Vlaanderen
is landbouw & visserij

GUIDE FOR INSECT FARMERS AND PROCESSORS

TOWARDS SUSTAINABLE AND HEALTHY INSECT REARING

DEPARTEMENT
**LANDBOUW
& VISSERIJ**

www.vlaanderen.be/landbouw

//

GUIDE FOR INSECT FARMERS AND PROCESSORS TOWARDS SUSTAINABLE AND HEALTHY INSECT REARING

//

Vlaanderen
is landbouw en visserij

This brochure is provided to you by:

Met de financiering van:

Authors
Thomas Spranghers (VIVES University College)
Filip Wouters (VIVES University College)
Sharon Schillewaert (VIVES University College)
Lotte Frooninckx (Thomas More University College)

Reading committee
Bart Mertens, Carl Coudron, Christine Breynaert, Christophe Keppens, Dominiek Vangansbeke, Dries Vandeweyer, Evelien Decuypere, Isabelle Laquière, Jeroen De Smet, Jonas Claeys, Katleen Van den Eynden, Leen Bastiaens, Leen Van Campenhout, Liesbeth Van Nieuwenhove, Lynn Biermans, Nikolaas Viaene, Paul Proost, Sara De Bolle, Veerle Van linden, Yves Arijs

Layout
Evert Vanneste + Department of Agriculture and Fisheries

Depot number
D/2021/3241/169

It is important to emphasise that no protocols have been developed and laid down yet for insect rearing and processing. For this reason, we limit ourselves in this guide to providing the principles and elements of focus associated with the techniques examined. The authors are in no way responsible for any problems with insect rearing and processing that result from consulting and following this guide.

Guide for insect farmers and processors towards sustainable and healthy insect rearing.

Department of Agriculture and Fisheries

TABLE OF CONTENTS

INTRODUCTION

THE ROLE AND DESIRABILITY OF INSECTS

Thanks to the focus on insects in research in Flanders and abroad and their potential as an alternative food source, insects have often attracted media attention in Flanders since September 2013. At that time Bugs' Food won the Brussels Sustainable Economy Academy Award and renowned chefs presented the opportunities of insects in talk shows. The relationship between humans and insects, however, is sometimes more surprising than just as a source of food or animal feed. Owing to their diversity, insects all have their specific function in our ecosystem and in people's daily lives.

When insects do not become a news item as a food ingredient, it is often their pollination function in nature and horticulture that is emphasised. Unfortunately, this goes hand in hand with the difficulties those same pollinating insects are faced with. The population and diversity of wild bees and bumblebees are declining very sharply. Humans are trying to fill this gap by increasingly using cultivated bumblebees and honeybees. The latter, however, also make the news every year due to large winter losses.

Insect products can also be used as feedstock for materials. The best known example is the cocoon filament of the silkworm. In addition, there are insects such as moths, which are also lepidopterans, and beetles that will, whether desired or not, eat into clothes and cause old clothes to decompose. The copra beetle, for example, is gratefully used in taxidermy or for cleaning up cadavers. Insects thus serve as an aid in processing organic material. When converting catering waste and manure to compost heaps or pastures, insects should be protected and encouraged.

The relationship between humans and insects can be less pleasant when pests hamper economies or serve as vectors for the transmission of diseases. Some insects are controlled as pests, whereas others are used as natural enemies. The beneficial Ichnneumon wasps, for instance, are used to control certain harmful caterpillars, thrips and flies.

Sometimes insects are simply kept as pets or as art objects. In the latter case mainly for their decorative value. Frequently kept decorative insects are cockroaches, stick insects, leaf insects and butterflies. Apart from their ornamental value, insects can also be kept for the sound they produce. In non-Western cultures, this custom is more established.

OPPORTUNITIES OF INSECTS FOR POLICY AND SOCIETY

Both policymakers and society are showing a growing interest in sustainable food and circular food systems. This increases the pressure within Europe to enhance protein self-sufficiency. In reality, this mainly implies looking for alternatives to 'conventional' animal products in our diets, and to soya or fish meal in animal feed. In this context, insects are highlighted as a source of high-quality animal protein for human food and animal feed. They also contain other valuable nutrients such as fats, chitin, vitamins and minerals.

On the other hand, insect rearing offers opportunities for the many waste streams to be processed by Europe. In a climate where rational use is made of raw materials, waste is given a second life. Waste becomes a waste stream and this stream becomes a new raw material. Insects have the capacity to convert low quality waste streams to high quality applications in human food, animal feed and industrial applications. This should be done, however, within a strict legal framework that guarantees (food) safety at all times.

1 LEGISLATION

1.1 STARTING TO REAR INSECTS

All operators, including insect farmers (hereafter referred to as 'producers') who are active in the food chain in Belgium must be registered with the Federal Agency for the Safety of the Food Chain (FASFC). These producers must be registered with the FASFC in accordance with the Royal Decree of 16 January 2006. Authorisation or approval is required to perform certain activities (see below).[1]

An agricultural number is not compulsory, but approved farmers who meet the conditions laid down by the Flemish Agricultural Investment Fund (Vlaams Landbouwinvesteringsfonds/VLIF) can be eligible for 30% investment aid if they make the necessary investments for insect rearing. More information on the conditions and procedure can be found at www.vlaanderen.be/landbouw/vlif.

No training is required to start rearing insects. The Bachelor's programme 'Animal Care' (Dierenzorg) offers limited information about insect rearing. In the Netherlands, trend lectures and a basic course in insect rearing can be attended. In Belgium, as part of the Introsect project (2019-2023: see Chapter 4), internships are offered to farmers who are interested in converting (partially) to insect rearing.

However, several grants are subject to training requirements. See www.vlaanderen.be/landbouw/subsidies for the requirements to be met by requests for grants from the Department of Agriculture and Fisheries.

Town planning permits and environmental licences, see www.vlaanderen.be/landbouw/insecten > legislation

Below an overview is given of the legislation governing the use of insects for human food and animal feed, as well as the feed given to insects. In Chapter 7 you can read more about the residual substrate left over from the rearing process (manure, insect parts and unconsumed feed, the so-called frass).

1.2 INSECTS FOR HUMAN FOOD

1.2.1 Novel food

As there is no conclusive evidence that insects were consumed to a significant degree by humans in the EU before 15 May 1997, insects are regarded as novel food (or novel food ingredient) in Europe. They are therefore covered by Regulation (EU) 2015/2283 on novel foods: https://ec.europa.eu/food/safety/novel_food/legislation_en.
Due to the absence of legal certainty at the time with regard to the scope of former European Regulation EC (No) 258/97 concerning novel foods and novel food ingredients, the Belgian authorities allowed the marketing for human consumption of 10 whole insects on the Belgian territory. On the other hand, the new European Regulation (EU) 2015/2283, which is in force since 1 January 2018 and repeals Regulation EC

[1] Royal Decree laying down further rules for approvals, authorisations and prior registrations issued by the Federal Agency for the Safety of the Food Chain

(No) 258/97, is very clear: all insect-based products (not only parts of insects or extracts, but also whole insects and their preparations) are considered to be novel foods due to the absence of evidence of a significant history of consumption within the European Union prior to 15 May 1997.

The tolerance policy that was established in Belgium before 1 January 2018 was continued for a number of whole insects on the basis of the novel food authorisation applications submitted before this date. The extension of this tolerance policy therefore only applied to the insect species and their respective uses described in the applications which were submitted in time. It therefore not only concerned the insect in question but also the type of processing the whole insects were subjected to and the categories of products in which the whole insects are processed. Before 2018, applications were submitted by the Belgian Insect Industry Federation (BiiF) for house cricket *(Acheta domesticus)*, yellow mealworm (*Tenebrio molitor*) and migratory locust *(Locusta migratoria)*. Before 1 January 2018, an authorisation application was submitted for these insect species and their products, for which the tolerance policy in Belgium continued to apply until January 2021 pending a decision at EU level: https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/2018_01_revision_insects_stateoftheplay_en.pdf

Applications were submitted for various insects and their products from different European countries. You can find an overview at the following link:
https://ec.europa.eu/food/safety/novel_food/authorisations/summary-applications-and-notifications_en.

Owing to a recent court ruling[2] the Belgian tolerance policy had to be reviewed. The ruling now provides legal certainty about the fact that whole insects do NOT fall within the scope of the previous Novel Food legislation. Consequently, the tolerance policy was repealed and replaced by the transitional measures in paragraph 2 of Article 35 of Regulation (EU) 2015/2283. The whole insects, and their respective uses included in the applications for authorisation, which fulfil the criteria (because they were legally placed on the market before 1 January 2018 and an application for authorisation was submitted at the latest before 1 January 2019) are the following: house cricket *(Acheta domesticus)*, banded cricket *(Gryllodes sigillatus)*, yellow mealworm *(Tenebrio molitor)*, lesser mealworm *(Alphitobius diaperinus)* and migratory locust *(Locusta migratoria)*.

Naturally, authorisation to place these species on the market is subject to compliance with the general principles of the food legislation in force, including the application of good hygiene practices, traceability, notification duty, labelling (with mention of possible allergens), control of chemical and microbiological hazards and the implementation of an auto-control system based on the HACCP principles (see Chapter 2.2.2). For more information, consult the website of the Federal Agency for the Safety of the Food Chain (FASFC, http://www.favv.be/professionelen/). If you have any further questions, contact your Local Control Unit via LCE (http://www.favv.be/professionelen/contact/lce/).

Before a Novel Food can be placed on the market, it has to undergo a scientific assessment. Based on this, authorisation will either be granted or not for placing the product concerned on the market in the European Union.

[2] In Case C-526/19 of 1 October 2020: http://curia.europa.eu/juris/liste.jsf?lgrec=fr&td=;ALL&language=en&num=C-526/19&jur=

The general authorisation procedure can be found in Implementing Regulation (EU) 2017/ 2469 and Regulation (EU) 2015/2283 on novel foods. This procedure stipulates that the applicant for authorisation must submit an application to the European Commission. The scientific assessment of the novel food is then carried out by the European Food Safety Agency (EFSA). Based on this assessment and after consultation with the Member States the European Commission will take an implementing decision on whether or not to authorise the novel food.

The authorisations are generic, meaning that the novel foods may be placed on the market by any operator, provided that the specifications and conditions of use laid down in the authorisations are respected. There is one exception: if the authorisation application contains scientific data which are subject to data protection by exclusive ownership and which were found to be essential for the assessment of safety, the authorisation of the novel food may be limited to the operator who submitted the application. However, the data protection will be valid for 5 years. After this period the authorisation will become generic.

More information on novel foods is available at
https://www.health.belgium.be/nl/voeding/voedselveiligheid/nieuwe-voedingsmiddelen/wat-een-nieuw-voedingsmiddel

https://www.health.belgium.be/en/faq-novel-food-aux-insectes-destines-lalimentation-humaine.

For specific questions, you can contact the FPS Public Health at the e-mail address
novelfood@health.belgium.be.

1.2.1 FASFC regulations

The FASFC (Federal Agency for the Safety of the Food chain) has issued a circular setting out guidelines for rearing and marketing insects and insect-based foodstuffs for human consumption. This circular is available at http://www.favv.be/professionelen/levensmiddelen/omzendbrieven/.

As a farmer of insects for human consumption, you must register with the FASFC. You can find the registration form via FAVV - Aanvraagformulier voor een registratie, een toelating en/of een erkenning (afsca.be). The direct sale of live animals by producers as well as the slaughter of insects using methods that do not substantially alter the insects, such as cooling, freezing or using gas (CO_2), are currently regarded as implicit activities of the rearing process.
Other slaughter methods used, such as heat treatment (boiling water, etc.) are considered to be part of the processing of the insects. As such, this activity is not an implicit part of the rearing process.
A processing operator must develop an auto-control system which is based on the principles of Hazard Analysis Critical Control Points (HACCP) and includes the hazards associated with the processing step (2011-06-27 circular-HACCP-V7-nl.pdf (favv.be)). Insect farmers who perform the processing step are obliged to register an additional activity with the FASFC.
Currently, operators who bring insects or insect-based foodstuffs on the market for human consumption require **authorisation** from the FASFC. This depends on the activity carried out by the operator, e.g. food retail, chocolate manufacturer, hotels, restaurants and pubs, etc.

In the near future, European regulations and national legislation will change and impose an **approval for** certain processing activities of insects and insect-based foodstuffs for human consumption. More information is available at http://www.favv.be/professionelen/erkenningen/.

1.3 INSECTS FOR FEED

In the wake of the BSE crisis, a total ban was introduced on feeding farmed animals with animal proteins (Regulations 2000/766/EC, (EC) No 999/2001, (EC) No 767/2009, (EC) No 1069/2009). This means that insects - as farmed animals - must not be fed with animal proteins, and subsequently that insects must not be fed to farmed animals. Nowadays, an additional set of exemptions has been put in place for processing in feed for aquaculture. It concerns the following seven insects (Table 1):

Insect species authorised for aquaculture	
Black Soldier Fly	*Hermetia illucens*
Common Housefly	Musca domestica
Yellow Mealworm	Tenebrio molitor
Lesser Mealworm	Alphitobius diaperinus
House Cricket	Acheta domesticus
Banded Cricket	*Gryllodes sigillatus*
Field Cricket	Gryllusas assimilis

Table 1: insect species authorised for aquaculture

At the time of publication of this guide, these insects (or parts thereof) may be used as feed in aquaculture ((EU) 2017/893). In addition, all insects may be fed to domestic animals and fed live to non-ruminants and to farm and pet animals. Finally, purified fats may be used in any feed. In addition, all insects may be fed to domestic animals and fed live to non-ruminants and to farm and pet animals. Finally, purified fats may be used in any feed.

Insects used as livestock feed must be produced and processed in accordance with the standards set out in the livestock feed legislation. These are the same standards to be met by the feed for insects. Dead insects and products of dead insects must first be processed in a Category 3 processing establishment approved by the Belgian regional authorities before they can be used as animal feed (EC 1069/2009).

1.4 FEED FOR INSECTS

To make the production of insects economically profitable and sustainable, it is often suggested to use side streams as feed. Not all side streams, however, may be used as feed for insects. In addition, the permitted streams must meet several conditions.

Insects are regarded as farmed animals by European Regulation 1069/2009 (Art. 3 definition 6). This means that substrates used as feed for insects must comply with the applicable legislation. Only feed that originates from companies registered with the FASFC and complies with the legislation in force for the

animal feed sector may be used
(http://www.favv.be/dierlijkeproductie/dierenvoeding/insekten/default.asp).

The basis is Regulation (EC) No 183/2005 laying down requirements for feed hygiene during the production of feed, the placing of feed on the market and the use of feed. This Regulation also regulates the approval and registration of operators.

Regulation (EC) No 767/2009 lays down conditions governing the placing on the market and use of feed materials and compound feed. For example, animals in the EU may only be fed with safe feed. The feed may not contain products on the negative list in Annex III of this legislation, including faeces and digestive tract content, hides treated with tanning substances, seeds and plant propagating materials treated, after harvest, with plant protection products, wood, waste water, urban waste and packaging. Furthermore, feed materials or compound feed may be placed on the market only if the mandatory labelling requirements are complied with.

In addition, the BSE legislation (Regulation (EC) No 999/2001) states that feed for farmed animals must not contain animal proteins that are prohibited under this legislation.

In addition, strict conditions apply to the products of animal origin that may be used as animal feed. These are included in the Animal By-Products Regulation (Regulation (EC) No 1069/2009). This law also prohibits the feeding of farmed animals with manure, catering waste, and unprocessed former foodstuffs containing meat or fish.

In summary, only the following animal products may be used as feed for non-ruminant farmed animals (including insects):

- milk, milk-based products, milk derivatives, colostrum and products derived therefrom
- eggs and egg products
- collagen and gelatine derived from non-ruminants
- hydrolysed proteins derived from non-ruminant parts and from ruminant hides and skins
- fish meal and compound feed containing fish meal
- dicalcium phosphate and tricalcium phosphate of animal origin and compound feed containing such phosphates
- blood products derived from non-ruminants and compound feed containing such blood products
- honey
- rendered fat.

A complete overview of the animal feed legislation can be found on the website of the FPS Public Health: https://www.health.belgium.be/nl/dieren-en-planten/dieren/dierenvoeding/overzicht-diervoederwetgeving

2 FEED

2.1 INCOMING INSPECTION, REGISTRATION AND STORAGE OF FEED

Upon receipt of the animal feed, an **incoming inspection** must be carried out of the following elements:
- products must be accurately labelled and documented
- packaged products must not be damaged
- products must not be rotten or mouldy.

Upon receipt, the feed must also be registered. This registration must include the following:
- name and nature of the feed
- name, address and registration number (FASFC) of the supplier
- date of receipt
- quantity
- batch number (if applicable)
- best before date (if applicable).

Feed must be **stored** so that:
- it cannot come into contact with fertilisers, biocides, waste, etc.
- It is easy to identify
- spillage or leakage is minimised
- spoilage or mildew is avoided. Typical is the distinction between fresh (wet) products and dry products. In the first case, refrigerated or even frozen storage is recommended. In the second case, storage may be possible at room temperature (20-25 °C) in a closed container in a dry place. Always follow the instructions.
- vermin cannot reach the feed and contamination with excrement is prevented.

2.2 FEED HYGIENE

The use of contaminated feed and drinking water can endanger primary production. Good hygiene measures can prevent contamination of feed. This section focuses on feed. You can read more about hygiene on farms in Chapter 4.8.

It should be possible to thoroughly clean the area where you store or handle animal feed.

Make sure this area can be cleared completely several times a year so that you can clean and disinfect it thoroughly. Put a cleaning procedure in place for this.

The material used to feed the animals should always be cleaned and disinfected after feeding. Put a cleaning procedure in place for this. After cleaning, you should also store the materials in such a way that they do not become contaminated.
Animal feed must not come into contact with fertilisers, biocides, waste, etc. For this reason, it is best to store animal feed in a closed area, where contamination with these contaminants cannot occur. For

example, make sure that waste/manure and feed are each left/stored on different sides of the building or site.

A **pest control plan** should prevent pests (rodents, birds and unwanted insects) from coming into contact with feed (see https://www.varkensloket.be/Portals/63/Documents/varkens_gezond_houden_brochure.pdf pages 46-53). Make sure pests cannot enter the building. If they do, you should control them (for insect pests, see also Chapter 4.9).

To prevent pests from entering, closed areas should not have any holes or cracks. For rodents, openings should not exceed 5 mm. Also use insect mesh with an opening smaller than 1.5 mm for ventilation openings.

To exterminate pests in areas where feed is stored or handled, you should only use authorised biocides (see https://www.health.belgium.be/en/list-authorised-biocides-and-annual-report). To control flying insects, you can use UV lamps that attract and kill insects.

For mice and rats it is best to set closed safe traps (mechanical, bait).

Always keep a floor plan with an overview and the technical information of the bait used. Also keep a record of all actions taken.

If the above techniques are not sufficient, it is best to call in a specialised pest control company.

2.3 NUTRITIONAL REQUIREMENTS AND FEEDING FREQUENCY

The main ingredients in feed are proteins, carbohydrates, fats, vitamins and minerals. These must be in a certain proportion to each other and vary according to the type of feed. Knowledge about the best possible nutritional composition and feeding frequency of feed for insects is still in its infancy. Below an overview is given of substrates that can be used as feed.

Yellow mealworm: *Tenebrio molitor* is fed with both a dry and a wet feed source. Wheat bran is used as a standard as dry food source. A sufficient quantity should be given so that the insects can eat from it for a longer period of time. The eggs or larvae are best supplied with the dry food source from the early onset (at the start-up). Larvae up to 3 weeks old are very small. As long as the humidity is optimal (80 % RH), no wet feed source is needed. After 2 to 3 weeks, the larvae are also given a wet feed source. Carrots are used for this (waste streams such as chicory roots are also perfectly usable). By finely chopping the carrots and spreading them evenly, a homogeneous growth is obtained and everything can be fully processed by the larvae. As a result, the remnants do not have to be removed from the rearing container.

