digestibility (in %) of a diet containing dried Black soldier fly (BSF) larvae meal or soybean meal (SBM) in young male growing pigs (Newton et al., 1977)

	BSF larvae	SBM
Dry matter	77.5	85.3
Crude protein	76.0	77.2
Crude fat	83.6	73.0
Crude ash	45.2	61.7
Crude fibre	53.8	49.2
NFE	84.7	91.2

Abbreviations: NFE = Nitrogen-free extract (a proxy for digestible carbohydrates)

Apparent faecal digestibility of dried housefly meal was evaluated in broiler chickens in two studies. Hwangbo et al. (2009) fed 4-week old broilers a diet with 30% dried housefly larvae meal or soybean meal for 7 days. Pretorius (2011) fed 3-week old broilers a maize meal-based diet containing 50%

dried housefly larvae meal or dried housefly pupae meal. Results of both studies are shown in Table 11.
Hwangbo et al. (2009) reported a very high apparent faecal digestibility values of crude protein for housefly larvae (98.5%) whereas Pretorius (2011) reported that crude protein of the housefly larvae diet was only 69% digestible. The latter study also showed that housefly pupae were higher digestible than the larvae. Digestibility of most amino acids is found to be around 90% or higher. Surprisingly, Pretorius (2011) reported considerably higher apparent faecal amino acid digestibility values than those for the crude protein digestibility.
Chitin can be digested with chitinase. It has been reported that broiler chickens can secrete chitinase in the gizzard (e.g. Han et al., 1997; 2000). No information was found for chitinase synthesis or secretion by pigs, although its intestinal microbiota was found to produce chitinolytic enzymes (Šimůnek et al., 2001).

Table 11 Apparent faecal digestibility (in %) of diets containing housefly (Hf) larvae, Hf pupae meal or soybean meal (SBM) in broiler chickens

	Hwangbo et al. 2009		Pretorius, 2011	
	Hf larvae	SBM	Hf larvae	Hf pupae
Dry matter	ND	ND	81	83
Crude protein	98.5	98.0	69	79
Crude fat	ND	ND	94	98
Crude ash	ND	ND	83	85
Crude fibre	ND	ND	62	58
Amino acids				
Arginine	95.6	93.9	BD	93
Cystine	92.7	87.6	ND	ND
Histidine	93.7	90.1	87	87
Isoleucine	92.2	93.3	ND	ND
Leucine	94.7	92.7	ND	ND
Lysine	97.6	92.7	ND	ND
Methionine	95.6	93.0	ND	ND
Phenylalanine	96.8	94.7	ND	ND
Threonine	93.3	89.3	93	97
Tryptophan	93.9	93.2	95	99
Tyrosine	96.1	93.8	ND	ND
Valine	94.5	91.1	91	91

Abbreviations: ND = not determined, BD = below detection limit.

5.1.4 Performance studies with insects as feed ingredient

The crude protein content of housefly larvae (maggots) is comparable to that of fish meal. For intensive rearing, if maggots are to be used as a source of proteins for poultry, they should be delivered in a dry form. When the nutritive value of maggots and the effect of maggot meal on the production performances of broiler chickens was analysed, Téguia et al (2002) concluded that from the technical and economic point of view, maggot meal could replace fish meal. Hwangbo et al (2009) investigated in South Korea the effect of maggot supplementation on the meat quality and growth performance of broiler chickens. Results indicated that feeding diets containing 10 to 15% maggots in biodegraded litter can improve the carcass quality and growth performance of broiler chickens. Awonyi et al (2004) found that the 25% replacement of fishmeal with maggot meal was the most efficient in terms of average weekly weight gain and protein efficiency rate. The live, dressed and eviscerated weights as well as the relative length, breadth and weights of the pectoral and gastrocnemius muscles of the chickens at 9 weeks were not significantly influenced by the diets. It was concluded that maggot meal is an inexpensive replacement for fish meal in broiler-chick feeding. Maggot production could at the same time alleviate the environmental problem of manure accumulation.

House fly larvae meal supplementation in a three phase feeding system significantly increased average broiler live weights at slaughter, total feed intake, cumulative feed intake as well as average daily gain (ADG) when compared to commercial maize - soy oil cake meal diet (Pretorius, 2011). In direct comparison of larvae inclusion levels with fishmeal in iso-nitrogenous and iso-energetic diet, no significant differences were observed between a 10% house fly larvae and a 10% fish meal diet regarding performance characteristic. The 25% house fly larvae meal diet yielded significantly better average broiler live weights at slaughter, total feed intake, cumulative feed intake (from the second week until slaughter) as well as average daily gain when compared to the 25% fish meal diet in the growth phases. Carcass characteristics of the 10% larvae, 10% fishmeal and commercial diets were compared. Chicks that received either the 10% house fly larvae meal or 10% fish meal supplementation produced significantly heavier carcasses and breast muscle portions than the chicks that received the commercial maize: soya oil cake meal. No treatment differences were found regarding breast and thigh muscle colour or pH (Pretorius, 2011).
Ramos-Elorduy et al. (2002) found that Yellow mealworm can potentially be used as an alternative protein source. Soybean meal (protein content 55%) was reduced to 31, 26 and 20% of the diet and replaced by replaced by 0, 5 and 10 % of mealworm, respectively. The basic feed source, sorghum (with 9% protein) was 61 to 64% of the diet (by weight), and did not change in the three treatments. She mentioned a number of literature studies with similar results by feeding poultry with *Anabrus simplex , the house crickets, the silkworm Bombyx mori, the Lesser mealworm, Tribolium castaneum*, and termites.

5.2 Functional properties

There are no studies found that report functional properties of insects as feed or food constituents. Examples of functional properties of non-insect chitin or chitin-derivates include enhancement of immune response in kelp groupers (*Epinephelus bruneus*) (Harikrishnan et al., 2012), acting as antibiotic/prebiotic in rats and chickens (Chen et al., 1999 and 2002, cited by Khempaka et al., 2011), and affecting hypolipidaemic properties in broiler chickens Hossain and Blair (2007). Information on properties such as palatability (e.g. taste, texture) is lacking.

5.3 Conclusion

Information on the nutritive value of insects as potential feed ingredients is readily available for Yellow mealworm larvae and housefly larvae but less for the other insects investigated. In relation to five categories of soybean meal (CVB, 2007): a.) CF<45 CP<480; b.) CF<45 CP>480; c.) CF45-70 CP<450; d.) CF45-70 CP>450 ; e.) CF>70 (CF = Crude fibre, CP = Crude protein), the protein content of Superworm and Black soldier fly larvae and prepupae is lower whereas that for Yellow mealworm, Lesser mealworm and housefly is equal or higher. Fat content varies considerably among insects. Proteins from Yellow mealworm larvae and Black soldier fly prepupae are in particular high in essential amino acids. There is a need for evaluation of nutrient digestibility of (processed) insects as feed ingredients, which is a prerequisite for formulating insect-containing feeds. In addition, potential functional properties (beneficial or detrimental) remain to be investigated.

6 Cost price and comparison with current protein sources

6.1 Current prices of insects and other protein sources

Prices of some high protein feed ingredients (published on 26th of April 2012 by the Animal Sciences Group in The Netherlands) are presented in Table 12.