An example of a feeding schedule for the dry and wet feed sources is given below (Table 2). Mealworms were reared here at 26 °C and 60 % relative humidity. This table shows the amount of feed to be added to a rearing container with a surface area of 2,400 cm^2. Rearing containers of this size have a yield of ± 2 kg mealworms each. Twelve grams of eggs were started with. However, this schedule may be deviated from depending on the density of the mealworms, the climate and the type of feed administered.

When the dry feed is (almost) completely processed into frass, i.e. the residual substrate consisting of manure, insect remains and unconsumed feed, supplementary feed should be given at once. The moisture source should be fed with a frequency of 3 times a week (Table 2).

Feeding schedule of dry and wet feed per rearing container per week		
Age of mealworms	Quantity of dry feed (g)	Quantity of wet feed (g)
0 week (start-up)	800	
2-4 weeks		3 x 60
5 weeks		3 x 60
6 weeks	3400	3 x 200
7 weeks		3 x 300
8 weeks		3 x 300

Table2: feeding schedule of dry and wet feed per rearing container per week (Introsect, 2020)

Black soldier fly: *Hermetia illucens* larvae can be reared on a wide range of substrates, ranging from chicken feed to waste streams such as spent grain, potato pulp and apple pulp. Crop residues (cauliflower leaves, Brussels sprout sticks and leaves, bean foliage, chicory roots, etc.) can also be used if they are supplemented with other raw materials (e.g. from pig breeding) to obtain a balanced black soldier fly diet (example of complete feed: 65 % ProtiWanze, 10 % mashed potatoes and 25 % maize gluten feed). Black soldier fly larvae are fed with wet substrates. The moisture of these substrates is between 60 % and 80 %. We initially aim for the best possible feed with 30 % dry matter, of which 15 % proteins, 40 % non-fibre carbohydrates and 2 % fat. Chicken feed is commonly used and usually contains 15-20 % crude protein, 50-60 % non-fibre carbohydrates and 2.5-7 % crude fat (on a dry matter basis).

Generally, 100 mg per larva per day is fed from day 6 until harvest, but this varies depending on the type of feed. If it concerns chicken feed, 75 mg/larva/day is already sufficient. However, if the larvae are used for the production of flies (reproduction), 100 mg/larva/day is also recommended. Larvae can be fed daily or once at the start of the cultivation. For the juvenile larvae (eggs up to 6 days), it is best to use high-quality feed (such as chicken feed). The feeding regime used is 500 g of feed of 70 % moisture per gram of eggs. As *H. illucens* lives in the feed, you should always add sufficient feed to prevent the larvae from starving. On the other hand, all the feed should be digested at harvest to avoid wastage and to obtain a residual fraction which can be sieved off and from which the larvae can be separated.

House cricket: *Acheta domesticus* is usually reared on chicken meal (16-22 % protein). Research shows that by-products of food production can be used, but that it is difficult to meet all nutritional needs in this way. Nevertheless, a diet can contain 60 % bran or up to 40 % spent grain without this resulting in reduced growth. As moisture source, sliced carrots or free water (only for the older nymphs) can be offered (preferably shallow and not stagnant, which is important for purposes of survival and hygiene: see below in Chapter 4). Various studies have already shown that sliced carrots do not add any nutritional value. Crickets use drinking water more efficiently than pigs and poultry. It takes 1.8 litres of water to produce 1 kg of crickets, whereas for pigs this is 4.6 litres. Chickens take in about 2 litres of water per kg of dry feed, whereas crickets take in only 1.1 litres.

According to former cricket farm Little Food, newly-hatched nymphs need a protein content above 20 % for optimal growth and survival. For the later stages, this may be slightly lower and waste streams such as press cake from linseed and sunflower oil production, wheat bran and coarse meal may be used. Wet feed was also provided in the form of carrots, apples and lemons.

During the 30 days of their life, 1 kg of crickets eat about 2 kg of feed. This means that a cage with 35 kg of crickets must eat 70 kg of feed (see Table 3 for feeding schedule).

Feeding schedule of dry and wet feed per cage of 35 kg per week		
Age of crickets	**Quantity of dry feed (kg)**	**Quantity of wet feed (kg)**
0 week (start-up)	2	
1 week	2 x 3.6	
2 weeks	4 x 5	2
3 weeks	3 x 10.5	4
4 weeks	2	

Table 3: feeding schedule of dry and wet feed per cage of 35 kg per week (Little Food, 2020)

Migratory locust: *Locusta migratoria* is fed with different types of grass. Fresh grass is used as a standard, supplemented with oats. Nymphs and grasshoppers are fed the same diet. The grass should be administered daily. At the same time, the old grass should be removed from the cages. Fresh grass is preferred, since certain components (such as much of the moisture and hormones) are already lost in old grass. A lawn where the grass is not mowed is therefore an additional advantage. The weight of freshly added grass should be almost equal to the total weight of grasshoppers present in the cage (± 2 g per adult). In addition to fresh grass, dry feed, such as oats or wheat bran, is offered *at will* to the grasshoppers to supplement their diet. This dry feed can be placed on a tray in the cage. Feeding *at will* not only ensures optimal growth, but also prevents cannibalism within the colony and the eating of carcasses. It is not necessary to provide extra water for grasshopper rearing. If the grasshoppers are provided each day with sufficient fresh grass, they will extract moisture from this grass.

3 PRODUCTION SYSTEMS

This guide gives an overview of what the production of the different species involves. The practical aspects for rearing yellow mealworm and black soldier fly were bundled together from the illustrated hands-on rearing guides developed during the VLAIO-LA Introsect project (still in development for house cricket and migratory locust):

https://www.inagro.be/Wie-is-Inagro/Projecten/project/157.

The production systems listed below are mainly based on pilot rearing set-ups of research institutes. Owing to progressive insights, optimisation is continuously pursued, but no standardised systems are in place yet. Information from commercial enterprises is scarce, with the exception of the former cricket farm Little Food. The company ceased its activities in 2019, but was willing to share its experiences. Their system provides a good basis, but still requires further optimisation.

3.1 PRODUCTION WITH OR WITHOUT REPRODUCTION

You can choose to only produce insects or to reproduce them as well. If you are just starting out as a farmer or are bound to a specific period, production is the most interesting. For production, the rearing of **yellow mealworms and black soldier flies** is limited to full-grown larvae (no pupation and subsequent fly rearing). **Crickets and grasshoppers** are then reared until they enter the adult stage. You buy the eggs or young larvae/nymphs from other farmers and you rear them until they are ready for harvesting. After that they leave your farm. If you want to be a self-sufficient farm in terms of egg production, you should complete the entire life cycle of the insects and let them produce eggs for a new population. This means you only need to buy the starter population once. It is recommended, however, to introduce a new population to the existing population from time to time in order to ensure genetic diversity.

3.2 YELLOW MEALWORM

3.2.1 Climate

Mealworms are typically reared at a constant temperature between 25 and 28 °C. Although they develop fastest at an ambient temperature of 31 °C, this is not recommended as active mealworms also produce heat themselves and temperatures above 31 °C are detrimental to growth. Up to 12 °C the larvae will grow, albeit much slower. Mealworms can also survive for a long time at lower temperatures (5 °C), e.g. when kept in the refrigerator.
A high relative humidity (60-75 %) is beneficial for the rapid development of mealworms. However, if the relative humidity is higher than 80 %, problems may arise with the feed in which the larvae live. The usually dry feed will then become damp, which increases the chance of mould formation. High humidity can also lead to the development of flour mites (see Chapter 4.9). These mites occur naturally on grain products. It is therefore often decided to set the relative humidity to a maximum of 75 % as a compromise between optimal growth and maintaining hygienic rearing conditions. Mealworms can also be reared in less humid conditions, although this does have an impact on the development speed.

Both larvae and beetles grow better in darker conditions, as they are sensitive to light and will burrow deeper at the sight of light.

3.2.2 Infrastructure and materials

Equipment for mealworm rearing (Kweekhandleiding Meelworm, 2020)	
Climate controlled rearing room	• Controlled up to 27 °C and 60 % RH. If necessary, humidifiers and/or heaters can be used. • Air circulation and ventilation • Logger for climate control is recommended • Cooling (optional)
Rearing containers	• Rearing containers should have a sufficiently large surface area (± 2,400 cm^2) and smooth sides • Raised corners are recommended to ensure sufficient ventilation • Rearing containers should be stackable for maximum space utilisation and to keep out light and vermin • If no reproduction takes place on the farm, a starter culture of one-week-old mealworms should be purchased for each container per rearing cycle
Container transport	Pallet truck, hand truck, etc.
Container washer	High-pressure cleaner or washing station (depending on the scale of the cultivation)
Shredder	Optional, to reduce coarse feed (e.g. moisture sources)
Weighing device	For weighing feed (up to 15 kg) and larvae (0.1 g)
Sieve (mealworm harvesting)	Wire sieve with mesh size 2-3 mm or vibrating screen (see Chapter 5)
Reproduction	
Oviposition sieve	Optional, mesh size 2 mm
Larvae-pupae sieve	Fish grader, mesh size 3.5 mm (see Chapter 5)
Dead beetle separator	Optional, to separate dead beetles from live ones. *See below.*

Table 4: equipment for mealworm rearing (Kweekhandleiding Meelworm, 2020)

Separation of dead and live beetles: when a new oviposition container is started, some of the beetles will have died. These can be separated from the healthy beetles by adding an egg tray to the beetles. The healthy beetles will climb onto the egg tray. The dead beetles can also be separated from the healthy ones using a mechanical separator (see Figure 1). The healthy beetles will cling onto the mesh of the conveyor belt while the dead ones will fall back down. Can also be used to separate pupae from beetles.

Figure 3: mechanical beetle separator (Inagro, 2020)

3.2.3 Process

It is recommended to separate larvae for production from the population for reproduction. Mealworms for reproduction are preferably in smaller numbers in a rearing container (5,000 mealworms) than larvae for production (10,000 - 15,000 larvae). This will give the mealworms more space to grow. They will pupate better and grow into bigger and healthier beetles. A starter population (purchased or from in-house reproduction) is usually a mixture of dry feed and young mealworms. In total you need about 2.1 kg of wheat bran per kg of mealworms (so 4.2 kg in a rearing container). This number should be reduced by the weight of the starter population (the weight of the eggs/young mealworms is negligible). Larvae up to 3 weeks old are very small. As long as the humidity is optimal, there is no need to give them wet feed. The larvae stay in their dry feed. After 4 weeks, give the mealworms wet feed 3 times a week until pre-harvest fasting. From 8 weeks onwards, check whether the larvae still have enough dry feed. If the quantity of wet feed administered has not been processed by the next feeding session, reduce the quantity to prevent the dry feed from becoming mouldy. If no or very few wet feed remnants are left in the rearing container, you may add more feed.

After 8 to 11 weeks, the mealworms are fully grown and ready for harvesting. The exact time depends on various factors. When the mealworms are fully grown, they will move more slowly and no longer gain weight. The green dot on the growth curve below indicates the moment during the growth stage when the mealworms should be harvested. However, there is often some variation in the containers, which means harvesting should take place when the first pupae appear. Before the mealworms are ready for harvesting, they should fast for 1 to 2 days. They should not be given any additional feed. When the feed is processed, only frass remains (the residual fraction of feed, insects, larvae or eggs and faeces). This can be easily sieved off. Starving the mealworms for more than 2 days will result in reduced weight per specimen.

If you choose to reproduce and let some mealworms pupate, you should take into account that there may be cannibalism. Especially the immobile stages of egg and pupa can be damaged by the mealworms and beetles. To avoid loss of pupae due to cannibalism, it is important to separate mealworms from pupae when the mealworms start to pupate. Mealworms are smaller and more agile than pupae. You can sieve off the pupae with a fish grader (mesh size 3.5 mm). The pupae remain on the sieve, while the mealworms and the residual substrate fall through the sieve. As soon as the mealworms start to pupate, sieve them off once to three times a week. The more often you sieve them off, the better the cannibalism is under control, but the more work you will have as a farmer. It takes about 4 weeks for all the mealworms in a rearing container to pupate.

Pupae of the same age from different rearing containers may be put together. After one week, they will simultaneously transform into beetles. This will minimise cannibalism. Yellow mealworm beetles have the same diet as their larvae, which means they also eat wheat bran as dry feed and carrots (or other vegetables or fruit) as wet feed. Feed the yellow mealworm beetles according to their needs. If you see mostly frass in the rearing container, give them additional dry feed. When the wet feed has been fully processed, give a little more feed during the next feeding session. The yellow mealworm beetles eat less than the mealworms, as they no longer have to grow. They lay their eggs in the dry feed on the bottom of the rearing container. The feed thus also serves as oviposition substrate.

Eggs are produced in the rearing containers intended for this purpose. You should keep 200 grams of beetles in each rearing container (60 x 40 cm). Due to the cannibalistic nature of yellow mealworm beetles, the beetles may eat the eggs, especially if a large number of beetles live in the same substrate for a long period of time. Cannibalism can largely be avoided by placing the yellow mealworm beetles on a sieve. The eggs fall through the sieve, which means the beetles can no longer reach them. The sieve should have a mesh size of 2 mm, is preferably made of stainless steel and should be easy to clean. Always provide dry feed both on and under the sieve. You can either buy the oviposition sieve or make it yourself. Move the oviposition sieve from the old oviposition container to a new one twice a week. You may move the old oviposition container to the production room. Using an oviposition sieve is not a requirement, but the beetles will produce more eggs this way. Still, it will give you more work as a farmer.

If you do not use an oviposition sieve, the beetles will be between the substrate and the eggs. With a 3 mm sieve you can separate the beetles from the dry feed and their eggs. The dry feed with the eggs is put back into the old oviposition container, as some eggs are still sticking to the bottom of the container. This oviposition container can now be moved to the production room. Start a new oviposition container for the beetles. The yield (the number of mealworms) per container depends on the number of beetles and the time they spend in a container. You can use the formulas below:

log10 (number of mealworms) = 1.79 + 0.636 * beetle days + 1.87 * 10-4 * surface area of rearing container (cm^2)

Beetle days = log10(beetles (g) * oviposition duration (days))

If you want to determine the exact number of eggs and predict your yield (more) accurately, you should put common wheat flour instead of wheat bran in the oviposition container for the beetles. Common wheat flour can be sieved off with a 500 µm sieve, so that the eggs remain on the sieve. This allows you to determine the total weight of the eggs. Our experience shows that 1 yellow mealworm beetle egg laid in common wheat flour weighs on average 0.6 mg. It is best to use an oviposition sieve so that the common wheat flour remains pure for a longer time. More contamination (e.g. beetle remnants) makes it more difficult to sieve off the common wheat flour and leads to a less accurate determination of the yield. Afterwards, put the eggs which you sieved off back into the wheat bran.

3.3 BLACK SOLDIER FLY

3.3.1 Climate

To simulate a tropical climate, it should be sufficiently warm and humid. Recent research has shown that the number of eggs per female is highest (up to 1,200/female) at a temperature of about 30 °C. The optimal temperature for full breeding is between 27 °C and 30 °C. This, however, strongly depends on the feed used and the age of the larvae: during the first week larvae grow better at 30 °C; after that 27 °C is sufficient. The feed moisture level is very important and will change during cultivation. This is because the larvae themselves can raise the temperature of the feed (up to 50 °C), causing much moisture to evaporate. If the feed becomes too dry, growth will stop.

Flies prefer tropical conditions (30 °C and 80 % relative humidity). A high humidity level makes it easier for the flies and eggs to survive. Some farmers have a water spraying system per cage to spray several times a day. For larvae, feed moisture is more important than humidity, which means a RH of 60 % is sufficient.

The larvae can be kept permanently in the dark. To induce the flies to mate, a light source should be present. This may be either natural (day) light or artificial light, or a combination of both. Artificial light preferably has a high colour temperature (>6000K), and may be either a mercury vapour lamp (high or low pressure) or LED. Light is essential, but do not forget to allow the flies some rest too. Twelve hours of light and twelve hours of darkness are ideal for the flies.

3.3.2 Infrastructure and materials

Equipment for rearing black soldier flies (Kweekhandleiding Zwarte soldatenvlieg, 2020)	
Rearing room (climate-controlled)	• Controlled up to 27 °C and 60 % RH. If necessary, you can use humidifiers and/or heaters. • Air circulation and ventilation • Logger for climate control is recommended • Cooling (optional)
Rearing containers	• Maximum 60 x 40 cm for manual handling • Larger formats are also possible, but mechanical support is then required due to the weight of the containers • Raised corners are required for a good airflow over the larvae • If there is no reproduction on the farm, a starter culture of one-week-old mealworms should be purchased for each container per rearing cycle
Pop-up nets	For rearing from egg to larvae of 5-7 days old
Shredder	Optional, if you need to crush coarse feed
Mixer	For mixing the wet feed for the larvae, e.g. concrete mixer

Sieve	For harvesting, wire sieve with mesh size 3-4 mm or vibrating screen
Weighing scales	To weigh all kinds of things
Container transport	Pallet truck, hand truck, etc.
Container washer	• High-pressure cleaner or washing station (depending on the scale of the cultivation) • Cleaning of containers, rearing room, etc. • To be used preferably with hot water
Reproduction	
Fly cage	*See below*
Lamps	Induce mating in flies. Suitable types: • Halogen lamp (325W) • JM GREEN BLACK SOLDIER FLY Breeding (LED 150 W) • Highbay (LED 100 W 5700 K)
Eggy	• Oviposition site of the flies • Eggies should preferably have as many cracks and crevices as possible • Stacks of wooden (or bamboo) slats are often used for this, with about 1 mm gaps between the individual slats • You can also opt for more durable and more hygienic materials, such as plastic slats • Is placed on a tray with attractant (dead flies (and/or pupae), residual substrate and water) • https://leden.inagro.be/Portals/484/WP5%20Fontys%20Eggie.pdf

Table 5: equipment for rearing black soldier flies (Kweekhandleiding Zwarte soldatenvlieg, 2020)

Fly cage: many different cage designs are already being used, ranging from simple nets with separate components which you can walk into to more integrated systems (in which pupae containers, eggies with attractant, drinking place, lighting, etc. form a whole). The latter have the advantage of being user-friendly (compact, easy to clean). In the end, the yields are high and the eggs can be harvested efficiently. Such a cage was developed by Inagro:
https://www.bioboosteurope.com/assets/files/Report-Insect-Breeding-.pdf.

There are four common options for placing the pupae in the cage (Figure 2). The main difference is the way in which the flies can get into the net. All the methods presume that the flies are attracted by the light and enter the cage as a result of this light impulse.

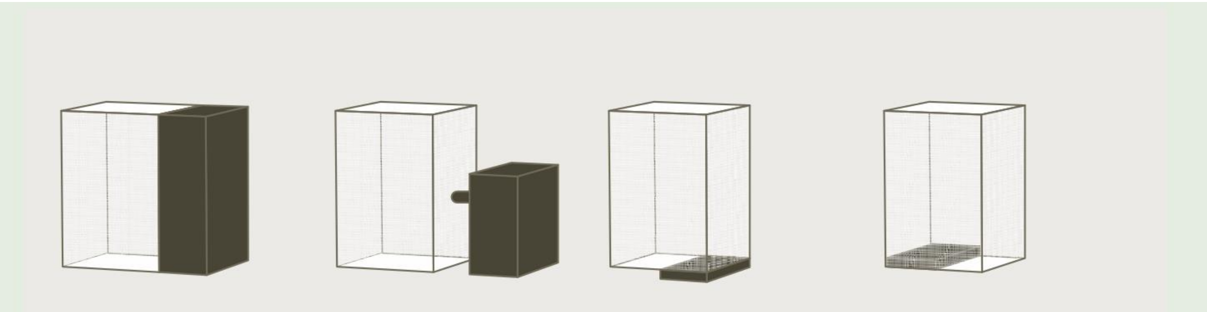


Figure 4: the different options (The transparent part depicts the actual fly cage (where the flies will mate) and the darkened part is the pupae room.) (Inagro, 2020)

3.3.3 Process

The process for production and reproduction is the same from day 1 to 5: you start rearing eggs to five-day-old larvae. From then on, a different feeding schedule is applied for production and reproduction.