Table 12 Price of some high protein feed ingredients (ASG, 2012)

Feed ingredient	Price (€/T)
Soybean meal	410
Lupines	350
Rapeseed meal	300
Peas	294
Maize gluten meal	227
Sunflower meal	210

Prices of feed ingredients for animal feed were rising fast during the second half of the last decennium and the rise was much higher than the rise for meat prices. Particularly the rise of the price of fishmeal is remarkable (Figure 8). Because higher feed costs cannot be passed to consumers the search for alternative protein sources will be continued.

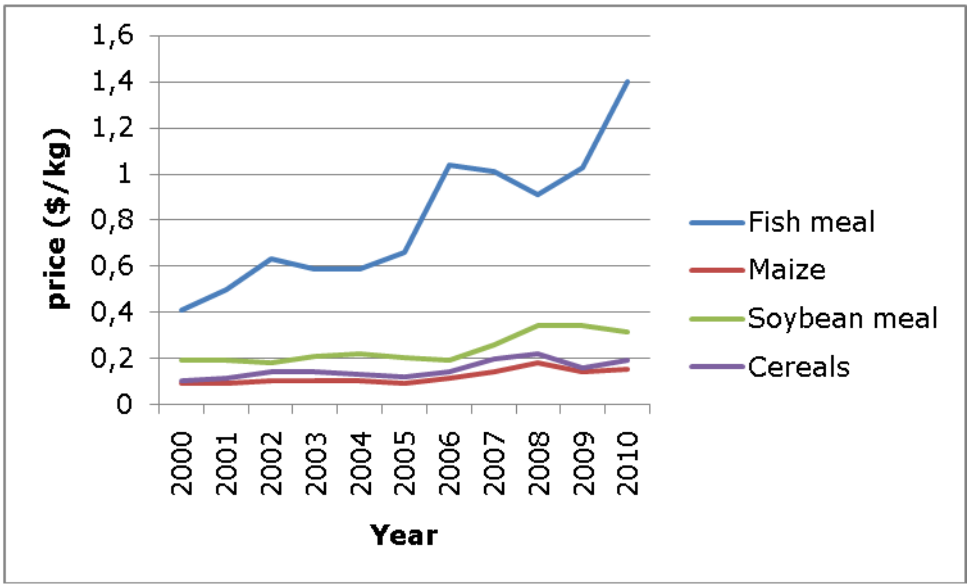

Figure 8 Price of feed ingredients 2000-2009 ($/kg) (Meuwissen, 2011)

The FAO is expecting that the prices for a number of feed ingredients will rise in the period from 2010 – 2019, however the rise will be less than in the period 2007 – 2008 (Figure 9).

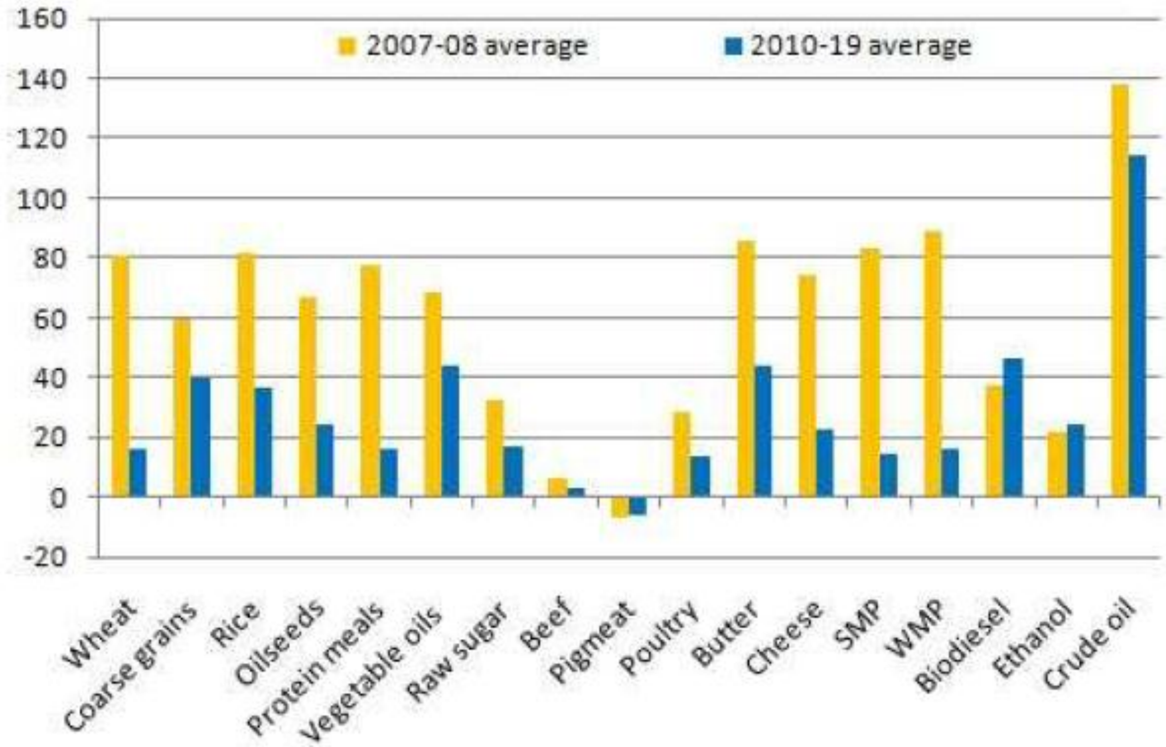

Figure 9 Increase or decrease of cost prices of products and feed ingredients in the period 2007 – 2008 and from 2010 – 2019 (Meuwissen, 2011)

Currently, insects are more expensive compared to standard meat, however the cost price varies per insect species. As an example, the price of mealworms is at this moment € 4.75/kg live weight, which is high compared to prices of other feed ingredients.

As an alternative for vegetable proteins insects are not competitive at this moment. In order to make a good comparison the price has to be adjusted for nutritional value (protein content and composition), dry matter content and the possibility for extraction.
Taking into account the above mentioned factors the cost price of mealworms has to be decreased by >95% in order to be competitive. Mealworm protein is 51 times more expensive than soy protein.

The price of € 4.75/kg live weight for mealworms is the total of € 0.71 housing costs, € 1.09 feed costs, € 2.14 labour costs and € 0.81 other costs. The level of automation/mechanization is low on the insect rearing companies and as a consequence the labour productivity is low. Increasing the size of the insect rearing companies with a higher level of automation/mechanization will decrease the cost price of insects.

Table 13 Prices of various protein sources, 88% dry matter (Meuwissen, 2011)

Protein source	Protein content (%)	Price/kg product (€)	Price/kg protein (€)
Mealworm	50	15.80	31.70
Fishmeal	65	1.24	1.91
Grain	12	0.14	1.17
Soybean meal	45	0.28	0.62

6.2 Target cost prices of insects

For the entrance of volume markets the price of insect protein products has to be about € 0.40 - € 0.60 per kilogram live weight based on 35% dry matter (De Vor, 2011). The cost price should be reduced by a factor 12. Compared to the relative build-up of the cost price for intensive livestock farming the cost price should be decreased per category: labour by a factor 89, housing by a factor 30, feeding by a factor 5 and other costs by a factor 6.
Maybe functional properties of insects (chitin, chitosan) may be used as addible value.