Store the purchased eggs at 27 °C. They will hatch after 3 to 4 days. Humidity should preferably be high (> 60 %) to avoid dehydration, but make sure the eggs do not get wet. You can hatch the eggs directly over their feed. When the one-day-old larvae hatch, they fall into the concentrated feed and can immediately start eating and growing. The disadvantage of this technique is that the larvae do not hatch all at the same time. As a result, the size of the larvae in the container may vary greatly. In order to avoid strong variation in larva size, another, more labour-intensive technique is sometimes used. Place maximum 10 g of eggs in a 5-litre bucket on a platform, but without feed. Check the buckets daily and take out the one-day-old larvae. Sprinkle these larvae in a rearing container with feed. This does not guarantee an even growth, but in this way the starter material is at least of the same age.

In both techniques, the one-day-old larvae are reared on concentrated feed (chick starter crumble, e.g. FARM 1 Crumble) for the first few days. Give 0.5 kg of concentrated feed (30 % concentrated feed, 70 % water) per gramme of eggs (or one-day-old larvae). This guarantees a good start and prevents young larvae from dying.
In practice you should place 10 g of eggs or one-day-old larvae in a rearing container (60 x 40 cm) together with 5 kg of feed. The thickness of the layer of feed is very important: between 2 and 3 cm is optimal. This begins as a wet mash, which dries out to a fine powder after 5 to 7 days. Place these containers in a net to prevent common houseflies or other pests from contaminating the feed.
Under good conditions, this will result in approximately 300,000 larvae of 3 to 4 mg after 5 to 7 days at 27 °C. These 300,000 larvae should now be divided between 15 rearing containers. Ultimately, you should aim for about 20,000 larvae per container, which will result in a yield of up to 4 kg per container of 60 x 40 cm. However, the yield strongly depends on the feed used. It is useful to check the number of larvae per container, as this will determine the amount of feed. If you give too much feed, the wet feed mash may not dry out sufficiently, which means the larvae can no longer be harvested. After dividing the young larvae (per 20,000), a distinction is made between larvae for reproduction (the next generation of flies) and larvae for production (larvae that can be harvested). From now on, the larvae will produce heat themselves. As a result, active containers can easily heat up to 40° C.

For production, 20,000 larvae should be transferred to a rearing container with 10 kg of prepared feed. To minimise the amount of work, you can add all the feed at once. After 7 to 14 days, the larvae are done feeding and are ready for harvesting. A container ready for harvesting can be easily identified by the nature of the residual substrate: the mash has been processed into a dry powder.

The larger the pupae, the bigger the flies and the more eggs they will lay. For this reason, larvae intended for reproduction are reared entirely on high quality feed (chick crumble). To that end, use 14 kg of feed (70 % moisture) to rear 20,000 larvae to the prepupal stage. The development into prepupae usually takes a bit longer than that of larvae for production: this may take up to two weeks. When 80 % or more of the larvae have reached the prepupal stage, they are harvested and washed. Sieve the prepupae from the residual substrate, as you would do when harvesting larvae. This only works if the substrate is sufficiently dry and fine. If it is still too wet and sticky, this will be a hopeless task. If sieving is not possible, add water to the rearing container. This is an unfavourable situation for the prepupae, as they are looking for a dry place to pupate. Because of the water they will try to escape the container en masse by crawling up the slippery sides. Make sure they do not drown. Place the rearing container in a larger collection container with dry material such as kitchen paper or wheat bran. This will absorb the moisture from the wet larvae and dry them out, so they will not escape from the collection container. You can now easily remove the prepupae from the collection container. You can sieve off any wheat bran on a 3 mm sieve. Now wash the prepupae (and the remaining white larvae). Pour them into a tub of water. The prepupae will float, while the remaining larvae will sink. Skim the prepupae off the surface so that they are the only ones left. Washing also reduces the smell of the pupae, which can help to prevent uncontrolled egg laying in the cages. Moist prepupae will flee. Therefore, after washing, place them in a container with dry substrate, such as kitchen paper or wheat bran. The wheat bran can be sieved off again. If the prepupae stop moving, this means they have reached the pupae stage. Normally this stage takes one week (at 27 °C), but beware: the first flies sometimes pop up sooner than expected! If the fly cage is not yet ready for the next flight, it is best to place these containers in a net (e.g. a pop-up net).

The fly cage is first filled with pupae. The general guideline for this is about 1 kilogram of pupae per m^3 net. As a farmer, you want to have control over where the flies will lay their eggs. You can do this by using an attractant, such as chicken feed mixed with water, rotten fish or a mixture of dead flies, larval droppings and water. The smell of the attractant will attract female flies, which will want to lay their eggs there. After that, put an eggy close to the attractant. Place a small container with the attractant in the cage, cover the container with mesh and place the eggy on the container. The eggy should preferably have as many cracks and crevices as possible. Stacks of wooden (or bamboo) slats are often used for this, with about 1 mm gaps between the individual slats. You can also opt for more durable and hygienic materials, such as plastic slats. As long as there are no other disturbing odours in the room (originating from rearing containers or unwashed pupae), the flies will mainly lay their eggs in the eggy. After the first flies are detected in the net, it takes about 6 days before you can harvest the first eggs. From then on, you can harvest eggs daily for one week. To limit the work, you can also harvest every other day. In this case, you should check daily whether the eggies are full.

To harvest eggs, remove the eggy from the fly cage and scrape off the slats one by one. Over the period of one flight (start-up to end of a fly cage, about 12 days), 1 kg of pupae can produce about 50 g of eggs (or 250 to 300 kg of larvae at harvesting).

Twelve to fourteen days after the first flies appear in the cage, the flight is over. The number of live flies in the cage will now drop quickly. You can now clean the cage and prepare it for a new flight. It is very important to clean the cage after each flight to avoid odours and diseases. You can extend the number of productive days of a cage by placing fresh pupae in the cage every two days. However, the dead flies will then quickly pile up on the bottom of the cage, which may lead to unhygienic conditions. In addition, the dead flies will rot, which may lead to uncontrolled egg laying. Therefore, remove the dead flies and empty the net completely in good time and clean it thoroughly.

3.4 HOUSE CRICKET

3.4.1 Climate

House crickets thrive in hot environments with temperatures up to 30 °C with an optimal temperature of 28 °C. Temperatures above 30 °C shorten the life cycle, but if the temperature rises to 38-40 °C, mortality may occur.

House crickets thrive in humid environments with a relative humidity of around 50-60 %. Young crickets and eggs require an even higher humidity of up to 70-100 %, which is why they are usually reared separately from older crickets.

All stages can be reared in the dark.

3.4.2 Infrastructure and materials

Equipment for rearing crickets (Little Food, 2020)	
Rearing room (climate-controlled)	• **Humidification (controlled up to 75 % or via separate humidifier)** • **Heating (controlled up to 28-31 °C or via separate heater)** • **Air circulation** • **Ventilation** • **Cooling (optional)** • **Monitoring and logging climate data**
Housing	• Compartments consisting of plastic sandwich panels filled with stacks of egg trays (see below) • Roll of cardboard to place on the egg trays under the feeders and drinkers • Elongated feeders and drinkers (up to ± 3 m long) • Water tank and drinkers with float for constant water level (3-4 mm). For the smallest nymphs you can place a mop cloth in the drinker (to prevent drowning). For the larger ones you can use rolls of rough scourer (does not rot, but regular cleaning/disinfection/replacement is recommended). The

	transition to the water should be straightforward. For this purpose, you can place a rubber band in the drinker.
Crate washer (optional)	High-pressure cleaner or washing station, depending on the scale of the cultivation
Weighing scales	To weigh the crickets, feed, etc. (nymphs can also be dosed with plastic pots according to volume)
Sieve	Drum screen for harvesting
Reproduction	
Oviposition substrate	Mixture of moist sand and peat (50/50)
Oviposition cage	See below
Plastic containers	To gather nymphs

Figure 5: equipment for rearing crickets (Little Food, 2020)

Egg trays serve as substrate and shelter for crickets (Figure 4). Alternatively, you can also use wine box dividers. Sufficient volume is required which is in proportion to the size of the crickets. It is therefore recommended to successively add trays as the crickets grow (Figure 3).

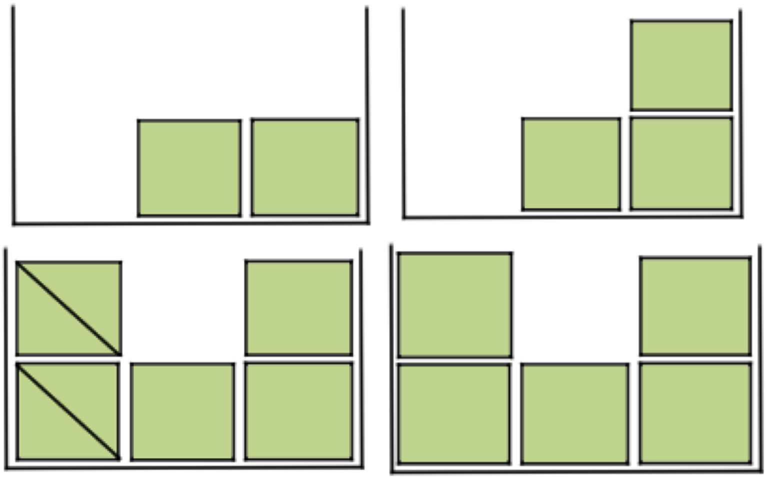


Figure 6. evolution of the rearing cage (Little Food, 2020)

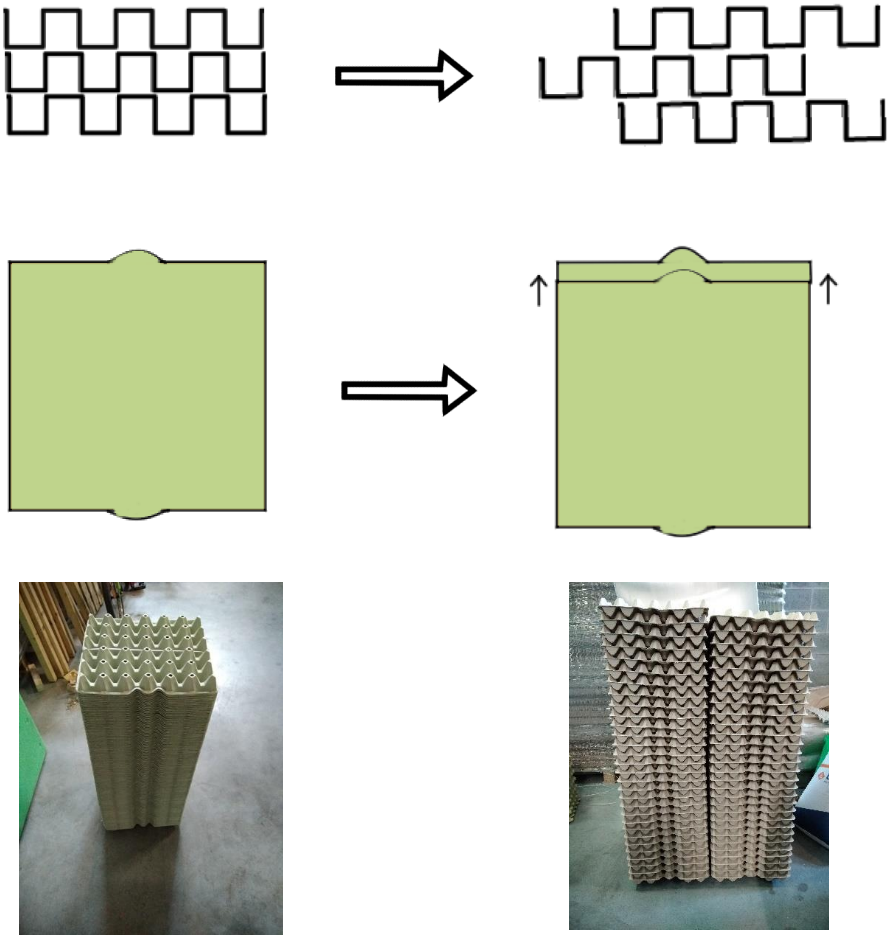


Figure 7: arrangement of egg trays (Little Food, 2020)

To start a cage, you need 3 stacks of egg trays. A first row is placed in the length of the cage on the floor against the right wall of the container. The row should stop about 50 cm from the cage door to leave sufficient space to place the water tank that controls the drinker. Then a second row is made next to the first.

Crickets are given two different types of feed and therefore need two separate feeders. One for dry feed and one for wet feed. To this end, three metres of the cardboard roll is placed on the egg trays on top of the row of trays against the right wall of the cage and is stabilised with two wooden rods. Distribute four litres of dry feed over the entire surface area of the feeder. Wet feed should only be given after 15 days.

The drinker provides permanent access to water, which is a vital need for crickets (Figure 5). It is therefore very important that you carry out this step correctly. Place a clean drinker on the left-hand row of egg trays and the water tank at the entrance to the cage. After that, connect the tank to the water inlet and the drinker. At the bottom of the drinker, you can place a roll of rough scourer (to reduce drowning). Now open the inlet and fill the drinker. Check that there are no leaks or other problems. If necessary, adjust the height of the float. It is best to change the water daily.

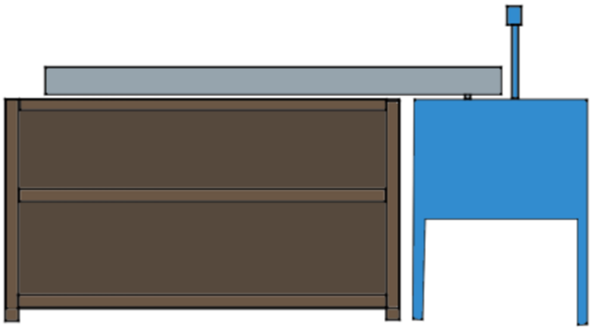


Figure 8: drinker (Little Food, 2020)

The oviposition cage is divided into two parts (Figure 6):

- the top container contains the soil with the eggs. It has an opening in the middle through which newborn nymphs can fall into the bottom container. This conainer must remain open in order to prevent mould formation

- the bottom container contains egg trays that serve as substrate for the nymphs, a moist cloth so that the nymphs have everything they need to survive

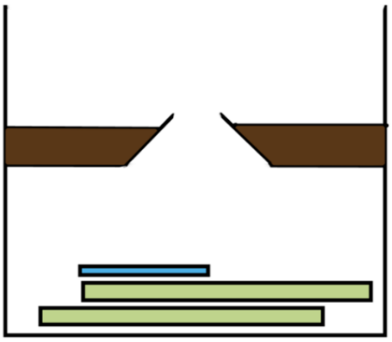


Figure 9. oviposition cage (Little Food, 2020)

3.4.3 Process

Crickets lay their eggs in moist soil (or substrates such as coconut pulp). It is best to replace the soil with eggs every day. The harvested soil with eggs is best stored at a humidity of 100 %. The easiest way to do so is by simply sealing off the soil and opening it again the day before the crickets hatch. The incubation period is about ten days. Not all eggs hatch at the same time, which means you need a structure that allows all the eggs to hatch and guarantees the survival of the nymphs. **Observe** this cage from the 8th day onwards to make sure everything is in order: check that all the eggs have hatched so that the nymphs can be collected and put in their rearing cage. To collect the nymphs, you need a sufficiently deep plastic container.

The method is as follows:

- remove the top part of the oviposition cage
- shake the damp cloth to make the nymphs fall off
- remove the cloth and the feeder
- take the egg trays and shake them in a plastic container to collect the nymphs that are on them and set the trays aside
- pour the rest of the nymphs from the oviposition cage into the plastic container (be careful not to pour more than 250 ml at a time, otherwise there is a risk that the nymphs on the bottom will suffocate)
- the nymphs are now ready to be dosed and placed in their new cage
- dose the nymphs carefully so that you know the quantity and have cages of the same size which require constant work
- write down on a sheet of paper the number of nymphs counted (this number must be entered in the register afterwards)
- pour the nymphs into the new cage (a 3 m^2 cage with 1,000 egg trays should contain 700 ml of nymphs. If necessary, divide the nymphs between two new cages)
- repeat this procedure if there are any nymphs left

The harvesting and dosing stages are very stressful for the nymphs. You should therefore do this as soon as possible to reduce stress and ensure the survival of the crickets.

The nymphs are very small at first and walking the path to the drinker can be a huge challenge for them. Before placing the nymphs in the cage, you should sprinkle the trays with a bit of water before installing the feeder en drinker (Figure 7). In this way you prevent the nymphs from dying in the water. However, do not sprinkle too much water and do not let the trays soak, as this can cause microorganisms to grow in the cage.

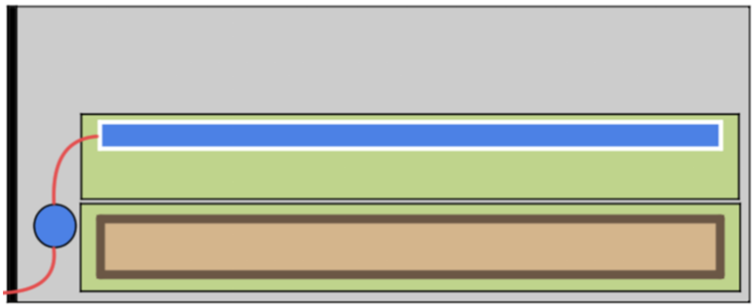


Figure 10: start-up of the rearing cage (Little Food, 2020)

As the crickets grow older, it will be necessary to give them more substrate to ensure their well-being. This increase in the crickets' life volume takes place gradually. If you follow the steps below in the right order, you will also ensure that the interior of the cage remains accessible for as long as possible. It also makes it easier to change tissues or clean the feeder and drinker.

The cage is expanded for the first time after 7 days (Figure 8). It will be necessary to prepare 2.5 stacks of egg trays to add a whole row to the cage. This row is placed at the top of the rightmost row. Clean the feeder before placing food on it. When the cage reaches its 15th day, the space of the cage should be increased again. For this, you should again prepare two and a half stacks of egg trays. Divide the prepared egg trays into two equal stacks. Place the first one in the bottom left corner of the cage halfway up the original rows. Place the second stack on top of the first. It is also necessary at this stage to increase the accessible feeding space. Therefore, at this stage, place a small feeder on top of the egg trays.

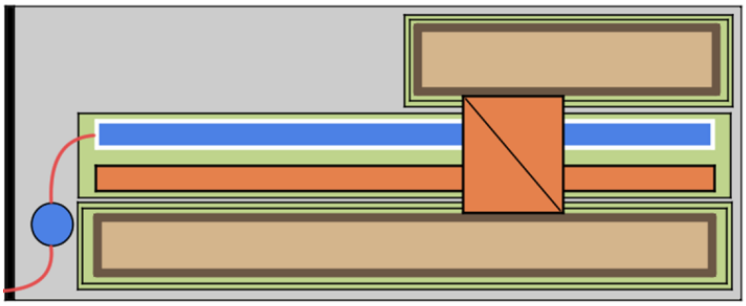


Figure 11: first expansion of the rearing cage (Little Food, 2020)

In the third and final stage, you should expand the cage by adding another 2.5 stacks (Figure 9). The new trays will complete the two floors of trays on the left side of the cage. In addition, replace the small feeder with a large one to provide as much feeding space as possible. This step takes place on the 22nd day of the cage. Also clean the feeder before placing the last trays.

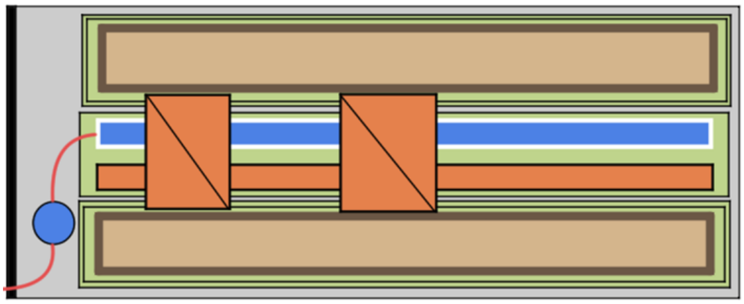


Figure 12: last cage expansion (Little Food, 2020)

3.5 MIGRATORY LOCUST

3.5.1 Climate

An optimal climate has a temperature of ± 30 °C. Too low a temperature will slow down the growth and development of the nymphs (more instars). If the temperature is too high, the yield will drop. The adult grasshoppers will be smaller and they will exhibit more cannibalistic behaviour due to stress.

Sufficient humidity (40-60 %) is especially important for the viability of the eggs, so that they do not dry out. You can remedy this by keeping the oviposition substrate sufficiently moist. Too high a humidity increases the risk of diseases during rearing.

A cycle of 14 hours of light to 10 hours of darkness is recommended. Lamps that emit a spectrum within the infra-red range (e.g. type of incandescent lamp) are preferable, as they also produce heat and the thermostat can thus be lowered.

3.5.2 Infrastructure and materials

Equipment for rearing grasshoppers (Kweekhandleiding Locusta migratoria, 2020)	
Rearing room (climate-controlled)	• **Humidification (controlled up to 60 % or via separate humidifier)** • **Heating (control up to 30 °C or via separate heater)** • **Exposure (14 h light/10 h darkness)** • **Air circulation** • **Ventilation** • **Cooling (optional)** • **Monitoring and logging climate data**
Housing	Cages adapted to the life stage (see below)
Feed	Fresh grass and dry feed (e.g. oats)
Safety	Due to the high risk of allergens, wearing a mouth mask and gloves is recommended when handling grasshoppers
Crate washer (optional)	High-pressure cleaner or washing station, depending on the scale of the cultivation
Weighing scales	To weigh nymphs, feed, etc.
Reproduction	
Oviposition substrate	Mixture of moist sand and peat (50/50)
Oviposition jar	Plastic or glass jar with a height of at least 10 cm

Table 6: equipment for rearing grasshoppers (Kweekhandleiding Locusta migratoria, 2020)

Since the adults can fly, migratory locusts are usually housed in cages/terrariums. Materials such as (plexi) glass and metal are recommended so that you get a sturdier structure, as they can bite soft materials to pieces. In addition, these materials are easier to clean more thoroughly. For this reason, wood is not really recommended.

Figure 10 shows an example of a cage for rearing migratory locusts. In this design, the frame is made of aluminium or stainless steel, as the cage should not be too heavy to move. The front is made of Plexiglas. It contains an opening so that you can reach the inside of the cage. The cage can be closed with a sliding system, for instance. The other sides of the cage are lined with mesh (stainless steel) so that the grasshoppers can also use the height of the cage. The cage also has sufficient ventilation. Make sure the holes in the mesh are not too large, as the little nymphs could escape from the cage. By placing mesh in the cage itself, the migratory locusts can also use the height of the middle space.

The cage is fitted with a faeces collection tray. A frame is placed over the collection tray in between which you can clamp/place the oviposition jar. In addition, the base of the cage is formed by 2 different plates: 1 perforated (bottom) plate and 1 closed (top) plate. The perforated plate is provided with a hole so that the adult migratory locusts can use the oviposition jar. The perforated plate is used as base by the adults (and larger nymphs). Now make a seal for the hole of the oviposition jar so that the faeces can fall into the collection tray. The small nymphs can still escape through this hole. Therefore, make sure the base is sealed. When the nymphs are bigger, you can remove the sealed base and replace it with the perforated base. For practical reasons, it is recommended to ensure that the top of the cage can be completely removed. As a farmer, you may choose the dimensions of the cage yourself, but standard dimensions are ± 50 x 50 x 50 cm.

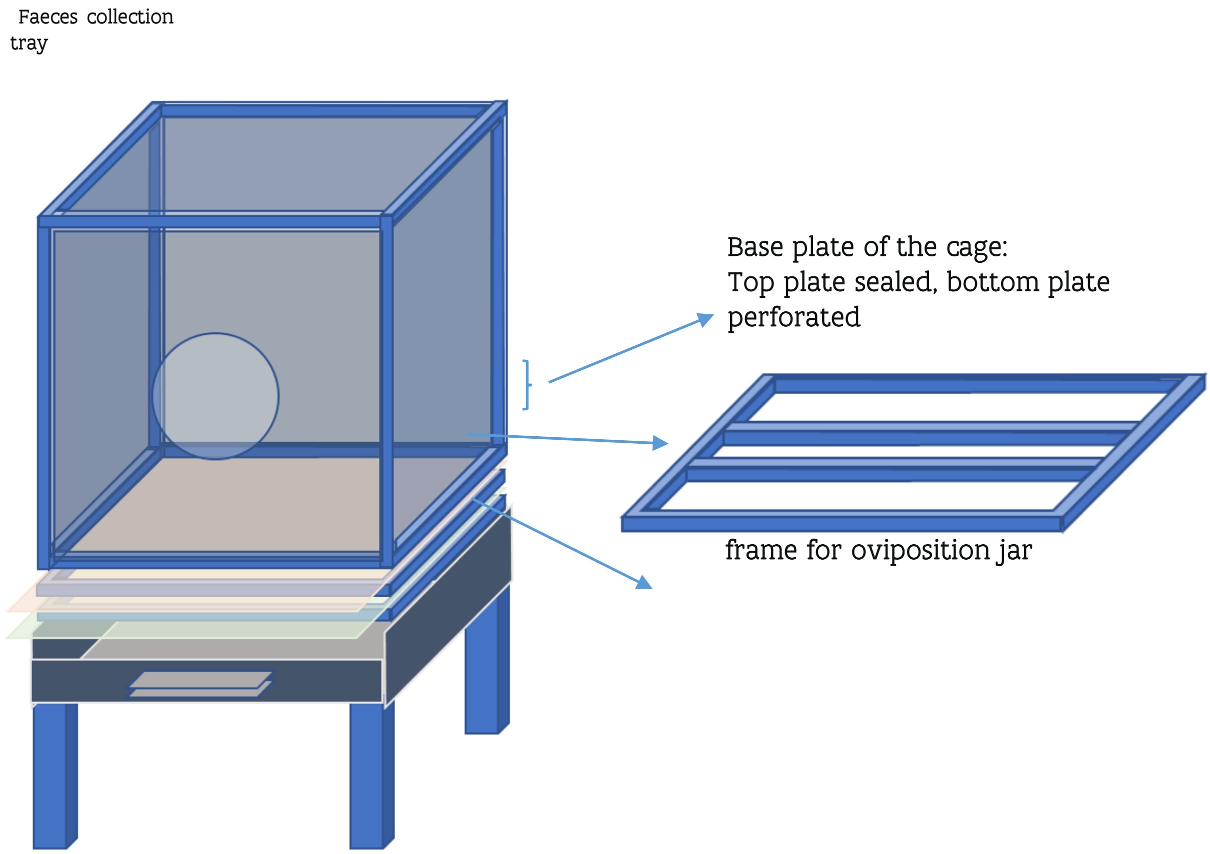


Figure 13: sample cage for housing migratory locusts (Thomas More, 2020)

3.5.3 Process

Migratory locusts lay their eggs in pods. On average, one migratory locust lays about 5 pods during its life cycle. An average of 50 to 80 grasshoppers emerge from each pod.
First, the migratory locust searches for the ideal oviposition site to ensure a high survival rate for its young. The female keeps the eggs in its oviducts until it finds the ideal oviposition site. In other words, the cages must provide the ideal oviposition site, otherwise the female will lay few to no eggs. You can create the ideal oviposition site in a plastic (or glass) jar of at least 10 cm deep. A higher jar (e.g. volume of 1 litre) is recommended, as the migratory locust prefers to dig a tunnel with its ovipositor to deposit its eggs in. A moist substrate with a soft structure, for example a mixture of 50 % peat and 50 % sand moistened with water, should be chosen as oviposition substrate. The migratory locust will deposit its eggs only in moist substrate (not too wet!) to prevent the eggs from drying out. It is sufficient to replace the egg jars once a week during reproduction.

After about 10 days, the eggs purchased or produced will hatch. By keeping the eggs in the (original) moist oviposition substrate until hatching, you prevent the eggs from drying out. As previously mentioned, ensure a relative humidity level of 40 to 60 %.

Check the density of the eggs before placing them in a cage. At a young age, the nymphs can be reared at a higher density, but they need more space as they grow. This is because migratory locusts are cannibalistic, which can lead to a large number of them dying, especially when they have to compete for space. Moreover, this may allow potential diseases to spread quickly throughout the entire population. It is often impractical to manually remove the nymphs from the cage during production. You can therefore choose to start with the optimal density during the adult stage (see below). This is especially recommended if you want to continue rearing these grasshoppers for reproduction. One disadvantage of this is that during the first instars, when the nymphs are still small, space is lost. Still, it will save you time and effort. If you still want to start with a higher density of nymphs, you will have to move some of them to another cage during the last instars (from instar 4 onwards). In this case, it is recommended to respect the optimal density during the adult stage. During the first instars, a density 3 times higher than during the adult stage may be applied, i.e. ± 2,400 specimens per m^3. It is especially important that you meet the needs of the animal. When a large number of them are dying, it is often an indication that the density is too high.
You can check the density by letting the nymphs hatch in a container, for example. However, make sure it is sealed to prevent escape. Based on weight, you can weigh the desired density per cage, assuming an average weight of … g per newborn nymph. This method has the advantage that by harvesting daily, you can place nymphs of the same age together in the cages. This allows you to better control the rearing process. All harvested egg jars should then best be placed together in a container before the eggs hatch. Every day or every two days (depending on the quantity of egg jars) you can move the jars to another container.

Once the nymphs have hatched from the eggs, it takes about 5 to 6 weeks for them to develop into sexually mature adults. During this production period, you should provide the migratory locusts with fresh grass each day, even during the adult stage. It is important that you also remove the faeces that end up next to the cages on a daily basis in order to maintain hygiene in the rearing room. This also benefits the health of the farmer. As mentioned earlier, migratory locusts are cannibalistic. For this reason, you should inspect the cages daily for the presence of carcasses and remove them if possible. It is best to do so when the nymphs are large enough so as to reduce the risk of them escaping. This action can limit the spread of potential diseases.
As the nymphs grow, they will need more space, especially during the adult stage, as they will look for the necessary space to lay their eggs, which will lower reproduction. If you have opted for a high density during the first instars, you will have to lower the density during the last instars and certainly during the adult stage to avoid cannibalism and optimise reproduction. A density of 100 specimens per cage or 800 per m^3 is appropriate during reproduction. Migratory locusts are ready to be harvested when they have developed from the last instar to the adult stage.

3.6 HOUSING INSECTS: ORGANISATION, MAINTENANCE AND MONITORING

3.6.1 Utilisation of space

Harvesting, cleaning containers, and storing, mixing and weighing feed are best done in work areas specifically organised for this purpose. In the case of the black soldier fly, flies and larvae cannot be kept in one and the same room because the smell of the larvae disturbs the oviposition of the flies. Therefore, you should reserve a second, insulated room for the flies.

3.6.2 Ventilation

A ventilation system removes emissions from the insects, such as CO_2, H_2O, volatile organic compounds (VOC) and NH_3, and supplies oxygen. In addition, it also removes fine particles, mould spores and the like, which benefits the farmer's health and reduces the risk of allergic reactions. Good ventilation is also necessary to achieve a uniform temperature distribution in the production room. In busy production rooms, it is advisable to monitor CO_2 en NH_3 concentrations. **The limit for CO_2 is 900 ppm. For NH_3 it is 50 ppm for acute exposure and 20 ppm for chronic exposure.**

Mechanical ventilation may be used to add or remove both heat and humidity. Especially in larger insect farms, mechanical ventilation and climate control are efficient ways to achieve a year-round balance between humidity, temperature and airflow, regardless of the outdoor climate. The technology is based on a desiccant drying wheel (rotor) that removes moisture from the outside air, heats it up and then blows the warm, humid air back into the rearing room. This mechanism optimises energy efficiency on the farm and is therefore cost-effective.

3.6.3 Calibration/monitoring/maintenance techniques and sensors

To keep the rearing room running optimally, it is important to follow the maintenance specifications of the sensor manufacturers. E.g. the sensors (temperature, CO_2 or relative humidity) must be calibrated from time to time. In the case of a classic humidity sensor, this may also mean that the water reservoir of the wet bulb thermometer needs to be topped up.

If hard water is used to humidify the air, over time this may lead to blockages in the sprayers due to scale. Installing a water softener will only shift this problem, as the calcium is exchanged for a salt which may cause salt precipitation. It is therefore recommended to use soft water for spraying, such as rainwater. If this is not available, you may choose to invest in a reverse osmosis device that makes it possible to produce low mineral water.

Insects produce dust. Air from inside the rearing room that is blown away during ventilation may carry this dust. For this reason, dust filters are often installed to avoid that emissions pollute the immediate surroundings of an insect farm. Over time, these filters will clog up with the captured dust, disrupting the airflow through your rearing room. You should therefore keep in mind to change the filters in good time.

3.6.4 Alarm systems

All freezers present should preferably be fitted with an alarm system in order to be able to intervene quickly in case of a breakdown.

It is also best to fit the rearing rooms with a monitoring system so that you can intervene if the temperature reaches the set limits. Too low a temperature slows down the rearing cycle and too high a temperature may kill the insects.

Table 8 gives another overview of the desired rearing conditions for the different species.

Optimal environmental conditions

	Yellow mealworm		Black soldier fly		House cricket		Migratory locust	
	Larva	Adult	Larva	Adult	Nymph	Adult	Nymph	Adult
Temperature (°C)	25-28	25-28	27-30	27-30	28-30	28-30	30	30
Humidity (%)	75	75	60	80	70-100	50-60	40-60	40-60
Light or Dark (hours L or D)	24 D	24 D	24 D	12 L and 12 D	24 D	24 D	14 L and 10 D	14 L and 10 D
Feed	Grain streams with vegetables/fruit as moisture source		Grain streams mixed with water (60-80 % moisture), compound feed (e.g. as for pigs) possibly supplemented with vegetables/fruit and crop residues		Grain streams with vegetables/fruit as moisture source (free water for older nymphs)		Fresh grass supplemented with grain streams (no moisture source or free water needed)	
Feed conversion*	1.6		1.2		1.8		No data	

Table 7: optimal environmental conditions

*kg of dry feed per kg of growth in the case of high-quality feed (except for migratory locust where it is kg of fresh grass per kg of growth)

3.7 AUTOMATION

When production volumes exceed 50 tonnes/year, it will become increasingly important to reduce labour costs through automation. This automation can be a lever for increasing the scale of production and, as a result, reduce costs even further. In addition to automation, much time can be saved in this still young insect sector by improving procedures.

Yellow mealworm and black soldier fly: The systems for rearing mealworms and black soldier fly larvae are the easiest to automate. Research is currently being carried out for instance into how automatic feeding can be introduced by means of a feeding robot. As a company expands, labour costs will continue to rise. Adding feed to the containers is the most time-consuming. However, this process can be automated using a feeding robot (the following pertains to mealworms). This may reduce labour costs by up to 75 %, which represents a considerable saving. Several companies already have (or are currently developing) such systems. However, these designs are usually protected by business confidentiality. One exception is the Dutch company De Schanekamp where a 6-axle CX210LFE02 Kawasaki robot was installed. With its large working range, high handling weight and minimal footprint, this system is ideal for (de)palletising mealworm rearing containers. The robot is equipped with a pneumatically operated clamp gripper for two containers. The specific environment was taken into account in the design. Roller conveyors for pallets were used that can be loaded with a hand pallet truck. As a result, the pallets are automatically fed into the chamber. The robot handles the containers and pallets and stacks them on a neighbouring second position, after which everything can finally be driven back automatically to the rearing chamber. The complete chamber with conveyors and sensors is controlled by a powerful Kawasaki robot controller. The result is one clear programme and a simple, centralised touch screen operation.

More information on the Kawasaki robot controller is available at https://duurzaaminsecteneten.nl/insecten-kweken/automatisering-breekt-door-in-insectenkweek/.

However, many other automatic feeding concepts are possible. For example, a paternoster system was designed by Fontys University of Applied Sciences in the Netherlands. In Flanders, research institutes Inagro and VIVES are currently developing another concept of automatic feeding by means of a feeding robot with a mobile feeding station and limited movement of the rearing containers. This robot has already been built (in contrast to the Fontys system) and is being used for research. By fitting this robot (or the containers) with sensors, precision agriculture can be achieved.

More information on the paternoster system is available at https://leden.inagro.be/Portals/484/WP5 Fontys Paternoster.pdf.

House cricket: According to Little Food, the most time-consuming steps in cricket rearing are watering, harvesting, filling cages, egg production and feeding. They suggest breaking down the rearing process into different systems: egg production and cricket rearing in production farms. These systems therefore need to be developed and automated in different ways.
This parameter can be measured by the worker's efficiency: how many kg of crickets can one person process for each production step. The company arrived at a work efficiency of about 7.5 tonnes of crickets/year/person. Their goal was to increase this number to 150 tonnes/year/person for a company that focuses solely on cricket rearing. This seems rather unrealistic, since it differs by a factor of 20. Scaling up is the main reason why this would be possible, in addition to automation. Taking care of a 20 kg cage requires almost the same amount of work as taking care of a room with 10 tonnes of crickets when feeding and watering are automated. In the chicken industry, one farmer can take care of about 90,000 chickens or 225 tonnes. The techniques used do not have to be developed from scratch and can be further optimised for insect rearing.

The following companies have already developed prototype systems for insect rearing or are showing an interest in this sector:

- Cadcamatic: https://www.cadcamatic.be/
- Catael: https://www.catael.be/
- Roxell: https://www.roxell.com/nl/node/9
- Vermeulen Construct: https://www.vermeulenconstruct.be/

3.8 HYGIENE AND DISEASE PREVENTION

It is recommended to wet clean the rearing containers with detergent after each rearing cycle. In order to prevent re-contamination, you can air-dry the containers when cleaning them manually or dry them with disposable material. Preferably clean the rearing containers mechanically. It is also best to buy rearing containers that have as few bulges as possible on the inside and the outside, as these are more difficult to clean. By cleaning the rearing containers mechanically, you can avoid contamination from one breeding cycle to the next, provided you use detergent and duly apply water management techniques.

There is no general best method for cleaning and disinfecting a rearing room. However, a hygiene plan can list specific elements that are important and which you will perhaps forget over time. You can draw up this plan by analogy with the following example for poultry houses: Reinigen en ontsmetten op het pluimveebedrijf | DGZ.
Since all insects need a high temperature (27 °C and more) to grow optimally and this is coupled with a high relative humidity (60 % and above), rearing chambers are very susceptible to microorganism development. This not only compromises quality and food safety, but may also jeopardise the health of the insects.
Yellow mealworm and black soldier fly - For mealworms and black soldier fly larvae, a number of pathologies have already been described on the website Diseases & Disorders (insectdoctors.eu).