Cost price reduction is mainly possible by a reduction of labour, housing and other costs.
Possibilities to reduce the cost price:

- Reduction of feed costs by increasing feed efficiency and use of bio-waste products
- Reduction of labour costs by mechanization, automation and logistics
- Reduction of housing costs by increasing the size of insect rearing companies and more efficient use of the buildings.
- Reduction of energy use, heat exchange and optimal ventilation, etc.
- Use of high-productive protein rich insects
- Increase of productivity by upgrading/breeding and rearing
- Improvement in efficiency of extraction (in case of pure protein)
- Decreasing processing costs, such as freeze drying

People involved in the insect – animal feed chain stated that the maximal price of insect products as feed ingredient for pigs and poultry should be € 1.00 - € 1.50 per kg to be a competitive alternative protein source. Looking at the current most frequently used protein rich feed ingredients, insect protein is most competitive with fishmeal. The price per kg product for fishmeal is € 1.24 and is expected to increase in the near future.
Expert judgement indicated that a reduction in cost prices of insect products is possible.

7 Workshop with stakeholders

A workshop with stakeholders was organised on 5 June 2012 at Impulse, Wageningen, The Netherlands. A list of stakeholders was compiled by the project group and the Ministry of Economic Affairs, Agriculture and Innovation. Main purpose of this meeting was to identify opportunities and obstacles to the widespread use of insects as a sustainable feed ingredient. In total 57 stakeholders were invited to participate in the workshop. On 5 June 2012, 48 stakeholders participated in the workshop (Annex 4). Prior to the workshop the project team divided the stakeholders in six groups related to research, feed safety, insect rearing companies, animal feed companies, project team and others. An overview of the number of stakeholders per group is presented in Figure 10.

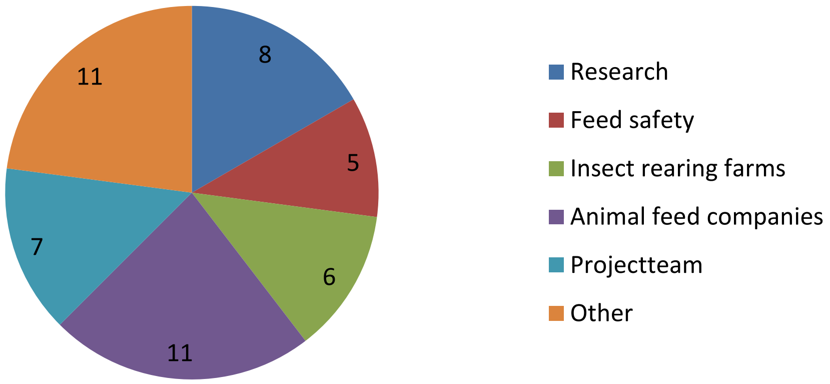

Figure 10 Number of stakeholders per group

The workshop consisted of two different sessions. During the morning session the results of the desk study were presented by members of the project team followed by a plenary discussion. After a coffee break two sessions were organised in which stakeholders presented their vision on 1) Sustainable use of organic waste by insects in relation to quality and safety and 2) Large scale use of insects as feed ingredient.
In session 1 two stakeholders (Carine van Vuure, VION Ingredients and Roel Potting, NVWA, Food and Consumer Product Safety Authority) presented their vision. In session 2 the vision from the field was presented in three pitch talks by the stakeholders Hans Calis (Kreca), Hendrik de Vor (Coppens Diervoeding) and Walter Jansen (JAMO).

In the afternoon session a more interactive part of the workshop was organised. Three propositions were presented by the moderator Gert van Duinkerken and stakeholders were asked to give their opinion on the proposition by taking place in one of four quarters as presented in Figure 11.

Agree *In short notice* *<5 year*	*Agree* *On long term* *>5 year*
Disagree	*No opinion*

Figure 11 Four possible opinions during the interactive afternoon session

Stakeholders in different categories received a paper with a different colour as presented in Figure 12.

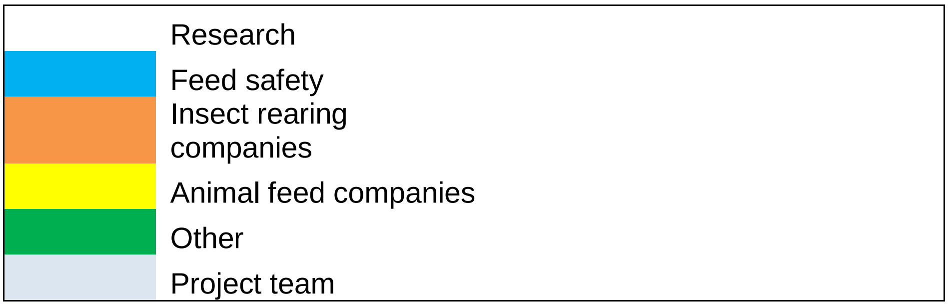

Figure 12 Colours for the different groups

After introduction of the proposition, stakeholders were divided in mixed groups (consisting of stakeholders from all groups) and were asked to join one of four discussion groups. In a first discussion session four opportunities were selected to discuss and in a second session four obstructions were selected to discuss.
The four opportunities were: 1) Profitability, 2) Optimization of organic waste, 3) Innovation and 4) Optimization of the insect rearing company. The four obstructions were: 1) Profitability, 2) Competition with other protein sources, 3) Large scale production and 4) Legislation

The outcome of the workshop is categorized in four categories (1. Opportunities – Possibilities; 2. Obstructions – Threats; 3. Suggestions – Required actions; 4. Points of attention) and these are presented in the next four paragraphs:

7.1 Opportunities – Possibilities

- Possible functional properties of insects (i.e. chitin) may facilitate the use of insects as feed ingredients.
- A low carbon footprint would facilitate insects such as mealworms to be used as feed ingredients.
- The use of insects in petfoods:
    - May be profitable as the value of petfood is higher than that of pig/poultry feed.
    - Insects are already being used in feed for fish, birds and hamsters.
    - On the other hand, relatively cheap animal co-product meals are used in petfoods making it less feasible to incorporate insects in petfoods. It may therefore be more feasible to apply insects as feed ingredients in aquaculture or in pig and poultry diets.

7.2 Obstructions – Threats

- Costs for production are currently too high.
- There may be an increased risk of accumulation of dioxin in the production cycle (waste-to-feed/food).
- There is a risk of Campylobacter contamination in insects as feed ingredients. This depends on the species and life stage of the insect and requires adequate processing of the insects (combining safe-sourcing with safe-processing).
- Product safety is vital and should be monitored.
- Environmental legislation may be an obstacle for large-scale production of insects.
- Novel diseases may arise when insects are produced on large-scale e.g. using waste.