House cricket - Crickets in particular are very susceptible to disease. The Acheta domesticus densovirus (AdDNV), for instance, can really wreak havoc. The AdDNV is a subfamily of a single-strand DNA virus that infects invertebrate species. Infection causes high mortality rates in populations of house crickets, especially in the last nymphal stage and in young adults. Moreover, the growth of crickets is delayed and individual crickets become petrified for several days until they die. The densovirus enters through the body surface or the intestines. Studies also showed that it can be transmitted through the air and thus between different rearing rooms (Szelei, et al., 2011). In addition, AdDNV may be present in the insulation and survive for months on house crickets' epidermis (Weissman, Gray, Pham, & Tijssen, 2012).
Other diseases can also be found on this website Diseases & Disorders (insectdoctors.eu).

Little Food's rearing system suffered from pests (larder beetle, see Chapter 4.9) and viruses. This resulted in a huge variation in production numbers. Because insect rearing requires substantial numbers of animals/m^2 and vaccination is not possible, disease prevention is crucial. There are several elements, however, that can be improved. Below is a summary of what the company proposed:

1) The system: a system based on the chicken industry and designed to prevent disease. Reproduction is separated from production, which is decentralised. All the rearing rooms are emptied after a production cycle, enabling complete disinfection.
2) The species: the species *Acheta domesticus* is very susceptible to viruses. This is probably due to the fact that it is the most intensively reared cricket species, as a result of which viruses were able to develop. Other species are less susceptible to viruses: *Gryllodes sigillatus* or *Gryllus bimaculatus.*
3) Hygiene: hygiene is very important, especially for reproduction and egg storage.
4) Water quality: good water quality is crucial to prevent diseases.
5) Better rearing conditions for the animals intended for reproduction so that their eggs are of excellent quality.

6) Selection to create a pedigree.

Migratory locust: scientific information on diseases in grasshoppers can be found, for example, in the Encyclopedia of Entomology (Capinera et al., 2008).

3.9 PEST CONTROL

Pests must be prevented during rearing, as this can quickly get out of hand. Pests create competition for food and space, which can lead to reduced growth. Moreover, pests can damage the eggs etc., which can reduce your yield. Pests also create an unpleasant working environment and can cause secondary problems, diseases, technical problems and contamination of the end product.

Pest prevention starts with good company hygiene. Wash the rearing containers thoroughly after rearing and try to vacuum the rearing room thoroughly once a week. Get your feed and other supplies from an approved supplier to reduce the risk of contamination. It is advisable to provide separate rooms for storing the feed so that you have a buffer in case of contamination. Contaminated batches can be placed in the freezer for 24 hours. It is best to clearly separate what enters and what leaves the company. Keeping a logbook may help to do so (see example in Chapter 14: Annex). Check the rearing containers regularly. This allows you to intervene in time when a pest problem occurs at the farm.

The following is a list of pests that can occur when using dry feed **(especially in the case of yellow mealworm and house cricket)**.

Flour mite

Identification:

Flour mites have a colourless body with slightly darker mouth parts and legs. As flour mites are about 0.4 mm long, they are not visible to the naked eye. They feed on moulds and substances with a high protein and fat content (KAD, 2019).

Figure 14: flour mite

Approach:

1) Prevention: high humidity can also lead to the development of flour mite: a mite that occurs naturally on grain products. It is therefore often decided to set the relative humidity at a maximum of 70 % as a compromise between optimal growth and maintaining hygienic rearing conditions

2) Control by temporarily reducing humidity to ± 50 % (Jaenen, 2019)
3) Control with predatory mites: a lot of commercial species are reared on flour mites (Macrocheles, Cheyletus, Blattisocidae). However, these predatory mites thrive best on plants. In mealworm rearing there is a risk of them ending up in a sub-optimal environment, which may reduce performance. This is to be further examined
4) Control with acaricides

Flour moth

Identification:

- Adult insects: 7 - 9 mm long, wingspan of 15 - 20 mm. The first third of the front wings are pale yellow. The rest of the wings are reddish brown. Flour moths are mainly active at night and are therefore often not noticed until it is too late
- Larvae: yellowish white, reddish or greenish (depending on diet) with a brown head

Figure 15: flour moth

Damage:

They can be noticed in rearing containers by the webs they make. The flour moth larvae pupate in these webs (Anticimex, 2019a; Weisman, 1999).

Approach:

1) Prevention (do not bring contaminated feed inside)
2) When the flour moth occurs on the farm as a pest, it is advisable to remove all the infested rearing containers. Mealworms and beetles must be sieved off from the contaminated containers and wheat bran
3) Pheromone glue traps (adults)
4) Control with Trichogramma or *Habrobracon hebetor* ichneumon wasps (larvae)
5) Control with Spinosad (larvae)
6) Control with *Bacillus Thuringiensis* (make sure the right strain is used, so the mealworms are not affected! The subspecies kurstaki is effective specifically against caterpillars and is commercially available (DELFIN® WG)) or Azadirachtin
7) Control with pyrethrins and piperonyl butoxide

8) Fumigation with phosphine

Larder beetles

Identification:

- Common larder beetle *(Dermestes Lardarius*)
- Adult insects: 6 - 10 mm long. Black with a whitish stripe across the front of the wing covers
- Larvae: move fast. Brownish-red in colour and hairy (prickly) and clearly segmented. Pupate in solid material. The larvae grow slightly longer than 15 mm (Anticimex, 2019b; Kingsolver, 1999)
- Khapra beetle (Trogoderma granarium)
- Adult insects: 1.6 - 3 mm long. Hairy wings, light with dark spots. Males are dark brown or black and females are slightly larger with lighter colours
- Larvae: larvae are up to 5 mm long and are covered with dense, reddish-brown hair

Figure 16: larder beetle Dermestes lardarius

Approach:

1) Prevention (do not bring contaminated feed inside)
2) Monitoring with pyramid traps fitted with painter's tape, UV light traps and blunder traps (adults)
3) When the larder beetle occurs on the farm as a pest, it is advisable to remove all infested rearing containers. Mealworms and beetles must be sieved off from the contaminated containers and wheat bran
4) Control with sticky traps possible as long as the infestation is not becoming too large (adults)

Bread beetle

Identification:

- Adult insect: reddish-brown and 2 - 3 mm long. The neck shield covers the head like a monk's cowl. The body is covered with fine hairs. The wing cases have fine longitudinal stripes
- Larvae: active in early stages of development. Drill into hard starchy products, such as pasta and dry dog food

Damage:

- Infested products can be recognised by the exit openings of the beetles

Approach:

1) Prevention (do not bring contaminated feed inside; keep all starchy products tightly sealed or store them in a refrigerated room and immediately clean up any spilled feed)
2) Sticky trap or pitfall trap with or without attractant, blunder trap, UV light trap: effective in hot spots and high light areas where beetles fly
3) Control with pyrethrins and piperonyl butoxide

The flies listed below can actually cause nuisance in any insect rearing process (but especially where wet feed is used, as is the case for **black soldier flies**).

Common housefly

Common housefly *(Musca domestica*) is an opportunist that will also feed on the black soldier fly feed if given the opportunity.

Figure 17: common housefly

Approach:

1) Prevention: in order to avoid infestation with the common housefly, it is advisable to screen off the cultivation up to 5 to 7 day old larvae, for example by placing the containers with young larvae in pop-up nets. The second phase of rearing is less sensitive to this as the fast-growing larvae will suppress common houseflies
2) Sticky traps or UV light traps can detect and help control a limited population
3) Control: many pesticides are available on the market and pest control companies have much experience in controlling maggots and flies in stables. These methods can often not be used in insect rearing without disturbing production

Fruit flies

The presence of small flies (the size of fruit flies) around a rearing container is a sign that something is wrong in the container, for example, there are too few larvae, which can cause the feed to rot; there is mortality among the larvae, etc. It is best to remove these containers from the cultivation.

Figure 18: fruit flies

4 HARVESTING

Most farmers use sieving as a method for separating the insects from the residual substrate. With these techniques, fractions are separated on the basis of particle size and shape by gravity. For *T. molitor* and *H. illucens*, it is recommended to use vibrating screens with a mesh size of 2-4 mm. The inclination, amplitude and frequency of the vibrations, together with the size and shape of the sieve openings, the properties and the supply of the material, determine the operation of a sieve.

Yellow mealworm: when harvesting mealworms with a sieve (mesh size 2-3 mm) the frass and remaining feed fall through the sieve, whereas the mealworms stay on top of the sieve. To harvest large volumes, it is better to use a vibrating screen. This will save you time and work. After harvesting, the mealworms are best kept by freezing them at -20 °C.

When rearing mealworms, a great deal of sieving off is required for reproduction, rearing and harvesting and for maintaining a new parent generation.

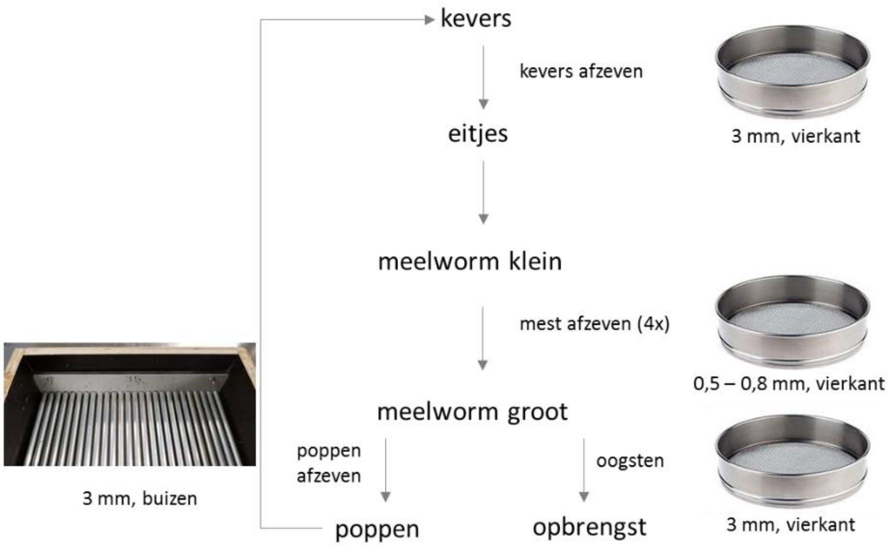


Figure 20: sieving at different stages (Inagro, 2018)

Measurements by Inagro show that when rearing proceeds entirely manually, sieving takes up about 60 % of the time. For this reason, flat vibrating screens are often used. Many sieves are available on the market that can be used for mealworm rearing. The report below contains a detailed overview of the pros and cons of the existing systems.
https://leden.inagro.be/Portals/484/Automatisatie_Entomatisation%20-%20Casestudie%20scheidingstechnieken.pdf

Black soldier fly: larvae are satisfied when the substrate has dried to a coarse powder and cooled. Harvesting is easily done by sieving off everything. A mesh size of 3 to 4 mm is sufficient for this purpose.

You can do this manually using smaller sieves, or more efficiently by means of mechanical vibrating screens.

House cricket: cooling or shaking the containers, so that the animals are easier to catch. Little Food developed a drum screen to separate the crickets from the egg trays. It is best to harvest nymphs of the 7^{th} stage. Adults (8^{th} stage) die fairly quickly and are only interesting for reproduction. The speed and angle of this machine can be changed. The harvested fraction also contains manure and some dead crickets. These fractions should be separated from the live crickets. For this, you will have to sieve again. You can also let the crickets climb on egg trays which you shake out again afterwards.

Migratory locust: harvesting grasshoppers is currently still labour-intensive, as it is done manually. The slaughter method is chosen depending on the sales market. If they are sold as live insects, the grasshoppers are caught. By cooling or shaking the containers, the animals are easier to catch. If the grasshoppers are offered frozen, it is an option to place the entire cage in the freezer provided there is sufficient space. The grasshoppers can also be refrigerated (at 5 °C), which prevents them from developing further, but still keeps them alive for a certain period.

5 KILLING, PRESERVATION, STORAGE AND TRANSPORT OF INSECTS

Insects can be killed in different ways. The most common techniques are killing by heating or freezing. Legally, it is not compulsory to kill insects first before processing them further: killing by shredding, for example, is also allowed.

You should bear in mind that every technique has an impact on the properties of the end product. You can read more about animal welfare in Chapter 12.

5.1 KILLING BY HEATING

Blanching is a technique whereby products are heated for a short period of time and then chilled to quickly stop the heating process. The product can be heated by means of hot water or steam.

In hot water blanching, the products are plunged in preheated water (70 to 100 °C). The duration depends on the type of product and the quantity, but usually this is around 1 to 5 minutes.

Steam blanching systems inject hot air (~100 °C) onto food as it passes through the blanching system on a conveyor belt. This method greatly reduces the leaching of water soluble compounds from the product, and is the preferred technique for smaller foodstuffs. Steam blanching systems are more energy efficient, and the possibility of rapid heating allows the processing time to be reduced. Owing to this reduced heat exposure, the colour, aroma and overall quality of the food are preserved. However, evaporation may lead to lower masses and product yields.

Immediately after the heat treatment, the products are chilled rapidly with cold water. A common alternative to chilling with cold water is chilling with cold air.

5.2 KILLING BY FREEZING

24h at -18 °C: preferably, the insects are frozen in thin layers in order to carry out the process as evenly and quickly as possible.

Shock freezer: in a study by Purscke et al. (2018) mealworms were frozen individually after blanching for 20 minutes at -38 °C in a Sagi F101L.

5.3 PRESERVATION, STORAGE AND TRANSPORT

If the insects are to be further processed, it is still recommended to kill them as soon as possible after harvesting. Live insects can be kept at refrigerated temperatures (4 to 10 °C) for several days. If live insects have to be transported, this is best done using refrigerated transport.

When insects are killed by blanching and not processed immediately, they should be frozen. Otherwise, they will have a limited shelf life (max. one week) at a chilled temperature (4 °C). When insects are killed by freezing, they should remain frozen after this step until the next processing step. Defrosting is best done at 4 to 6 °C.

Frozen insects (whether blanched or not) are also best stored in sealed packaging in an appropriate environment with reduced oxygen levels to prevent oxidation of the unsaturated fats. This is less important for black soldier fly larvae, as these larvae mainly contain saturated fats.

6 FRASS AND OTHER BY-PRODUCTS OF INSECT PRODUCTION

Side streams are created when harvesting insects and also during the rearing process. These residual fractions often consist of dead and live insects, feed remains, skin casings and faeces or a mixture thereof. How this residual substrate may be processed depends on the degree of separation between the different fractions.

According to the Committee on Animal By-Products (Commissie Dierlijke bijproducten/CoABP), it still needs to be demonstrated whether the different streams of the residual substrate can be separated. The status of the residual substrate (mixture) contains both Category 2 and Category 3 materials according to Regulation (EC) No 1069/2009.

You can process it through:

Composting or fermentation

- At a company licenced and approved for this purpose. An overview of these companies can be found on the website of the FASFC (http://www.favv-afsca.fgov.be/dierlijkebijproducten/erkendeoperatoren/).The composting and fermentation plants included on these lists are subject to sanitisation.
- The residual substrate must be transported to these plants as waste, which means with a commercial document. The transport must be carried out by a registered carrier and by order of a collector, trader or broker of Category 2 animal by-products.
- The compost or digestate produced here may be used as raw material for or as soil improver.
- Compost or digestate must be transported in accordance with the manure bank legislation. It is no longer waste, but a raw material.

Drying (sanitisation for 1h at 70 °C)

- At present, no companies are approved for drying animal by-products only. Companies must be licenced and approved for this purpose. Farmers can also apply for this themselves.
- The residual substrate must be transported to these plants as waste, which means with a commercial document. The transport must be carried out by a registered carrier and by order of a collector, trader or broker of Category 2 animal by-products.
- The dried residual substrate must have a raw material declaration provided by OVAM (https://ovam.be/grondstofverklaringen) before it can be used as fertiliser or soil improver. Without this declaration, it continues to be unprocessed waste.
- Dried residual substrate (with a raw material declaration) must be transported in accordance with the manure bank legislation. It is no longer waste, but a raw material.

Incineration

- According to Flanders' waste and materials policy, this should be avoided.
- Residual substrate must be transported as waste to a licenced incineration plant, i.e. with a commercial document. The transport must be carried out by a registered carrier and by order of a collector, trader or broker of Category 2 animal by-products.

The diagram below shows the current options:
http://www.afsca.be/dierlijkeproductie/dierenvoeding/insekten/_documents/restsubstraatinsectenapril2019_NL.pdf

In concrete terms, this means that:

If the residual substrate can be sanitised at the company, the company itself has to apply for an integrated environment permit and approval under Regulation (EC) No 1069/2009 for the processing of the residual substrate. If, in the future, a good method is found to separate manure from feed residues and insects, and the EU indicates that no sanitisation is required, farmers can also apply for a raw material declaration without a permit and approval. Without such a declaration, this stream continues to be regarded as waste, and transport must take place with a commercial document and by a registered carrier and collector, trader or broker.
When such a declaration is obtained, transport must take place in accordance with the manure bank legislation (VLM) (see below).

If the residual substrate is collected before it is sanitised, this stream is regarded as waste and transport must take place with a commercial document and by a registered carrier and collector, trader or broker.

In addition to the raw material declaration and sanitisation (i.e. sterilisation) of the residual substrate, additional requirements must be met depending on the status of the product obtained (e.g. exemption from FPS Public Health, Food Chain Safety and Environment for trading a fertiliser, soil improver or rearing substrate).

The Flemish Land Agency (Vlaamse Landmaatschappij/VLM) regards this soil improver or fertiliser as an "other fertiliser". The producer must identify itself to the VLM as a producer of other fertilisers. The other fertiliser must be transported by an approved fertiliser transporter or shipper.

7 PROCESSING METHODS

Below, you can read about a number of possible techniques that are currently being applied to other food products and that are being researched for their applicability to insects. By way of example we provide you with the research results of Lab4Food of KU Leuven (Vandeweyer et al., 2017; Wynants et al., 2018; De Smet et al., 2019) and VIVES University College. **It is important to emphasise in this context that no protocols have been developed and laid down yet for insects. For this reason, we limit ourselves in this guide to providing the principles and elements of focus of the techniques examined. The authors can by no means be held accountable for any problems with the processing of insects that may arise from consulting and following this guide.**

7.1 SANITISATION STEP

If the insects have not undergone sanitisation at the time of killing, they should first undergo a heat treatment for both chemical and microbiological reasons. This may include wet pasteurisation (blanching in boiling water or steaming) or dry pasteurisation (infrared, microwave (wattage and duration are very important here) or high hydrostatic pressure (HHP)). Depending on the method chosen, different chemical processes will either be stopped or activated and there will be a varying impact on the survival of (pathogenic) microorganisms in the insects. Pasteurised insects should be stored as soon as possible under refrigerated conditions (at 4 °C for several days at most or at -18 °C for a longer period) to avoid microbial growth (although some so-called psychrotrophic microorganisms can still grow at refrigerator temperature). Research by Lab4Food has shown that the commonly used sanitisation steps are insufficient to kill spore-forming pathogens. Treatment at (even) higher temperatures, whether or not combined with longer times, may offer a solution for this (Vandeweyer et al., 2017). More research is needed, however, to find out which time/temperature combinations are suitable for killing spores. Moreover, combinations of longer times and higher temperatures will lead to (even more) nutrient loss. The sanitisation step can also be carried out in the final sales packaging stage if it concerns canned insects. The advantage is that there is no risk of post-contamination after the heat treatment, which is, however, the case when insects are treated in bulk and then packaged.

7.2 PROCESSING

7.2.1 Whole insect

Following sanitisation, the whole insects can be packaged as 'fresh food' or be processed further. Further processing will often involve a drying process, or the insects can be finely mixed into a 'paste' (De Smet et al., 2019).

7.2.1.1 Drying

Various drying techniques are available. Drying is preferably done at low temperatures (below 100 °C) to ensure nutrient retention. In general, few differences are observed in terms of macronutrients between the different drying techniques. However, little research has been done into micronutrients and their influence on protein digestibility. It is already known that fat oxidation varies greatly depending on the drying technique. The choice of drying technique can also be made when a certain quantity of insects is dried (batch system) or via a continuous drying process (in-line system). Below is a list of techniques already researched at Lab4Food and VIVES University College:

- Freeze-drying: is currently the most widely used method as it guarantees good nutrient retention (watch out for fat oxidation). It requires a large investment and the process itself is expensive as well (works on the basis of batch system or semi-continuous system, which is time-consuming, with a high energy consumption).
- Microwave drying: also guarantees good nutrient retention (watch out for possible loss of vitamins such as B12). The equipment requires a large investment, but the process itself can be carried out both in batch and in-line, is relatively short and cheaper than freeze-drying (lower energy consumption) (Figure 17).
- Hot air oven drying (90 - 150 °C): proceeds quickly but results in discoloured mealworms and shrivelled black soldier fly larvae. High temperatures can lead to nutrient loss and reduced digestibility.
- Oven drying at low temperature (50 - 80 °C): specific food dryers are available for this purpose (Figure 18). Low-temperature drying ensures good nutrient retention. Long process during which mealworms discolour and black soldier fly larvae shrivel. According to Little Food, this produces beautiful crickets.

Figure 24: left: µWave Vac0350 batch microwave dryer (Püschner); right: MEAMDRY S 32 belt microwave dryer with 16 sources of 2 kW and a conveyor length of 4 m (MEAM) (VIVES, 2017)

Figure 25: food dehydrator Profi Line 10 trays food dryer (Hendi) (VIVES, 2019)

The following techniques were passed on to us by foreign companies:

- Tubular dryers: cheapest batch systems are quite expensive and can dry 5-10 kg/h. They are suitable for drying whole insects.
- Drum dryers: cheapest batch systems are quite expensive (comparable to batch microwave) but the process is more energy efficient than with tubular dryers. The process is faster than batch microwave drying (± 7 kg/h drying), but the high temperatures (125 °C) increase the risk of quality loss. Especially suitable for drying insect paste.

It is important to measure the water activity (a_w value) of the dry end product/semi-finished product, and not only the moisture content. An a_w value of less than 0.6 is aimed at for stable storage. This is a measure of the 'free' water present in the product. With a value of less than 0.6, no microorganisms can grow. It is impossible to say what moisture content corresponds to that value, as there is no strict link between a_w and moisture content.

7.2.1.2 Fermentation

Research has already been conducted into the use of a standard meat fermentation starter culture to ferment insects (paste). However, carrying out fermentation requires proper monitoring and expertise (De Smet et al., 2019).

7.2.1.3 Mixing

By means of a meat cutter or a vacuum bowl cutter combined with a micro-cutter, a fine paste can be made in which pieces of the exoskeleton are no longer tangibly present (Figure 19). However, microbiological safety should be very closely monitored, as this product is very sensitive to microbial growth. There are indications that storage at -21 °C is the best option for shelf life compared to refrigerated storage at 4 °C (De Smet et al., 2019).

Figure 26: left: bowl cutter (Stephan UM 12, A. Stephan); right: mealworm paste (Lab4Food, 2017)

7.2.2 Processing into meal

Insect meal can be made from dried insects or defatted dried insects or by drying a paste which can also be made from insects, whether defatted or not. Grinding whole insects often causes lumps due to the high fat content. For this reason, defatting is often performed first.

In order to obtain a fine meal, the fraction with the largest particle size is often sieved off. Making the insects chitin-free during processing may also result in a finer meal. An example of a device used to make insect meal is a Blixer (= a combination of cutter and blender/mixer) (Figure 20). The smallest system can hold 2 L and the largest up to 60 L. For large-scale meal production, the combination of a Retsch mill (ZM 200) and a three roll mill was tested as well (Figure 21).

Figure 27: Blixer (Robot Coupe) (VIVES, 2020)

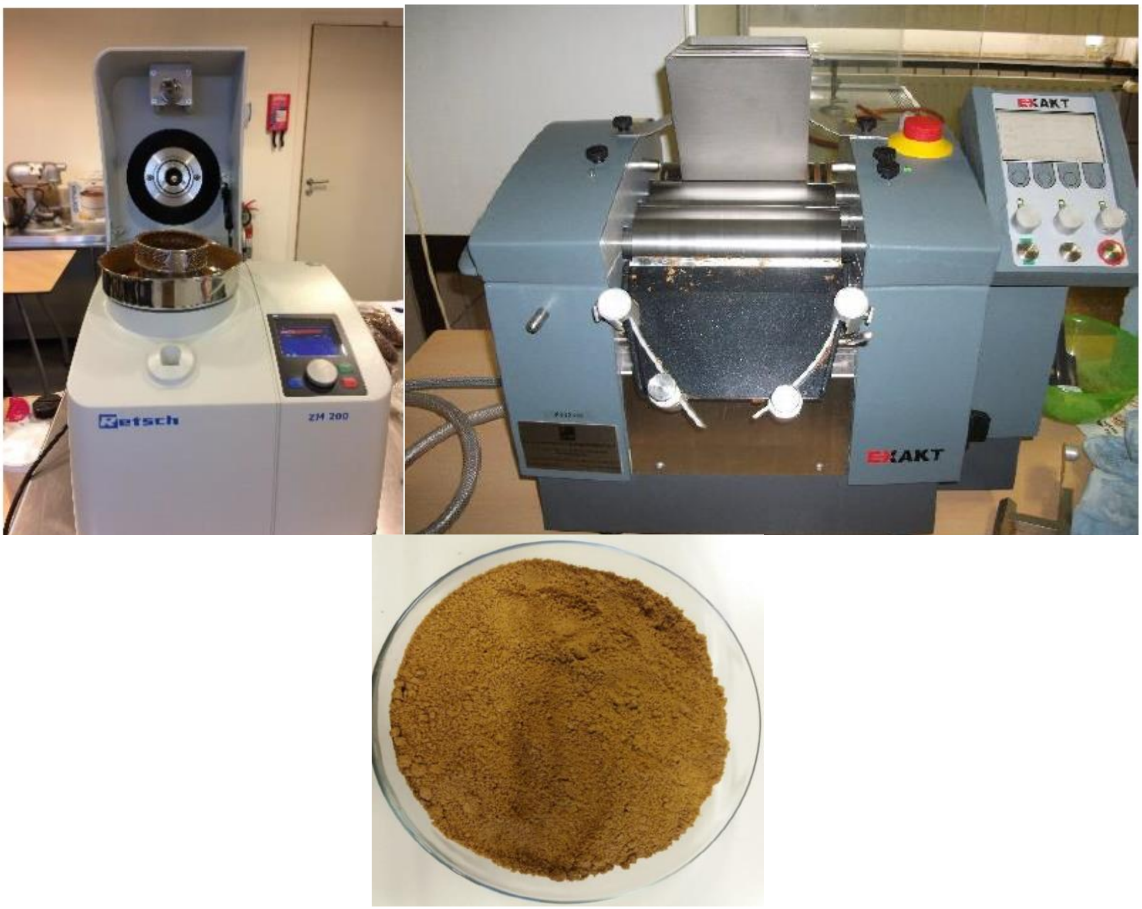


Figure 28: equipment ILVO; top left: Retsch mill (ZM 200, Retsch); top right: three roll mill (EXAKT, Three Roll Mill 80E, E&R); bottom: mealworm meal (Lab4Food, 2017)

7.2.3 Processing: fractionation - biorefinery

After harvesting, there are various ways to further process the insects into an end product. The insects can be used as live feed for reptiles and other animals or be processed further. Some examples of the latter approach are shown in Figure 22. A classic approach is to dry the insects and use them as intact insects or as meal (after grinding). The dried insect biomass is often defatted to separately market the insect oil and the defatted meal (sometimes called protein meal), and/or sub-fractions of the latter (Nongonierma & FitzGerald, 2017). Another approach is to first separate the chitin in the wet insect biomass mechanically in order to obtain a low-chitin fraction, which can then be further separated into an oil-enriched fraction and a de-chitinised and defatted meal (Soetemans et al., 2016). The chitin can be purified from the chitin-rich fraction and be converted to chitosan via (chemical or enzymatic) deacetylation. Hydrolysis of the entire insect meal to generate peptides is another way of fractionating insect biomass (Leni et al., 2020).

Defatting can be achieved by increasing the temperature (rendering, Aidos et al., 2006; Woodgate & van der Veen, 2004) or by using chemical methods such as solvent extraction with e.g. hexane (Mishyna et al, 2019; Choi et al., 2017; Ndiritu et al., 2017; Purschke et al., 2016; Bussler et al., 2016) or isoelectric point precipitation (Soetemans et al., 2019; Tzompa-Sosa et al., 2014; Yi et al., 2013).

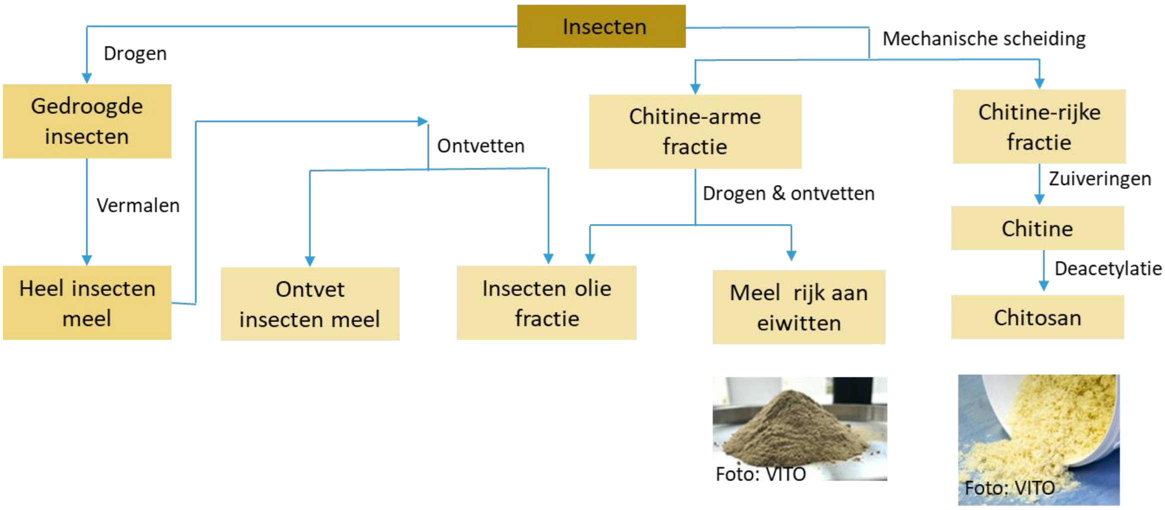


Figure 29: examples of processing fractionation of insects into ingredients (VITO, 2020)

7.2.4 Extrusion

Under the influence of temperature and pressure, insect paste or insect meal, possibly mixed with other ingredients, could be processed by means of an extruder. In a study by Smetana et al. (2018), the wet insect mash (high moisture extrusion) was pressed through a barrel at high temperature (maximum 170 °C) using rotating screws, after which the plastic material left the extruder via a cooled outlet die (Figure 23). This gave the product its final solid and textured shape. After rehydration with water (and flavourings), the product obtained a reasonable mouthfeel and chewability comparable to minced meat, but not to a slice of meat (Figure 24). Sample composition and water content were the main factors influencing the cutting strength of the extruded intermediate products with high moisture content. It was possible to maintain the meaty texture by adding up to 40 % insect protein concentrate in a mixture with 5-10 % soy fibre (dry matter), resulting in meat analogues with 25.0-30.8 % protein. Other factors such as amino acid losses, protein-protein interactions and the formation of peptide bonds in extruded samples were not part of this study (Smetana et al., 2018).

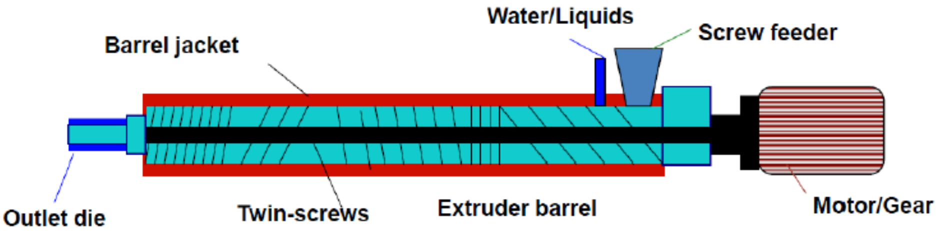


Figure 30: extruder (Deutsches Institut für Lebensmitteltechnik, 2017)

Figure 31: extruded insect paste mixed with soya (Deutsches Institut für Lebensmitteltechnik, 2017)

7.3 AVOIDING CONTAMINATION

In the case of whole insects, various sources of contamination should be considered. There may be physical contamination: presence of faeces, feed residues, cardboard, other insects. By using simple sieving techniques, you can avoid contamination during further processing. Fractions of equal size may be separated on the basis of density weight. There can also be chemical contamination, which usually originates from the insect feed or from pesticides or cleaning agents used during rearing. The main form of contamination has already been mentioned above and is microbiological in nature (bacteria and fungi that lead to spoilage and can cause food contamination/intoxication).

Before blanching, the temperature should be reliable and checked. In the case of wet blanching, the water should be changed with sufficient frequency. After blanching, work should be done under hygienic conditions in accordance with HACCP standards so that no recontamination or post-contamination occurs. The drying of insects is subject to HACCP regulations and must be completely separated from the insect rearing process.
The IPIFF has produced a guide for hygienic insect rearing and processing:
https://ipiff.org/wp-content/uploads/2019/12/IPIFF-Guide-on-Good-Hygiene-Practices.pdf

Regulation (EC) No 853/2004 sets out hygiene requirements. The standards for insects have not yet been established. However, microbiological criteria have been laid down in **Regulation (EC) No 183/2005 for feed hygiene and Regulation (EC) No 2073/2005 for foodstuffs,** as well as Belgian action limits for food:
http://www.favv.be/professionelen/publicaties/thematisch/actiegrenzen/

For information on how to interpret the action limits, you can contact the FASFC.

7.4 STABILISATION

Sanitised insects have only a short shelf life and should be kept at refrigerated temperatures. They can be dried to a stable product as whole insects or be processed into a 'paste'. Dried insects can be kept at room temperature at a low relative humidity, sheltered from sunlight. In order to avoid fat oxidation, it is also best to opt for sealed packaging, possibly even packaging under proper atmospheric conditions. The paste can only be kept for a few days when chilled at 4 °C and for a few months when chilled at -21 °C. If required, this paste can be dried using various devices (e.g. drum dryer).

8 PACKAGING

8.1 INCOMING INSPECTION OF PACKAGING

Packaging material should be checked to ensure that contact with (processed) insects does not result in contamination of the foodstuff due to changes in taste, aroma and/or colour. This can be done by using both sensory analysis and chemical-analytical tests (e.g. GC-MS profiling, electronic nose technology) for which established standards are in place. For technological support in sensory incoming inspections of packaging materials, you can always contact SENSTECH (Flemish Advice Centre for Sensory Quality of Food Products and Food Contact Materials). In principle, already approved food packaging materials should be sufficient.

ISO 13302:2003 Sensory analysis – Methods for assessing modifications to the flavour of foodstuffs due to packaging

European Standard DIN EN 1230-1 (2010): Paper and board intended to come into contact with foodstuffs - Sensory analysis - Part 1: Odour

European Standard DIN EN 1230-2 (2010) Paper and board intended to come into contact with foodstuffs - Sensory analysis - Part 2: Off-flavour (taint)

8.2 INFORMATION / LABELLING

https://www.health.belgium.be/nl/voeding/informatie-voor-de-consumenten/etiketttering/wat-moet-en-mag-op-de-etikettering-staan

In a nutshell:

- front size of at least 1.2 mm
- correct legal name
- list of ingredients
- allergens
- quantitative indication of ingredients
- net quantity
- best-before date and use-by date
- storage requirements and conditions of use
- (trading) name and address of the operator
- country of origin and place of origin of the end product and the insects (if different, state both)
- additional mandatory entries:
    - e.g.: date of 1st freezing, packaged in a protective atmosphere, etc.

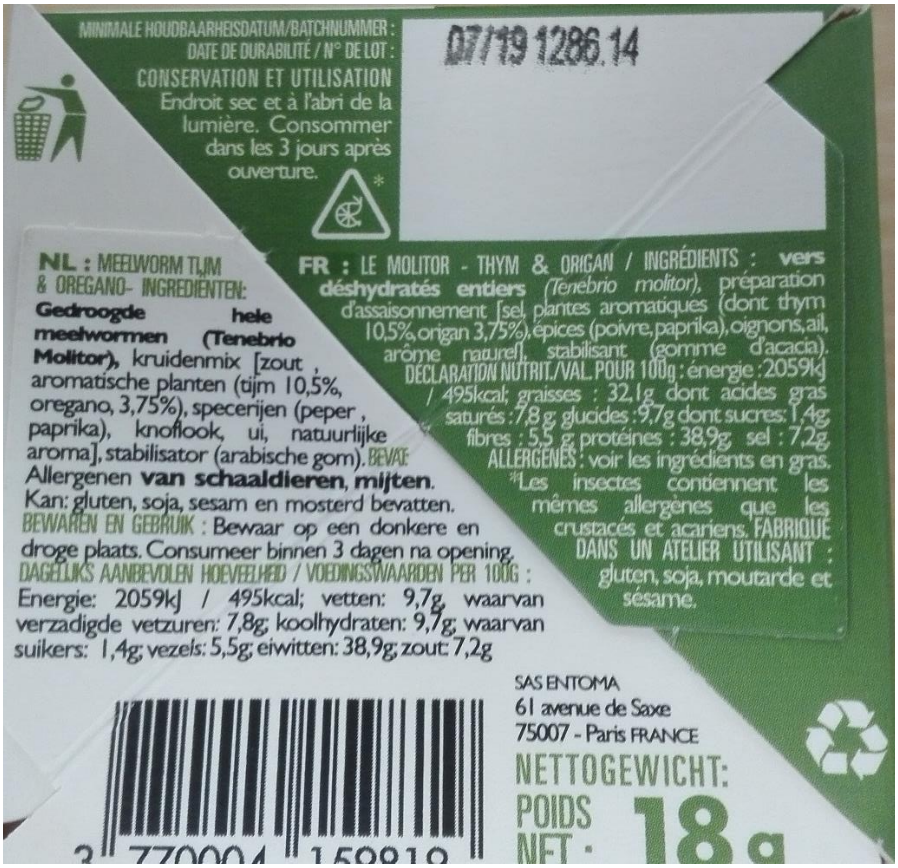


Figure 33: packaging Le Molitor by Jiminis (VIVES, 2020)

9 BUSINESS OPERATION - LABOUR

9.1 OCCUPATIONAL SAFETY

9.1.1 Allergens

An often underestimated problem in industrial insect rearing is the massive release of dust during sieving and feeding. This dust consists of various particles, such as feed (e.g. meal), manure and dander. Dust, and especially particulate matter, is not healthy to work in for a long time. In addition, these particles can contain proteins that can cause an allergic reaction. An allergic reaction is an overreaction of the immune system to a xenobiotic substance, such as a pollen allergy. In the case of insects, this can result, among other things, in itchy eyes, headache, shortness of breath (asthma), skin irritation or even allergic reactions after eating insects.

There are two main sources of allergens in mealworm rearing. On the one hand, the feeding of meal may induce a wheat allergy such as that experienced by bakers. On the other hand, insects themselves can also cause a specific allergy in farmers. This is of particular importance for people who already have a shellfish or dust mite allergy, since scientific research has already shown possible 'cross-sensitisation'. This means that people who are allergic to shellfish or dust mite may be more susceptible to an allergic reaction after eating mealworms.