7.3 Suggestions - required actions

- Clarify what the legal status is of insects as feed ingredients (cat III; invertebrates that are non-pathogenic; processed animal protein).
- Compilation of feeding tables for insects is required. In such tables, the nutritional value of substrates for specific insects should be described. The focus should be on the use of (low-quality) substrates for growing insects and not on the use of substrates that are currently already directly used as feed ingredient for livestock. Then, novel substrates should be evaluated.
- Research is required for
    - housing insects
    - nutritional value of substrates for insects
    - determining the nutritional value of insects
    - safety assurance
- The research can be performed in a collaborative approach by independent research institutes and feed companies; and results can be made publically available.
- Various players in the production chain should be involved in research, and strong coordination of research is important.
- Development of an insect rearing model by companies and researchers can provide a proof-of-concept and facilitate the production and use of insects as feed ingredients on a large scale.
- Use expertise on processing technologies in the fish & shrimp and animal co-product industries for processing of insects to feed ingredients.
- Up scaling of insect production will lead to profitability.
- Lowering of production costs can be achieved by an increase in mechanisation and technology.
- Identify critical factors that contribute to the success of prototypes.
- Involve NGOs to support the use of insect proteins or insects as feed ingredients.

- For large-scale production of insects:
    - Closed systems are required.
    - Different life stages/breeding stocks are kept separately.
    - Monoculture should be used.
    - Storage between substrates for insects should be separated.
    - Specific procedures for stress-free killing are required.
    - Specific methods of storage of products.
- VENIK, NEVEDI, government, knowledge centres, and NVWA need to collaborate for development of a strategy that results in laws and regulations by the European Commission.

7.4 Points of attention

- Price of insects is the most important aspect and this will determine which insects will be used in the future.
- A constant production with low variability in products is of importance. A feed data sheet is required.

7.5 Propositions

1. It will be technically feasible to use insects as sustainable feed ingredients.

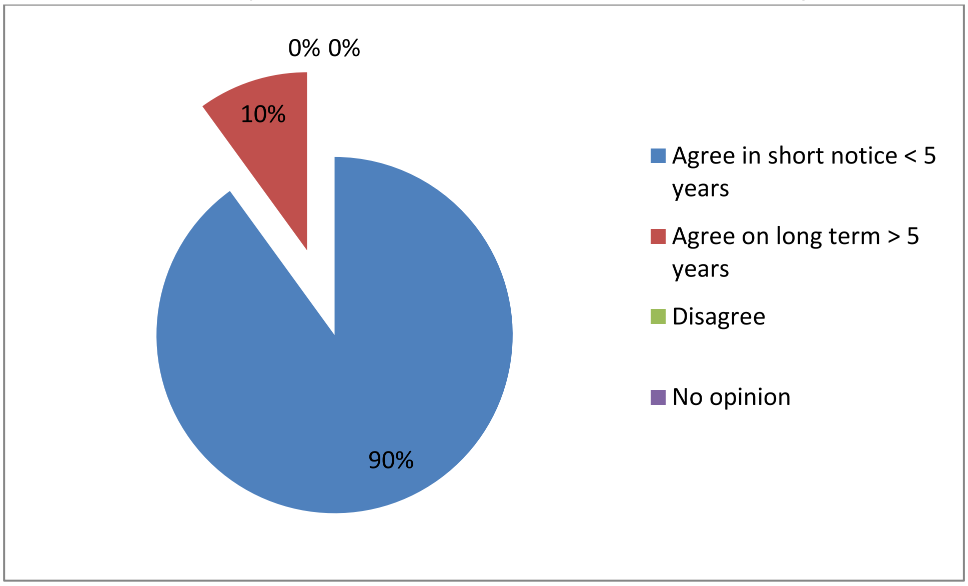

Figure 13 Distribution of opinions at proposition no. 1: It will be technically feasible to use insects as sustainable feed ingredients

Only 10% of the stakeholders took position in the quarter “Agree On long term >5 year” and about 90% of the stakeholders were standing in the quarter “Agree in short notice<5 year” (Figure 13).

Comments:

- Agree, long-term (>5 years): Due to low costs for personnel and equipment, it would be possible to reach an internal rate of return (IRR) of 60% or more on the long term.
- Agree, short-term (<5 years): It would be technically feasible on the short term but safe and economic insect production may be problematic.

2. It will be economically feasible to use insects as sustainable feed ingredients.

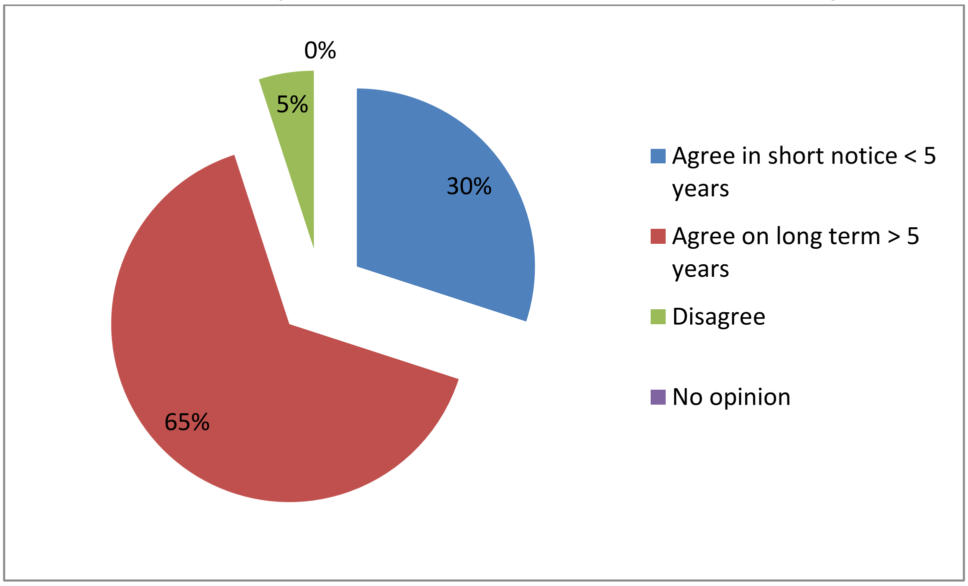

Figure 14 Distribution of opinions at proposition no. 2: It will be economically feasible to use insects as sustainable feed ingredients

At this proposition 65% of the stakeholders took position in the quarter “Agree On long term>5 year” and about 30% of the stakeholders were standing in the quarter “Agree
In short notice<5 year” (Figure 14). One stakeholder disagreed with this proposition. The comment is written below.

Comments:

- Disagree: The costs for production and product price of insects are currently too high to make it feasible even on the long term.
- Agree, short-term (<5 years): Based on the pitch of Hans Calis (Kreca) it may be feasible. Furthermore, the technological innovations in horticulture exemplify that production may further be optimised with reduced costs. Further specialisation of insect rearing requires however investments.
- Agree, long-term (>5 years): The current costs for production and product price of insects are too high and discouraging, but this may change as the prices of alternative feed ingredients increase in the future.
- Agree, short-term (<5 years): The price for insects as feed ingredients should not be compared to soybean meal, but other more high-quality (and expensive) ingredients.
- Agree, long-term (>5 years): It may be better to grow insects on manure than growing algae or duckweed on manure + water. The latter alternative obliges drying, which requires energy and, therefore, is expensive.
- Agree, long-term (>5 years): The current costs for production and product price of insects are too high and discouraging and the acceptability of the use of insects may be low. Furthermore, already 1900 or more insect species are consumed by humans. The use of insects as food may increase the competition and hinder the use of insects as feed ingredients. In response to this comment, it was indicated that soy is used as a food as well as a feed ingredient, without a difference in price.