Exposure to grasshoppers can also be a very strong trigger for developing inhalation allergies, both to the faeces (dust, dry aerosols!) and to the insects themselves (very mobile), or skin irritations. Furthermore, an inhalation allergy to the feed (grasses) may also occur (rather rarely).

Therefore, in order to be able to rear insects for a long period of time and to reduce the risk of susceptibility to allergies, it is necessary to protect oneself. We recommend adjusting the work method used for sieving/cleaning in order to release less dust into the air (avoid pouring it from a height) and/or applying local exhaust ventilation. This zone can also be demarcated more in order to limit the spreading of dust to other workplaces. Using compressed air and dry sweeping are best avoided. Vacuuming or wet cleaning is recommended. To reduce the risk of allergy development, you should avoid any other type of exposure (e.g. skin contact, contamination of office spaces as a result of exposed clothing). We recommend wearing long sleeves (ideally a type 5 safety suit) during work as well as gloves in order to limit skin absorption (or better said: skin contact). After use, you should carefully remove the safety suit inside out (do not clean clothing with compressed air). It is best to store this safety suit in a separate room. Clothing exposed to the insects (e.g. lab coat) should preferably not be worn in the offices (long-term exposure).

Even when there is sufficient ventilation, you will still need to wear personal protective equipment, especially if you work in rooms where a lot of dust is produced. There are various systems you can use to protect yourself. The most simple option is the regular mouth mask. Make sure to use the FFP3 variant (99 % filtration). However, according to both IDEWE and Professor Jeroen Vanoirbeek, these are not the best masks. On the one hand, they are not very comfortable to wear for a longer period of time. On the other hand, the way these masks fit snugly against the sides of the face is decisive for their efficiency. If they do not fit snugly (e.g. due to a beard) this will result in low filtration efficiency, which can create a false sense of security. This is also evident from personal experience, where two allergy sufferers were not helped by using such a mask. Another option is the full face mask. Ambient air is sucked in via a portable motor unit and filtered, after which the air is blown into the mask. Experience shows that this system is much more comfortable for employees. This system also appears to help the two allergic trial subjects. However, the disadvantage is that this system is about 200 times more expensive than a mouth mask. On the other hand, it is reusable. This system (Versaflo TR-315E+ motor unit + M-106 helmet) is currently being used at Inagro in combination with a suit (Ansell overall 2000) and gloves.

Recommendations:

1) Try to avoid the formation of dust and aerosols of dust as much as possible.
2) Try to concentrate and isolate as much as possible any dust producing processes.
3) Provide adequate extraction in the room. Internal filtration does not give good results.
4) Provide adequate personal protective equipment, preferably full face mask + suit.

9.1.2 Air purification (filtration)

9.1.2.1 General ventilation

In addition to ventilation in the rearing rooms, it is best to also provide general ventilation in the other rooms. It is best to keep the rooms to be ventilated (e.g. sieving room) as small as possible. In small rooms it is strongly recommended to wear an appropriate mask etc. Because of the small space you will otherwise create a place of extremely high exposure that can be hugely sensitising. The smallest possible space is needed to 1) optimise ventilation efficiency and 2) minimise the amount of air supplied. The latter is important in order to limit heat energy losses, especially in winter. Using a heat exchanger for this purpose seems difficult given the amount of dust.

9.1.2.2 Internal air purification

Internal air purification can take place by means of large ventilators that suck in the air present and purify it through (a series of) filters. Different systems are available for this.

A **HEPA filter air purifier** will physically remove particles from the air. However, there are many types of HEPA filters that stop between 85 % (E10) and 99.999995 % (U17) of the particles. Yet, it is unclear which filters are needed to stop allergens. In addition, the higher their efficiency, the more/much more expensive they are. A test also shows that these filters have to be changed quite regularly and therefore involve significant costs.

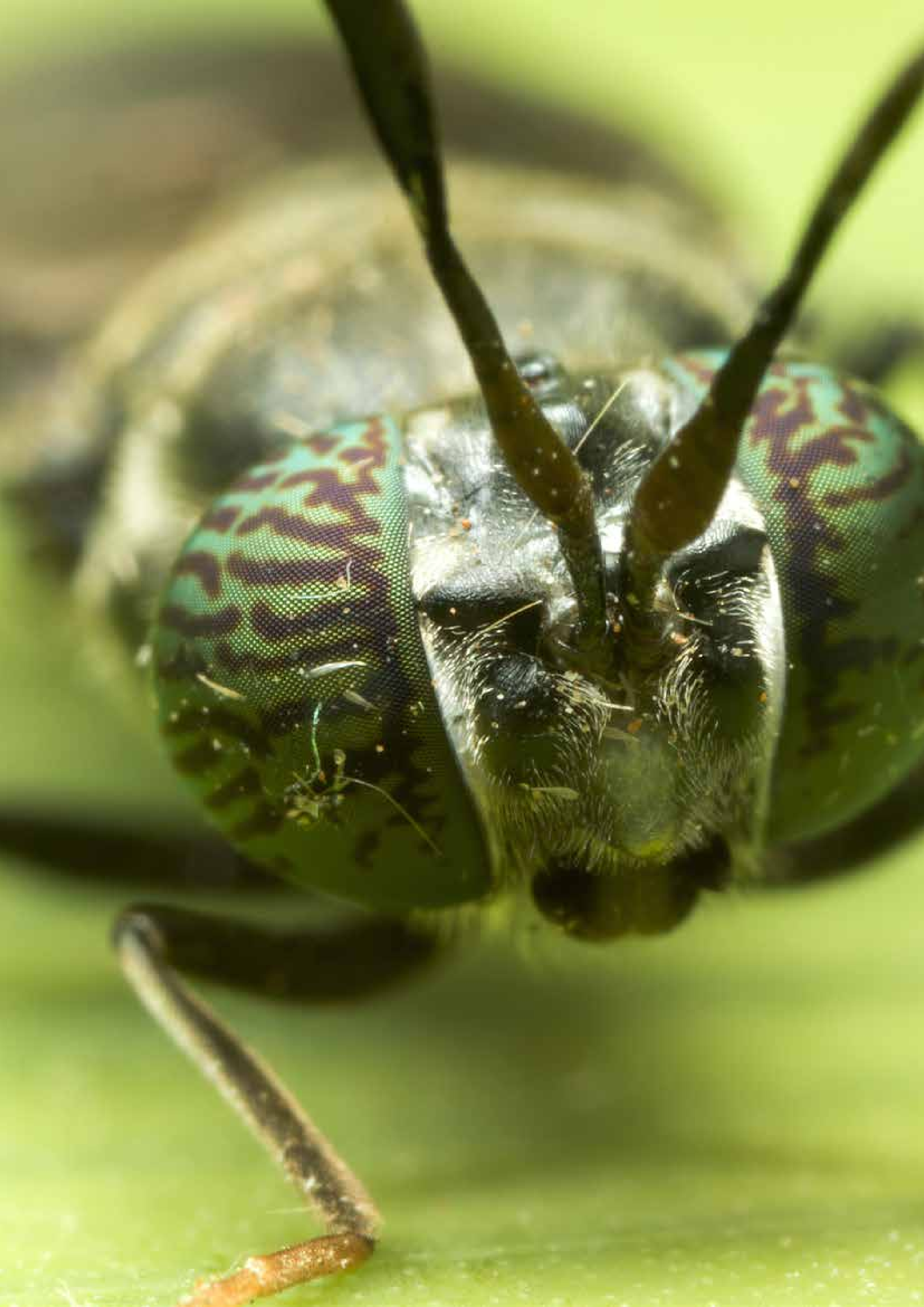
Ionisation filters work without a physical filter. The ionising radiation in the device gives the particles in the air an electric charge. The charged particles are then captured by the filter's blades or surfaces in the room (floor, walls, table, etc.), or the particles coagulate and drop from the air. Ionised allergens can still end up in the rearing room, but they will quickly disappear from the air. In theory, these ions should also help against odours, but a practical test shows that the ionisation filter has no effect on the odour in the rearing rooms.

Carbon filters are in principle only used to counteract odours and not to remove dust from the air. In the context of allergens, these filters are therefore not expected to have any effect.

9.2 HYGIENE

In order to avoid contamination during cultivation, the following guidelines are strongly recommended when entering the rearing rooms:

- provide a space before entering the rearing room where work overalls and other shoes or protective covers for the shoes can be put on
- limit access to the rearing rooms to strictly necessary visits
- wash your hands with soap.



10 BUSINESS OPERATION: REARING AND PROCESSING

10.1 PRECAUTIONARY PRINCIPLES

10.1.1 Food safety, risks (traceability, samples, etc.)

10.1.1.1 Food safety

See Chapter 3.2 (Feed hygiene), 4.3 (Rearing hygiene) and 8.3 (Processing hygiene).

10.1.1.2 Traceability

Identification by means of batch numbers
The use of batch numbers on the rearing containers is interesting for both rearing and reproduction. Adding a batch number is an easy way to identify the rearing containers. It makes it easy to monitor the rearing process in logbooks (see Chapter 14: Annex). By giving the batch numbers a date, you can immediately see how old the animals are. This is necessary, for example, to remove the oldest animals (beetles in oviposition containers).

A batch number can be written as: "Life stage - date in rearing container".

Recording by means of a logbook
A logbook can be interesting for recording all kinds of things. A logbook can help you plan the activities, as well as determine and document the larval yield. As a farmer, you can draw up the logbook according to your own experience, with the data you want to document.

In addition, keeping an IN and OUT register is required by law (see Chapter 14: Annex). The quantity of feed purchased is entered in the IN register. The OUT register shows the amount of insects harvested. A logbook of the feed given per batch number must be kept as well. The tables below show a sample logbook of mealworm rearing, where the larvae originate from an external company or from the farm's own reproduction.

Practical measures by means of stickers
In addition to the logbook and the use of batch numbers, a sticker can be affixed to the rearing container. This sticker contains information on which actions should be carried out during the rearing period and when. By filling in the dates in advance and affixing them to the rearing container, you do not have to consult the logbook each time to find out exactly what you need to do on a specific day, but you can work quickly and practically.

It is interesting to affix stickers of different colours to the oviposition containers when reproduction also takes place at the farm. That way you will know, after having removed the beetles, which larvae container you need to place with reproduction and which mealworms are intended for rearing.
Alternatively, traceable containers (e.g. RID system) can be used.

10.1.2 Pathogens, toxins, heavy metals

In order to limit pathogen risks, please refer to the previous hygiene regulations.

Due to the current legal restrictions on the feed that can be given to insects, the risks of toxins and heavy metals are fairly limited. Research shows, however, that each insect species has a specific sensitivity to the potential accumulation of pathogens, toxins and heavy metals, which can cause the imposed limits to be exceeded after all. For example, **mealworms** can accumulate arsenic, but this was not observed for cadmium and lead. In contrast, **black soldier fly larvae** can accumulate cadmium and, to a lesser extent, lead, copper and zinc (the latter two are essential minerals, but in excessive quantities they fall into the category of heavy metals). For **crickets** and **grasshoppers** several studies have been performed into heavy metals, originating from contaminated sites or exposed to enriched diets. Exposure to high levels in the environment led to elevated levels of lead, cadmium and mercury. **Migratory locusts** in particular have been shown to be able to accumulate copper and cadmium from feed.
For the time being, there is no evidence that the 4 insects included in this guide accumulate (myco)toxins. There are indications, however, that certain pesticides may accumulate.
During the Entomospeed project, research (including a summary of scientific literature) was carried out into the effects and potential accumulation of heavy metals, mycotoxins and pesticides in mealworms and black soldier fly larvae:
https://leden.inagro.be/Portals/484/Algemeen_effecten%20van%20mycotoxinen%20en%20insecticiden_HAS.pdf
If you decide to use legally permitted waste streams as feed, it can be important to analyse both the feed and the harvestable larvae for the presence of heavy metals, common pesticides and toxins.

10.2 ENERGY MANAGEMENT

Edible insects are often cultivated in warm conditions in order to achieve the best possible rearing process. However, it is important to remember that these insects themselves produce a lot of heat in the later larval stages. A rearing room full of nearly harvestable mealworms or black soldier fly larvae should even be adequately ventilated because the temperature reaches suboptimal limits. So, on the one hand, it is heated, and on the other hand, it is ventilated. Both processes require a lot of energy. In the ideal insect farm, this heat is recovered to heat the rearing rooms where the parent animals and young larvae are present. A deliberate choice can also be made to establish a production unit next to a company that produces residual heat.

In addition to recovering heat by means of heat exchangers, you can also use renewable energy (solar panels and collectors) to save on primary energy and reduce greenhouse gas emissions from the use of fossil fuels.

Processing insects into e.g. paste, meal or pellets and insect-based biorefinery can also be energy-intensive. Drying and pelletising in particular require a lot of energy and are, after climate control during rearing, very energy consuming.

10.3 EMISSION CONTROL

For purposes of ecological sustainability, it is necessary to limit and, to the extent possible, even avoid harmful emissions (primarily ammonia, methane, sometimes also particulate matter, and to a lesser extent nitrous oxide). Emissions are linked to the rearing conditions such as temperature, humidity and oxygen content (aerobic or anaerobic) of the insect species and the life stage, the activity of the insects, and the substrate in which they are being reared. It is advisable to measure or estimate direct emissions during rearing using mass balances (e.g. of incoming and outgoing nitrogen quantities). In addition to harmful emissions, nuisance emissions such as odours should also be limited. Chapter 10.1.1 (Allergens) discusses particulate matter emissions in more detail.

- Direct emissions should be avoided whenever possible. How to do so depends on the specific emissions and the requirements for feed and rearing conditions (temperature, humidity, density).
- Efficient feeding regimes and compositions can help reduce, for example, the formation of ammonia during black soldier fly larvae rearing by lowering the protein content of the feed to the minimum protein level needed by the larvae.
- Direct emissions which you cannot prevent are preferably captured and neutralised, e.g. by scrubbers.
- Indirect emissions from transport can be limited by opting for a short chain whenever possible. Just think of the transport kilometres linked to the purchase of feed, the processing location and the place of marketing.

The **limit value** for long-term human exposure to **CO_2** is **900 ppm**. The limit value for **ammonia is much lower: 20 ppm for long-term exposure, 50 ppm for acute exposure**. In addition, odour and particulate matter can also pose a problem in large-scale insect rearing. Ammonia emissions and odour nuisance are particularly prevalent in black soldier fly larvae rearing. This is mainly due to the substrate on which these larvae are reared. Odour problems can be solved with adequate ventilation, although care should be taken so as not to encourage other emissions such as ammonia emissions (the so-called stripping effect). Problems with ammonia emissions and to a lesser extent odour problems can be solved by using scrubbers (preferably biological scrubbers).

11 ANIMAL WELFARE

11.1 DO INSECTS FALL WITHIN THE SCOPE OF ANIMAL WELFARE?

11.1.1 Legal view

According to the Belgian Civil Code, animals do have feelings. Following the 4 February 2020 amendment, *animals* have been included as a separate category alongside *people* and *goods*. This is so stated in the Act containing Book 3 "Goods" of the Civil Code, Chapter 2 Quality Accounts; Title 2 Classification of Goods; Subtitle 1 General Categories: Art. 3.39. Animals: *Animals have sentience and biological needs. The provisions relating to physical objects shall apply to animals, subject to the legal and regulatory provisions for the protection of animals and the public order.*

The Act was amended following the European Treaty of Lisbon, which defines animals kept and used by humans as sentient beings. This treaty was ratified by Germany, Switzerland, France and Greece, among others (Pali - Schöll et al., 2019). In European law, Article 13 of the Treaty on the Functioning of the European Union states that animals are not machines, according to Cartesian thinking, but creatures that can suffer, experience pain and express feelings. Through this amendment as well as the Criminal Code, and in accordance with Belgian law, *the protection and welfare of animals* (Act of 14 August 1986) applies. *Animal welfare* has been a regional competence in Belgium since 2014. In 2018, the Brussels-Capital Region and the Walloon Region already stated that animals are sentient beings. Up till now, 19 February 2021, the Flemish Region has not followed this example and has not yet distinguished animals from goods. In the Commission for Brussels and the Vlaamse Rand and Animal Welfare, the then Minister for Animal Welfare, Ben Weyts, clarified this decision. He would first like to know the full impact of this decision.

In Belgian law no distinction is made between vertebrates and invertebrates, such as insects. In the explanatory notes to the bill sent to the Belgian Chamber of Representatives (DOC 55 0445/001 of 24 September 2019) that led to the amendment of 4 February 2020, 'animals' is understood to mean farmed animals, dogs, cats, rabbits, fish and pigeons. No further specification is made, however, as to what is to be understood by 'farmed animals'. Invertebrates such as insects are therefore not excluded *de facto* from this category. Directive 98/58/EC of 20 July 1998, on the other hand, which offers some protection to animals kept for farming purposes, does provide further specification. It excludes all invertebrate animals from the animal welfare rules. In doing so, it goes against the scientific opinion of EFSA (Pali - Schöll et al., 2019) (https://www.efsa.europa.eu/en/efsajournal/pub/4257). In addition, all previous European regulations adopted nationally, such as the general Royal Decree of 1 March 2000 on keeping farmed animals and the regulations on transport and killing, only apply to vertebrate animals and therefore not to insects.

At the national level, insects are clearly included in the General Act of 14 August 1986 on animal welfare and protection. This Act discusses animals, with the exception of the articles dealing with experimental animals, the killing of animals and the authorised interventions. This means that the remainder of the Act does apply to insects. They must be well cared for and their natural needs must be met. However, no specific standards are included and no rules on killing have been specified (Department of Environment and Spatial Development of the Flemish administration, animal welfare unit).

11.1.2 Biological - philosophical view

In the mid-60s, Ruth Harrison's book 'Animal Machines' denounced the way in which farmed animals were treated in industrial context. In response to the ensuing discussion, the British Government set up the so-called Brambell Committee. In its report to the British Government in 1965, this committee provided an initial impulse for the five freedoms of animal welfare drawn up by the Farm Animal Welfare Council in 1993. These freedoms were to constitute the preconditions for the way in which domestic animals are generally treated. Today, this list is even referred to when, for example, the welfare of zoo animals is under discussion. The five freedoms are:

1. Freedom from hunger and thirst
2. Freedom from discomfort
3. Freedom from from pain, injury or disease
4. Freedom to express normal behaviour
5. Freedom from fear or distress

Health or physical well-being (Duncan, 1977) was sometimes also regarded as welfare (Appleby, 1999). Today, however, a distinction is made. Health is said to focus rather on the physical condition of the animal, whereas the psychological aspects tell us something about its welfare (Wiepkema, 1997).

In the mid-60s, it was not assumed, like in Descartes' view, that farmed animals could feel pain (Appleby, 1999). Today, it is doubted whether insects can feel pain, let alone have any kind of well-being or feelings. Before the five freedoms can be applied to insect rearing, consensus should first be reached on this. This could be checked on the basis of an animal's subjective feeling, its normal biological functioning or the different behaviours it displays (Duncan & Fraser, 1997). Subjective feeling also implies that the animal can suffer and avoid a similar, negative situation in the future. This is, however, difficult to measure. Normal biological functioning is easier to measure, as any behaviour that is abnormal is considered to be a sign of negative welfare. However, it should be taken into account that animals do not immediately show abnormal behaviour when their welfare is being compromised (de Jong, 2000). Thirdly, the animal's ability to express its different behaviours can be assessed. To do so, the animal must be in an environment that allows it to express these behaviours. This environment can approximate to its natural biotope (Webster et al., 1986), but Broom (1993) points out that an animal is able to adapt to its environment. Examples are *urban wildlife* or seagulls that breed on the roofs of apartment buildings and sometimes never see the sea again. Animals sometimes express behaviour only in order to survive, as a life-or-death response (Poole, 1996).

First of all, the discussion should distinguish between the capacity to respond to potentially damaging stimuli from pain receptors or nociceptors, on the one hand, and the subjective or actual sensation of pain, on the other (Allen, 2004, 2011). The former is widespread in the animal kingdom. Insects will move away from an environment that contains extreme conditions for them or damages their tissue (e.g. Johnson & Carder, 2012). In Dutch, this is also described as a reflex. But a reflex is not necessarily pain. Pain tends to have this subjective co-optation of unease (e.g. Allen et al., 2005). Nociception may be dissociated from actual pain perception (Hardcastle, 1997). When a person is given morphine, they can still feel pain, but this is not accompanied by suffering or other behaviour which is typical of pain, such as crying out in pain. Likewise, an insect that has lost a leg can be said to have no pain or even to lack self-awareness because it continues to walk. Yet, this may equally be the insect's ability to cope with pain and to continue to survive (Eisemann et al., 1984). Again, no abnormal behaviour is expressed and no abnormality can be detected. For humans, it is difficult to perceive this subjective part of feeling pain in animals or insects (Allen, 2011; Allen et al., 2005, Sherwin, 2011; Shriver, 2006). This is why it is one of the most discussed topics among scientists (Allen, 2011; Merker, 2007; Reggia, 2013). We cannot decide whether or not an animal feels pain without first answering a number of questions (Adamo, 2016). One of these questions is whether an animal has to be self-aware to feel pain? Or what connections should definitely be made with the central nervous system to be able to assign an emotional experience to pain? The anatomy of the nervous system and evolutionary development between species play a role here and will be discussed below. There are some anchor points, however, for assessing whether an insect feels pain.

There is the *argument-by-analogy* (Allen et al., 2005; Sherwin, 2001; Shriver, 2006). This principle assumes that if two organisms have the same physiological and behavioural responses to a stimulus, then they must also experience this stimulus in the same way. The human being is taken as one of these two organisms. After all, we know best how humans experience pain. Still, this way of thinking would not hold true in the comparison between humans and insects (Allen, 2011). Among other things, the nervous systems of humans and insects differ too much (Bullock et al, 1977). Still, when applying an evolutionary perspective to the nervous system, the *argument-by-analogy* method would hold (e.g. Sherwin, 2001). The so-called neural circuits and tissues, or the part of the nervous system that has to do with self-awareness, behaviour and decision-making, can be found early on in the evolution, even in invertebrates such as insects and cephalopod molluscs like cuttlefish (Low, et al., 2012). In this sense, there is a presumption of awareness, well-being or welfare. This evolution of the brain remains separate from the individual development of the memory or the learning process. In most insect species, however, a learning process can indeed be observed. In other words, after having felt pain, an adjustment in behaviour can mostly be observed.

11.2 POSSIBLE IMPACT OF ANIMAL WELFARE ON INSECT REARING

11.2.1 Introduction

In view of the animal welfare standards for farmed animals, attention should be paid to animal welfare for insects in at least three areas: on-farm or during the rearing process itself, during transport and at the time of killing or slaughter.

11.2.2 On-farm welfare

The five freedoms provide a framework for describing animal welfare. In a review article by Arnold van Huis (2020), insect rearing is also considered against the background of the five freedoms of animal welfare. This article contains more details on this matter.

1. **Freedom from hunger and thirst**

To keep production animals in optimal condition, healthy and lively, they are always given feed and water. This does not automatically mean, however, that the species-specific conditions are met as well

(Erens et al., 2012). In order to obtain the desired end product from these insects, the optimal environmental conditions or conditions in terms of diet and density for specific species can be deviated from.

In addition, it is sometimes recommended to fast insects just before harvesting. As a result, less manure is sold. However, this does not appear to be necessary in terms of food safety (Wynants et al., 2017).

2. Freedom from discomfort

This can be achieved by rearing them or keeping them for production in an environment with an optimal climate where the insects can move freely to interact socially or to reproduce (e.g. laying eggs), or where they have several options to hide. In this way, they can escape potentially negative situations and end up in a more positive environment.

However, as with other farmed animals, insects are kept in higher concentrations than the densities in which they occur in nature (Boppré et aL, 2019). Since they develop metabolic heat and the ideal ambient heat spreads out over a narrow band, it is important to be able to control the conditions in commercial settings.

3. Freedom from pain, injury or disease

Not much is known yet about diseases in insects, except for honey bees *(Apis mellifera*) and silkworms *(Bombix mori*). The first major European projects around insect diseases started in 2020.

Furthermore, in industrial insect rearing, attention can be paid to pain or injury during automation (e.g. sieving), avoidance of cannibalism and killing during slaughter. The latter does not necessarily occur on-farm.

4. Freedom to express normal behaviour

For insects to be able to express normal behaviour, they must be in an environment where they can express this normal behaviour. This environment can approximate to their natural biotope. Still, in an industrial setting, it is also possible to create an environment that allows insects to adapt and still express several of their behaviours.

5. Freedom from fear or distress

As mentioned earlier, it is not easy to measure the subjective sensation of physical or psychological discomfort in animals.

11.2.3 Transport

The existing legislation on animal transport applies only to vertebrates and therefore not to insects.

When transporting live insects with consideration of their welfare, this transport will have to take place under the same optimal environmental conditions (abiotic conditions) (van Huis, 2020) as during rearing.

11.2.4 Slaughter or killing of insects

As of 1 January 2019, it is prohibited in Flanders to kill a vertebrate animal without prior stunning. This description is also found as such in European Regulation 1099/2009 on the protection of animals at the time of killing. However, this regulation does not apply to invertebrates or insects.

For the sake of caution, it may be assumed that invertebrates are self-aware and can feel pain, which means they must also be slaughtered in a humane manner. In a report commissioned by the Dutch Ministry of Economic Affairs, Hakma, Peters and van Huis also devoted a chapter to killing. They concluded that freezing, heating by boiling or blanching and grinding can in any case be considered as suitable methods for killing insects. 'Suitable' means economically suitable, as well as simple to use and fast-working. The latter two properties should promote painless killing.

12 REFERENCES

Adamo, S. A. (2016). Do insects feel pain? A question at the intersection of animal behaviour, philosophy and robotics. *Animal Behaviour, 118*, 75-79

Aidos, I., Kreb, N., Boonman, M., Luten, J. B., Boom, R. M., & Van Der Padt, A. (2003). Influence of production process parameters on fish oil quality in a pilot plant. *Journal of food science*, *68*(2), 581-586.

Allen, C., Fuchs, P. N., Shriver, A., & Wilson, H. D. (2005). Deciphering animal pain. In M. Aydede (Red.), Pain: new essays on its nature and the methodology of its study (pp. 351-366). Cambridge: MIT Press.

Anticimex (2019)a. *meelmotten bestrijden.* [Online]
Available at: Voorraadmotten bestrijden in opslagruimte - Anticimex

Anticimex (2019)b. *Spekkever bestrijden.* [Online]
Available at: Soorten kevers | De spekkever bestrijden - Anticimex

Appleby, M. C. (1999). What should we do about animal welfare? Edinburgh: Blackwell Science Ltd.

Berggen et al (2019). Approaching Ecological Sustainability in the Emerging Insects-as-Food Industry. Trends in Ecology and Evolution.

Boppré, M., & Vane - Wright, R.I. (2019). Welfare dilemmas created by keeping insects in captivity. In: Carere, C. and Mather, J.. The welfare of invertebrate animals. Springer International Publishing, Cham, Switserland, pp. 23 - 67.

Broom, D. M., & Johnson, K. G. (1993). Stress and animal welfare. Londan: Chapman & Hall.
Bullock, T. H., Orkand, R., & Grinnel, A. (1977). Introduction to nervous systems. San Francisco: W.H. Freeman.

Bußler, S., Rumpold, B. A., Jander, E., Rawel, H. M., & Schlüter, O. K. (2016). Recovery and techno-functionality of flours and proteins from two edible insect species: Meal worm (*Tenebrio molitor*) and black soldier fly (*Hermetia illucens*) larvae. *Heliyon*, *2*(12), e00218.

Caligiani, A., Marseglia, A., Leni, G., Baldassarre, S., Maistrello, L., Dossena, A., & Sforza, S. (2018). Composition of black soldier fly prepupae and systematic approaches for extraction and fractionation of proteins, lipids and chitin. *Food Research International*, *105*, 812-820.

Caparros Megido, R., Desmedt, S., Blecker, C., Béra, F., Haubruge, É., Alabi, T., & Francis, F. (2017). Microbiological load of edible insects found in Belgium. *Insects*, *8*(1), 12.

Capinera, J. L. (Ed.). (2008). *Encyclopedia of entomology*. Springer Science & Business Media.

Choi, B. D., Wong, N. A., & Auh, J. H. (2017). Defatting and sonication enhances protein extraction from edible insects. *Korean journal for food science of animal resources*, *37*(6), 955.

de Jong, I. C. (2000). Chronic stress parameters. Indicators of animal welfare? Groningen: Rijksuniversiteit Groningen.

De Smet, J., Lenaerts, S., Borremans, A., Scholliers, J., Van Der Borght, M., & Van Campenhout, L. (2019). Stability assessment and laboratory scale fermentation of pastes produced on a pilot scale from mealworms (*Tenebrio molitor*). *LWT*, *102*, 113-121.

Duncan, I. J. (1977). Behavioural wisdom lost. *Applied Animal Ethology, 3,* 193-194.

Duncan, I. J., & Fraser, D. (1997). Understanding animal welfare. In M. C. Appleby, & B. O. Hughes, Animal Welfare (pp. 19-31). Wallingford: C.A.B. International.

Eisemann, C. H., Jorgensen, W. K., Merritt, D. J., Rice, M. J., Cribb, B. W., & Webb, P. D. (1984). Do insects feel pain? A biological view. *Experientia, 40,* 164-167.

Erens, J., van Es, S., Haverkort, F., Kapsomenou, E., & Luijben, A. (2012). A bug's life: large-scale insct rearing in relation to animal welfare. Wageningen, the Netherlands: Wageningen University & Research.

Hakman, A., Peters, M., & van Huis, A. (2013). Toelatingsprocedure voor insecten als mini - vee. Laboratorium voor Entomologie. Wageningen: Wageningen Universiteit, pp 37.
Halloran et al (2016): Life cycle assessment of edible insects for food protein: a review. National Library of Medicine.

Hardcastle, V. G. (1997). When a pain is not. *Journal of Philosophy, 94*, 381-409.

Jaenen, A. (2019). Mijten, een plaag in onze insektenkweken. *Lacerta, 51 (2)*, 52-55.

Johnson, W. A., & Carder, J. W. (2012). Drosophila nociceptors mediate larval aversion to dry surface environments utilizing both the painless TRP channel and the DEG/ENaC subunit, PPK1. *Plos One, 7*, e322878

KAD (2019). *Meelmijt.* [Online]
Available at: https://www.kad.nl/kennisbank/dierplagen/mijten/meelmijt/

KAD (2020). *Khaprakever.* [Online]
Available at: https://www.kad.nl/kennisbank/dierplagen/kevers/tapijt-en-spekkevers/khaprakever/

Kashiri, M., Marin, C., Garzón, R., Rosell, C. M., Rodrigo, D., & Martínez, A. (2018). Use of high hydrostatic pressure to inactivate natural contaminating microorganisms and inoculated *E. coli* O157: H7 on *Hermetia illucens* larvae. *PloS one*, *13*(3), e0194477.

Kingsolver, J. M. (1999). Dermestid beetles. In: *Insect and mite pests in food*, 115-136.

Leni, G., Soetemans, L., Jacobs, J., Depraetere, S., Gianotten, N., Bastiaens, L., ... & Sforza, S. (2020). Protein hydrolysates from *Alphitobius diaperinus* and *Hermetia illucens* larvae treated with commercial proteases. *Journal of Insects as Food and Feed*, *6*(4), 393-404.

Low, P., Panksepp, J., Reiss, D., Edelman, D., Van Swinderen, B., & Koch, C. (2012). The Cambridge Declaration on Consciousness. Churchill College: University of Cambridge.

Merker, B. (2007). Consciousness without a cerebral cortex: a challenge for neuroscience and medicine. *Behavioral and Brain Science, 30*, 63-81.

Mishyna, M., Martinez, J. J. I., Chen, J., & Benjamin, O. (2019). Extraction, characterization and functional properties of soluble proteins from edible grasshopper (*Schistocerca gregaria*) and honey bee (*Apis mellifera*). *Food Research International*, *116*, 697-706.

Ndiritu, A. K., Kinyuru, J. N., Kenji, G. M., & Gichuhi, P. N. (2017). Extraction technique influences the physico-chemical characteristics and functional properties of edible crickets (*Acheta domesticus*) protein concentrate. *Journal of Food Measurement and Characterization*, *11*(4), 2013-2021.

Nongonierma, A. B., & FitzGerald, R. J. (2017). Unlocking the biological potential of proteins from edible insects through enzymatic hydrolysis: A review. *Innovative Food Science & Emerging Technologies*, *43*, 239-252.

Purschke, B., Brüggen, H., Scheibelberger, R., & Jäger, H. (2018). Effect of pre-treatment and drying method on physico-chemical properties and dry fractionation behaviour of mealworm larvae (*Tenebrio molitor* L.). *European Food Research and Technology*, *244*(2), 269-280.

Purschke, B., Tanzmeister, H., Meinlschmidt, P., Baumgartner, S., Lauter, K., & Jäger, H. (2018). Recovery of soluble proteins from migratory locust (*Locusta migratoria*) and characterisation of their compositional and techno-functional properties. *Food Research International*, *106*, 271-279.

Reggia, J. A. (2013). The rise of machine consciousness: studying consciousness with computational models. *Neural Networks, 44*, 112-131.

Reineke, K., Mathys, A., Heinz, V., & Knorr, D. (2013). Mechanisms of endospore inactivation under high pressure. *Trends in microbiology*, *21*(6), 296-304.

Sherwin, C. M. (2001). Can invertebrates suffer? Or, how robust is argument-by-analogy. *Animal Welfare, 10*, 103-118.

Shriver, A. (2006). Minding mammals. Philosophical Psychology, 19, 433-442.

Smetana, S., Larki, N. A., Pernutz, C., Franke, K., Bindrich, U., Toepfl, S., & Heinz, V. (2018). Structure design of insect-based meat analogs with high-moisture extrusion. *Journal of Food Engineering*, *229*, 83-85.

Soetemans, L., Uyttebroek, M., D'Hondt, E., & Bastiaens, L. (2019). Use of organic acids to improve fractionation of the black soldier fly larvae juice into lipid-and protein-enriched fractions. *European Food Research and Technology*, *245*(10), 2257-2267.

Stegeman, D., Janssen, A. M., Helsper, J. P. F. G., Van der Meer, I. M., & Van Kernebeek, H. R. J. (2010). *Technologie en grondstoffen voor vleesvervangers en hoogwaardige eiwitten* (No. 1179). Wageningen UR-Food & Biobased Research.

Szelei, J., Woodring, J., Goettel, M. S., Duke, G., Jousset, F. X., Liu, K. Y., ... & Tijssen, P. (2011). Susceptibility of North-American and European crickets to Acheta domesticus densovirus (AdDNV) and associated epizootics. *Journal of invertebrate pathology*, *106*(3), 394-399.

Tzompa-Sosa, D. A., Yi, L., van Valenberg, H. J., van Boekel, M. A., & Lakemond, C. M. (2014). Insect lipid profile: aqueous versus organic solvent-based extraction methods. *Food Research International*, *62*, 1087-1094.

van der Fels-Klerx, H. J., Camenzuli, L., Belluco, S., Meijer, N., & Ricci, A. (2018). Food safety issues related to uses of insects for feeds and foods. *Comprehensive Reviews in Food Science and Food Safety*, *17*(5), 1172-1183.

van Huis, A. (2020). Welfare of farmed insects. Journal of Insects as Food and Feed - Special issue: Advancement of insects as food and feed in a circular economy, Wageningen Academic Publishers.

Vandeweyer, D., Lenaerts, S., Callens, A., & Van Campenhout, L. (2017). Effect of blanching followed by refrigerated storage or industrial microwave drying on the microbial load of yellow mealworm larvae (Tenebrio molitor). *Food Control*, *71*, 311-314.

Webster, J., Saville, C., & Welchman, D. (1986). Improved husbandry systems for veal calves. London, UK: Farm Animal Care Trust.

Weisman, D. M. (1999). Larval Moths. In: *Insect and mite pests in food.* Baltimore: National Agricultural Library, 245-268.

Weissman, D. B., Gray, D. A., Pham, H. T., & Tijssen, P. (2012). Billions and billions sold: pet-feeder crickets (Orthoptera: Gryllidae), commercial cricket farms, an epizootic densovirus, and government regulations make for a potential disaster. *Zootaxa*, *3504*(1175-5326), 67-88.

Wiepkema, P. R. (1997). The Emotional Vertebrate. In M. Dol, S. Kasanmoentalib, S. Lijmbacg, E. Rivas, & R. van de Bos, Animal Consciousness and Animal Ethics. Perspectives from the Netherlands

Woodgate, S., & Van Der Veen, J. (2004). The role of fat processing and rendering in the European Union animal production industry. *BASE*.

Wynants, E., Crauwels, S., Lievens, B., Luca, S., Claes, J., Borremans, A., ... & Van Campenhout, L. (2017). Effect of post-harvest starvation and rinsing on the microbial numbers and the bacterial community composition of mealworm larvae (Tenebrio molitor). *Innovative food science & emerging technologies*, *42*, 8-15.

Wynants, E., Crauwels, S., Verreth, C., Gianotten, N., Lievens, B., Claes, J., & Van Campenhout, L. (2018). Microbial dynamics during production of lesser mealworms (Alphitobius diaperinus) for human consumption at industrial scale. *Food Microbiology*, *70*, 181-191.

Yi, L., Lakemond, C. M., Sagis, L. M., Eisner-Schadler, V., van Huis, A., & van Boekel, M. A. (2013). Extraction and characterisation of protein fractions from five insect species. *Food chemistry*, *141*(4), 3341-3348.

13 ANNEX: BLANK LOGBOOKS

Logbook IN: purchase of feed					
Delivery date	Supplier	Supplier address	Type	Quantity	Batch number

Figure 36: logbook IN: Purchase of feed

Feed logbook			
Batch number	**Date feed in**	**Type of feed**	**Quantity**

Figure 37: feed logbook

Logbook OUT: mealworms			
Larvae batch number	**Quantity**	**Date**	**Customer**

Figure 38: logbook OUT: mealworms

Logbook for rearing mealworms from on-farm reproduction			
Larvae batch number	**Rearing start date**	**Activity**	**Date**
		Sieving off frass	
		Starving	
		Harvesting	
		Sieving off frass	
		Starving	
		Harvesting	
		Sieving off frass	
		Starving	
		Harvesting	
		Sieving off frass	
		Starving	
		Harvesting	
		Sieving off frass	
		Starving	
		Harvesting	
		Sieving off frass	
		Starving	
		Harvesting	
		Sieving off frass	
		Starving	
		Harvesting	

Figure 39: logbook for rearing mealworms from on-farm reproduction

Logbook for rearing mealworms from an external company				
Batch number	**Origin**	**Rearing start date**	**Activity**	**Date**
			Sieving off frass	
			Starving	
			Harvesting	
			Sieving off frass	
			Starving	
			Harvesting	
			Sieving off frass	
			Starving	
			Harvesting	
			Sieving off frass	
			Starving	
			Harvesting	
			Sieving off frass	
			Starving	
			Harvesting	
			Sieving off frass	
			Starving	
			Harvesting	
			Sieving off frass	
			Starving	
			Harvesting	
			Sieving off frass	
			Starving	
			Harvesting	

Figure 40: logbook for rearing mealworms from an external company