3. It is safe and legally feasible to use insects as sustainable feed ingredients.

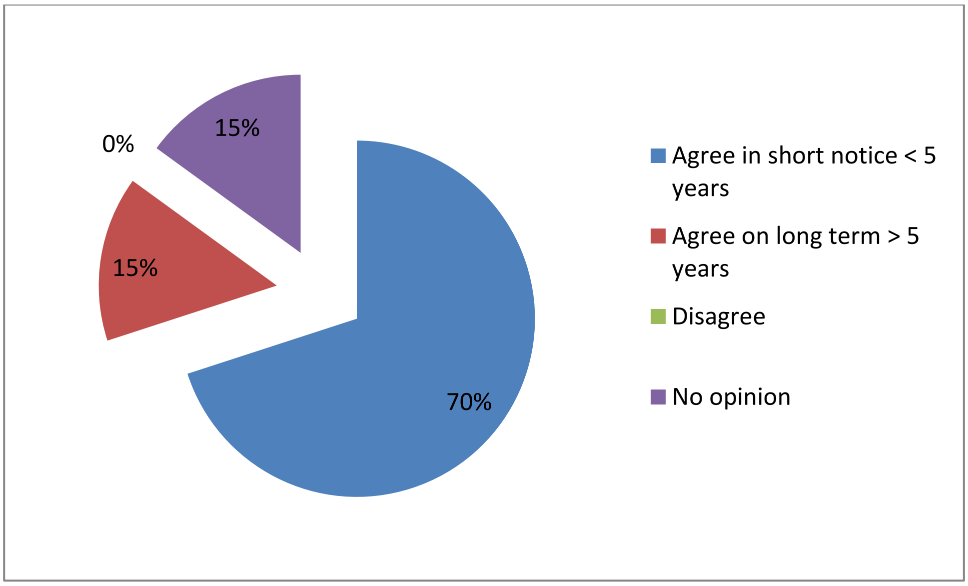

Figure 15 Distribution of opinions at proposition no. 3: It is safe and legally feasible to use insects as sustainable feed ingredients

At this proposition 15% of the stakeholders took position in the quarter “Agree On long term>5 year” and about 70% of the stakeholders were standing in the quarter “Agree In short notice<5 year”. Another 15% of the stakeholders took position in the quarter “no opinion” (Figure 15).

Comments:

- Agree, long-term (>5 years): It will be a time-consuming process. If some European countries will not cooperate, e.g. due to safety issues, then it may take 8 to 10 years. Considering the legislation, some insects may not be allowed but others will.
- Agree, short-term (<5 years): If the substrates used for raising insects are safe (e.g. non-manure substrates). Thereafter, it other substrates may be applied (step-by-step approach).
- Agree, short-term (<5 years): It will depend on the insect species and the substrate used whether this will be feasible within or after 5 years from now.
- Agree, short-term (<5 years): By means of innovation-power and -contract.

At the end of the workshop a "final measurement" was conducted on the statement “It is feasible to use insects on large scale as a feed ingredient”

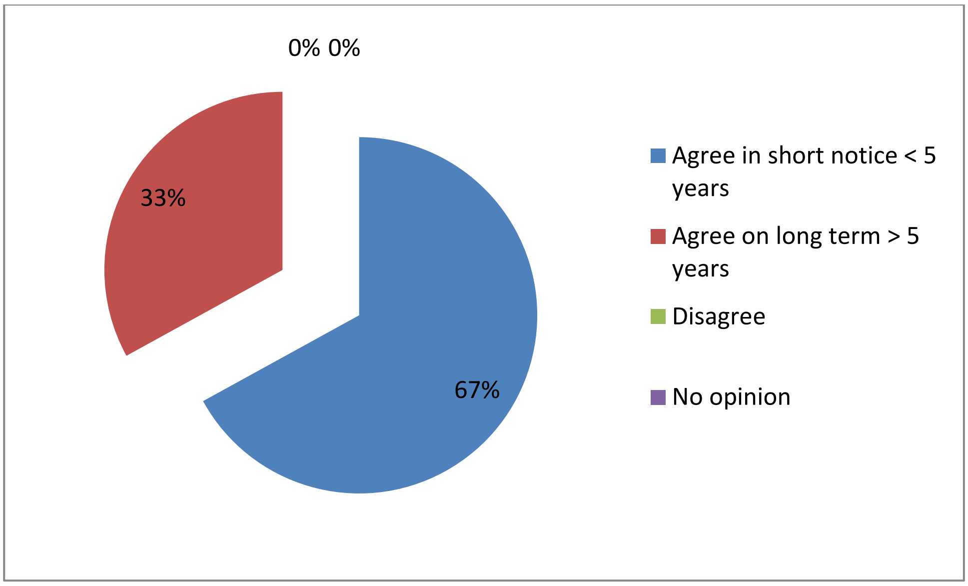

Figure 16 Distribution of opinions at “final measurement” proposition: It is feasible to use insects on large scale as a feed ingredient

Figure 16 shows that the participants unanimously believe that it is feasible to use insects on a large scale as a feed ingredient. Opinions varied about the time that this may become reality: already within 5 years or longer.

Figure 17 Final remarks at the workshop made by Dr. Annelie Boogerd of the Ministry of Economic Affairs, Agriculture and Innovation

General expectation in the workshop was that the use of insects as feed ingredient in fish feed is closest to reality and also in pet food. Moreover, also in pig and poultry feed inclusion of insect (products) as feed ingredient is feasible in the near future.

8 Conclusions and Recommendations

Use of insects as a sustainable protein rich feed ingredient in pig and poultry feed is technically feasible. Insects can be reared on low-grade bio-waste and can turn low-grade bio-waste into high quality proteins. Insects therefore can be a promising interesting link in the animal feed chain to fulfil the globally increased demand for protein. It is feasible to use insects on a large-scale as future feed material. However, opinions differed on the pace of this development: will it take less or more than 5 years? It was generally expected that the use of insects as a feed material in aquaculture is the nearest future application, as well as the use in pet foods. The application of insects in poultry and pig feeding was also considered realistic. Main bottlenecks were identified in the area of law and regulation and the possibilities to increase the scale of insect production at a low cost price.

The use of insects as a feed ingredient is feasible

- Use of insects on a large scale as a feed ingredient is expected to be technically feasible: already within five years.
- General expectation is that the use of insects as feedstock in fish feed is closest to reality, and also in pet food.

Large volumes can be used in feed

- For full replacement of soybean meal in fattening pig and broiler diets, large quantities (685 kiloton annually) of insects are required. Replacing 5% in compound feed for broilers would mean that still 72 kiloton of insects a year is required.
- Currently, the production volume of insects on rearing companies in The Netherlands is low and the market is mainly focussed on zoos and pet shops (to feed birds, reptiles, mammals and amphibians).

Most promising insect species

- Insects identified as most promising for large scale production are larvae of the Black soldier fly (*Hermetica illucens*), the Common housefly (*Musca domestica*), and the Yellow Mealworm (*Tenebrio molitor*).

Processing techniques need to be developed further

- Insects need to be further processed in order to get insects into a form in which they are usable in the feed industry.
- Shelf life of insects is increased significantly by processing methods like freezing and freeze drying, however these methods are expensive.

Legislative constraints need to be solved

- So far, in the EU, it is not allowed to use insect protein in feed for pigs and poultry due to the TSE regulation. Further risk assessment of use of insects as feed ingredient is required to develop new regulations.
- The currently used GMP+ certification for the animal feed industry should be adjusted for use of insects as feed ingredient.
- The ‘Gwwd law’ is principally applicable to invertebrates. This law will be changed in 2013 into ‘Wet Dieren’, which will be applicable for insects. Research on animal welfare items in insects is recommended.
- The production of greenhouse gas emission by insects is lower than for conventional livestock. It is recommended to perform a Life Cycle Analysis for the insect chain from substrates used for insect rearing to the end product in the poultry or pork production chain.

Insects upgrade low-grade bio-waste

- Insects are cold-blooded, they are highly efficient in converting low-grade feed to high quality protein. Bio-waste can be upgraded efficiently to high quality protein for use in pig and poultry diets.

Nutritional value is very promising

- Compared to soybean meal, crude protein content of black soldier fly larvae and prepupae is lower whereas that for mealworm and housefly is equal or higher. Fat content varies considerably among insects and can be substantial. There is a need for evaluation of nutrient digestibility of (processed) insects as feed ingredient.
- Potential beneficial functional properties of insect protein need to be further investigated in order to create an added value for insect protein.
- The Essential Amino Acid Index (EAAI) of the three insects in this study are above 1 indicating that these protein sources provided in general more of the essential amino acids than required for broilers as well as growing pigs.

Cost price can and must be reduced

- Maximum price of insects as feed ingredient for pig and poultry diets should be in the range of € 1.00 - € 1.50 per kg to be a competitive alternative protein source, especially to replace fishmeal.
- Cost price reduction is required to be able to use insects as protein source in pig and poultry diets on an economically feasible basis. Possibilities to decrease the cost price are: increase of feed efficiency of insects and the use of cheap bio-waste products, reduction of labour costs by mechanization, automation and logistics, reduction of housing costs by increasing the size of insect rearing companies and more efficient use of buildings, reduction of energy use, heat exchange and optimal ventilation, use of high-productive protein rich insects, and decreasing processing costs. On all these measures further research is recommended.

Recommendations for the industry: Increasing scale of insect production and cost price reduction

To make use of insects as a feed ingredient in pig and poultry diets on a large scale it is important to

- Increase the scale of insect production further with a continuous quantity and quality
- Decrease the cost price of insect rearing further in order to be competitive with currently used protein sources
- Determine the feeding value of bio-waste accurately per insect species
- Determine the feeding value of insect species accurately for livestock, such as pigs and poultry
- Improve shelf-life of insect products
- Further develop the insect chain with stakeholders that can contribute in the different links such as: suppliers of organic side-streams, insect rearing companies, processing industry of insects, animal feed industry, pig and poultry producers and Retail
- Increase the efficiency of insect rearing by
    - Decreasing labour costs by innovations in mechanisation, automation and logistics
    - Decreasing housing costs by increasing the scale of insect production and a more efficient use of buildings and decreasing the energy demand by use of heat exchangers and optimal ventilation
    - Searching for clients for rest products from the insect rearing company, such as substrates and rest of insects
- Decrease processing costs of insects by technological innovations
- Extract functional substances from insects for cosmetics, pharma, textile or paper. Value can be added in this way to the insects and as a consequence insects will be more interesting due to a further decrease of the cost price
- Start research on short term to make an introduction of insects as a feed ingredient for animal feed possible. Large scale research projects should be conducted to deliver the required information on short term. At this moment there are possibilities to initiate new research project via subsidies for innovation, 'Top-sector policy' but also in EU research programmes.

Recommendations for the authorities: Legislation and regulation

To make use of insects as a feed ingredient in pig and poultry diets on a large scale it is important to

- Study the possibilities to include insects as an animal feed ingredient in legislation and regulation. It is also recommended to start a lobby on European level to accept insects as a feed ingredient for livestock.
- Start research on the transmission of contaminants from bio-waste products (substrate for rearing insects) to insects and from insects to pigs or poultry. The authorities can act in a facilitating role

In general, the authorities may help to facilitate the process for introduction of insects as an ingredient in pig and poultry diets.

Recommendations for research

Recommendations for additional research (also included in draft Bidbook InsectCentre, in short notice available on http://www.insectcentre.nl/).

Basic research

- How can insects as feed ingredient contribute to animal health
- Establish functionality of nutritional compounds of insects in animals
- Develop efficient extraction techniques for protein, fat and chitin rich insect-fractions
- Greenhouse gas and LCA Analysis

Applied Research

- Develop processing technologies for insects
- How to prolong shelf life of insect products
- How can insects be processed in pig feed application
- How can insects be processed in poultry feed application
- How can insects be processed in fish feed application
- Other feed applications
- Analyzing opportunities and threats in chain collaboration

Valorisation

- Establish the optimal combination of insects and bio-waste as feed ingredient for pig and poultry feed
- Contamination of insects from bio-waste
- Contamination of pigs and poultry from insects
- How to guarantee a sufficient quantity of bio-waste of a certain quality
- What to do with rest products from substrate and insects

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Appendices

Annex 1 Insect rearing companies in the Netherlands

In the Netherlands 18 companies are involved in rearing insects. In this Annex nine of these companies are included.

Members of VENIK (Dutch society of insect rearing companies):

- Insectenkwekerij Van de Ven http://www.insectenkwekerij.nl/
- Kreca produces a number of insect species, e.g. crickets (Gryllussigillatus and Achetadomesticus); mealworms (Zophobasmorio, Alphitobiusdiaperinus, and *Tenebrio molitor*); locusts (Locustamigratoria), redrunners (Shelfordellatartara), fruitflies and wax moths. http://www.kreca.com
- Meertens only produces Locusta migratoria. http://www.mik-meertens.nl/

Some other companies:

- Vivara produces mealworms. http://www.vivara.nl/sub_category/id=43/vogelvoer.html

- De krekelkoerier produces the same as Kreca, but also silkworm. http://www.krekelkoerier.nl/
- Locusta insectenkwekerij (type of insects not clear but at least locusts. http://www.locusta.eu/
- Mous Live Bait, Balk (Friesland) produces mealworms (Alphitobiuslaevigatus and *Tenebrio molitor*, Sun Beetle (Pachnodamarginata peregrine), wax moth (Galleria mellonella), cockroaches (Blapticadubia), and maggots. http://www.livebait.nl/
- Meelwormenkwekerij Gwk
- VIWO Holland produces mealworms. http://www.viwo.nl/

Annex 2 Authorities and regulations on risk assessment of feed ingredients

EFSA (http://www.efsa.europa.eu/en/efsawhat/riskassessment.htm)

The Emerging Risks Unit of the European Food Safety Authority (EFSA) in Parma Italy carries out risk assessment regarding food and feed safety. In close collaboration with national authorities and in open consultation with its stakeholders, EFSA provides independent scientific advice and clear communication on existing and emerging risks.

In the European food safety system, risk assessment is done independently from risk management. As the risk assessor, EFSA produces scientific opinions and advice to provide a sound foundation for European policies and legislation and to support the European Commission, European Parliament and EU Member States in taking effective and timely risk management decisions. The Emerging Risks Unit is responsible for establishing procedures to monitor, collect and analyse information and data in order to identify emerging risks in the field of food and feed safety with a view to their prevention.

In the course of the identification of new trends in food/feed production, the use of insects, particularly their potential use in animal feed was flagged up as a future issue in the EU. From a food/feed safety point of view there is the potential for exposure to farm animals, and so indirectly, humans, to new hazards and/or increased exposure to known hazards. In order to identify potential risks, a better understanding of the insect species that may be exploited and also their rearing and processing is required.

NVWA (http://www.vwa.nl/english)

The task of the Netherlands Food and Consumer Product Safety Authority (NVWA) is to protect human and animal health. It monitors food and consumer products to safeguard public health and animal health and welfare. The Authority assesses the whole production chain, from raw materials and processing aids to end products and consumption.

The Netherlands Food and Consumer Product Safety Authority is an independent agency in the Ministry of Economic Affairs, Agriculture and Innovation and a delivery agency for the Ministry of Health, Welfare and Sport.

The three main tasks of the Netherlands Food and Consumer Product Safety Authority are: supervision, risk assessment and risk communication. Other important activities are incident and crisis management and policy advice for the Minister of Economic Affairs, Agriculture and Innovation. A significant part of its work involves liaising with other ministries. Maintaining international contacts is also of vital importance.

The Office for Risk Assessment and Research of NVWA is involved in two ways of using insects as food and feed:

1. They are about to complete a risk assessment of using insects as food. The main question to be answered was “Are there risks (chemical, microbiological, parasitological) associated with the consumption of heated and unheated insects.”
2. Soon they will start a risk assessment of using insects as feed also when grown on manure.

General Food Law (http://ec.europa.eu/food/food/foodlaw/index_en.htm)

In all EU Member States and many third countries, the overarching principles concerning food safety and consumer protection are established in national legislation. However, at EU level, food legislation has evolved without some of these basic principles having been established in an overarching legal instrument.

On the 28th of January 2002 the European Parliament and the Council adopted Regulation (EC)178/2002 laying down the General Principles and requirements of Food Law.
The aim of the General Food Law Regulation is to provide a framework to ensure a coherent approach in the development of food legislation. At the same time, it provides the general framework for those areas not covered by specific harmonised rules but where the functioning of the Internal Market is ensured by mutual recognition.
It lays down definitions, principles and obligations covering all stages of food/feed production and distribution.

The food law aims at ensuring a high level of protection of human life and health, taking into account the protection of animal health and welfare, plant health and the environment. This integrated "farm to fork" approach is now considered a general principle for EU food safety policy. Food law, both at national and EU level, establishes the rights of consumers to safe food and to accurate and honest information. The EU food law aims to harmonise existing national requirements in order to ensure the free movement of food and feed in the EU. The food law recognises the EU's commitment to its international obligations and will be developed and adapted taking international standards into consideration, except where this might undermine the high level of consumer protection pursued by the EU.

The Regulation establishes the principles of risk analysis in relation to food and establishes the structures and mechanisms for the scientific and technical evaluations which are undertaken by the European Food Safety Authority (EFSA). Depending on the nature of the measure, food law, and in particular measures relating to food safety must be underpinned by strong science. The EU has been at the forefront of the development of the risk analysis principles and their subsequent international acceptance. Regulation EC 178/2002 establishes in EU law that the three inter-related components of risk analysis (risk assessment, risk management and risk communication) provide the basis for food law as appropriate to the measure under consideration. Clearly not all food law has a scientific basis, e.g. food law relating to consumer information or the prevention of misleading practices does not need a scientific foundation. Scientific assessment of risk must be undertaken in an independent, objective and transparent manner based on the best available science. Risk management is the process of weighing policy alternatives in the light of results of a risk assessment and, if required, selecting the appropriate actions necessary to prevent, reduce or eliminate the risk to ensure the high level of health protection determined as appropriate in the EU. In the risk management phase, the decision makers need to consider a range of information in addition to the scientific risk assessment. These include, for example, the feasibility of controlling a risk, the most effective risk reduction actions depending on the part of the food supply chain where the problem occurs, the practical arrangements needed, the socio-economic effects and the environmental impact. Regulation EC/178/2002 establishes the principle that risk management actions are not just based on a scientific assessment of risk but also take into consideration a wide range of other factors legitimate to the matter under consideration.

Food safety and the protection of consumer interests are of increasing concern to the general public, non-governmental organisations, professional associations, international trading partners and trade organisations. Therefore, the Regulation establishes a framework for the greater involvement of stakeholders at all stages in the development of food law and establishes the mechanisms necessary to increase consumer confidence in food law. This consumer confidence is an essential outcome of a successful food policy and is therefore a primary goal of EU action related to food. Transparency of legislation and effective public consultation are essential elements of building this greater confidence. Better communication about food safety and the evaluation and explanation of potential risks, including full transparency of scientific opinions, are of key importance.

Regulation on requirements for feed hygiene (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:035:0001:0022:EN:PDF)

The pursuit of a high level of protection of human and animal health is one of the fundamental objectives of food law, as laid down in Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (3). That Regulation also lays down other common principles and definitions for national and Community food law, including the aim of achieving free movement of feed within the Community. Council Directive 95/69/EC (4) established the conditions and arrangements applicable to certain categories of establishments and intermediaries in the animal feed sector, to enable them to exercise their activities. Experience has shown that these conditions and arrangements constitute a sound basis for ensuring feed safety. That Directive also established conditions for the approval of establishments producing certain substances listed in Council Directive 82/471/EEC of 30 June 1982 concerning certain products used in animal nutrition Commission Directive 98/51/EC of 9 July 1998 laying down certain measures for implementing Council Directive 95/69/EC laying down the conditions and arrangements for approving and registering certain establishments and intermediaries operating in the animal feed sector (6), established certain measures that included arrangements for imports from third countries. The principal objective of the new hygiene rules set out in this Regulation is to ensure a high level of consumer protection with regard to food and feed safety, taking particular account of the following principles:

(a) that primary responsibility for feed safety rests with the feed business operator;
(b) the need to ensure feed safety throughout the food chain, starting with primary production of feed, up to and including, the feeding of food-producing animals;
(c) the general implementation of procedures based on the principles of hazard analysis and critical control points (HACCP), which, together with the application of good hygiene practice, should reinforce feed business operators’ responsibility;
(d) that guides to good practice are a valuable instrument to help feed business operators at all levels of the feed chain comply with feed hygiene rules and with the application of HACCP principles;
(e) the establishment of microbiological criteria based on scientific risk criteria;
(f) the need to ensure that imported feed attains a standard that is at least equivalent to that of feed produced in the Community.

Undesirable substances in animal feed (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2002L0032:20061020:EN:PDF)

Rules on feedstuffs are needed to ensure agricultural productivity and sustainability and to make it possible to ensure public and animal health, animal welfare and the environment. In addition, there is a need for comprehensive regulation on hygiene in order to guarantee good quality feedstuffs on individual farms even when they are not commercially produced. The same rules concerning the quality and safety of products
intended for animal feed have to apply to the quality and safety of water consumed by the animals. Products intended for animal feed may contain undesirable substances which can endanger animal health or, because of their presence in livestock products, human health or the environment. It is impossible to eliminate fully the presence of undesirable substances but it is important that their content in products intended for animal feed should be reduced, with due regard to the substances' acute toxicity, bio-accumulability and degradability, in order to prevent undesirable and harmful effects. It is at present inappropriate to fix this content below the levels detectable by methods of analysis to be defined for the Community. The methods for determining residues of undesirable substances are becoming increasingly sophisticated, so that even quantities of residues which are negligible for animal and human health can be detected. Undesirable substances may be present in products intended for animal feed only in accordance with the conditions laid down in this Directive and may not be used in any other way for the purposes of animal feed. This Directive should therefore apply without affecting other Community provisions on feedstuffs, and particularly the rules applicable to compound feedstuffs. This Directive must apply to products intended for animal feed as soon as they enter the Community. It must therefore be stipulated that the maximum levels of undesirable substances that are set apply in general from the date on which the products intended for animal feed are put into circulation or used, at all stages, and in particular as soon as they are imported. Products intended for animal feed must be sound, genuine and of merchantable quality and therefore when correctly used must not represent any danger to human health, animal health or to the environment or adversely affect livestock production. Using or putting into circulation products intended for animal feed which contain levels of undesirable substances that exceed the maximum levels must therefore be prohibited. The presence of certain undesirable substances in complementary feedstuffs must be limited by fixing appropriate maximum levels. While in certain cases a maximum level is fixed, taking account of background levels, continued effort is still needed to restrict the presence of some specific undesirable substances to the lowest possible levels in products intended for animal feed so as to reduce their presence in the feed and food chain. It should therefore be permitted, under this Directive, to lay down action thresholds well below the maximum levels fixed. Where such action thresholds are exceeded, investigations must be carried out to identify the sources of the undesirable substances and steps taken to reduce or eliminate such sources. Where animal or human health or the environment is endangered, Member States should be allowed temporarily to reduce the fixed maximum permissible levels, to fix maximum levels for other substances or to prohibit the presence of such substances in products intended for animal feed.

Annex 3 Amino acid profile (% of crude protein, % relative to lysine) and mean essential amino acid index of processed and unprocessed insects and soybean meal as reference protein source

Amino acid	Mw	LMw	MW	Hf		BSF		SbM
	larvae	larvae	larvae	larvae	pupae	larvae	prepupae	
	n=13	n=1	n=1	n=9	n=5	n=1	n=1	CVB
% of crude protein								
Arginine	5.8	4.9	4.9	4.9	4.7	5.3	6.1	7.5
Cystine	5.8	0.8	0.8	0.7	0.4	0.1	ND	1.5
Histidine	3.6	3.8	3.0	2.8	2.4	4.5	2.7	2.7
Isoleucine	6.7	3.8	4.7	3.2	3.5	4.7	4.7	4.6
Leucine	10.7	5.9	9.7	5.7	5.3	8.4	7.1	7.7
Lysine	6.4	5.7	5.2	6.9	5.5	8.0	6.0	6.2
Methionine	2.1	2.8	1.1	2.2	2.1	2.0	1.7	1.4
Phenylalanine	5.4	4.1	3.5	5.0	4.4	5.2	4.6	5.2
Threonine	5.1	3.4	4.0	3.3	3.2	1.3	4.1	3.9
Tryptophan	1.6	1.6	0.9	3.2	ND	0.5	ND	1.3
Tyrosine	7.8	7.0	7.0	5.1	5.2	6.0	7.1	3.7
Valine	8.2	4.8	5.2	4.4	4.2	8.1	6.4	4.8
Total	69.0	48.8	49.9	47.5	40.9	54.2	50.4	50.5
% relative to lysine								
Lysine	100	100	100	100	100	100	100	100
Arginine	88	86	93	74	84	66	101	121
Cystine	34	13	15	10	8	2	ND	24
Histidine	67	67	58	42	45	57	45	44
Isoleucine	95	66	90	49	64	58	77	74
Leucine	168	103	185	86	98	105	118	124
Methionine	28	48	20	32	38	26	28	23
Phenylalanine	72	72	66	74	79	65	76	84
Threonine	86	60	76	49	61	16	68	63
Tryptophan	34	28	17	41	ND	6	ND	21
Tyrosine	120	122	133	77	93	74	118	60
Valine	126	84	100	65	75	101	106	77
Essential amino acid index[1]								
Growing pig	1.72	1.35	1.16	1.25	1.19	1.24	1.43	1.29
Broiler chicken	1.68	1.29	1.11	1.18	1.11	1.18	1.35	1.23

Abbreviations: Mw = Mealworm, LMw = Lesser mealworm, MW = Morio worm, Hf = Housefly, BSF = Black soldier fly, SbM = soybean meal, ND = not determined.

[1]Mean essential amino acid index is calculated for each amino acid profile found in literature. A value of 1 refers to a complete accordance between requirement of target animal for essential amino acids and presence in the protein source. For each amino acid that is more available than required the index will go up and vice versa.

Annex 4 List of stakeholders participating in the workshop

Name		Company
Boekel	Tiny van	Agrotechnology & Food Sciences Group
Boetje	Martine	Ontwikkelingsmaatschappij Oost NV
Boogerd	Annelie	Ministerie EL&I
Bosch	Guido	ASG DW Diervoeding
Caessens	Petra	PROTIN
Calis	Hans	Kreca
Corijn	Daniëlle	5-Sterrenregio
Duinkerken	Gert van	Wageningen UR Livestock Research
Eeckhout	Mia	Hogeschool Gent
Enckevort	Ard van	Denkavit
Gort	Frank	Productschap Diervoeder
Guérin	Oriane	Zetadec bv
Hagelaar	Geoffrey	Wageningen UR Management Studies
Hoekman	Jans	Ontwikkelingsmaatschappij Oost NV
Huis	Arnold van	Wageningen UR Entomologie
Jansen	Walter	Jagran BV
Koning	Lian de	Agrifirm Innovation Center
Koppert	Paul	Koppert Biological Systems
Koppert	Arjan	Koppert Biological Systems
Koppert	Jonathan	Koppert Biological Systems
Lakemond	Catriona	Agrotechnology & Food Sciences Group
Lemmens	Tom	Vitelia Voeders
Litjens	Roel	Thielen Consult BV
Marchal	Leon	ForFarmers
Meul	Marijke	Hogeschool Gent
Noorlander	Guido	Lenersan Poortman
Olde Heuvel	Erica	NVWA
Oonincx	Dennis	Wageningen UR Plant Sciences Group
Oosterom	Rob van	NVWA
Ottevanger	Else	ASG DW Diervoeding
Pannevis	Marinus	Mars Petcare Global R&D
Peters	Marian	Venik
Potting	Roel	NVWA
Raamsdonk	Leo van	RIKILT
Simons	Piet	Dutch Poultry Centre
Spiegel	Marjolein van der	RIKILT
Stroucken	Willeke	Provimi Pet Food NL BV
Thielen	Wim	Thielen Consult BV
Vahl	Harry	Vahl Feed and Health
Valk	Henry van der	Technology Foundation STW
Veldkamp	Teun	Wageningen UR Livestock Research
Vereijken	Johan	Wageningen UR Food & Biobased Research
Vor	Hendrik de	Coppens Diervoeding
Vrij	Marleen	Zetadec bv
Vuure	Carine van	VION Ingredients
Verwer	Cynthia	Louis Bolk Instituut
Wichers	Harry	Agrotechnology & Food Sciences Group
Winden	Sandra van	Ministerie EL&I

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