9. Processing edible insects for food and feed

9.1 DIFFERENT TYPES OF CONSUMABLE PRODUCT

After being wild-harvested or reared in a domesticated setting, insects are killed by freeze-drying, sun-drying or boiling. They can be processed and consumed in three ways: as whole insects; in ground or paste form; and as an extract of protein, fat or chitin for fortifying food and feed products. Insects are also fried live and consumed.

In countries where edible insects are traditionally eaten, food habits have shifted towards Western diets. To counter this, initiatives have been undertaken, for example, in Mexico, where tortillas are being enriched with yellow mealworm (Aguilar-Miranda *et al.*, 2002). This section gives examples of innovative projects that have developed promising edible insect products.

9.1.1 Whole insects

In tropical countries, insects are often consumed whole, but some insects, such as grasshoppers and locusts, require the removal of body parts (e.g. wings and legs). Depending on the dish, fresh insects can be further processed by roasting, frying or boiling. In the Lao People's Democratic Republic, among other countries, insects can be found in markets as ready-to-eat snacks or fried with lime leaves.

9.1.2 Granular or paste form

Grinding or milling is a common method for processing a large variety of foods. Soybeans, for example, are often transformed into tofu or other meat analogues. Meat is processed into products such as hamburgers and hot dogs, and fish into popular foods such as fish fingers. In much the same way, edible insects can also be processed into more palatable forms. They are often ground into paste or powder and added to otherwise low-protein foods to increase their nutritional value. An easy way to obtain powder is by drying and grinding the insects. In Thailand and the Lao People's Democratic Republic, chilli paste with crushed and ground giant waterbugs (*Lethocerus indicus*) is very popular as a main ingredient (and is known locally as jaew maeng da in the Lao People's Democratic Republic and nam phik in Thailand). The flavour of giant water bug is now reproduced artificially and is readily available. In societies where consumers are not accustomed to eating whole insects, granular or paste forms may be better accepted.

9.1.3 Extracted insect proteins

Western consumers may be reluctant to accept insects as a legitimate protein source because insects have never played a substantial role in their food culture. Extracting insect proteins for human food products – a process already being carried out – could be a useful way of increasing acceptability among wary consumers. In some cases, isolating and extracting insect protein is desirable to increase the protein content of a food product. However, supplementing food products with insects in such a way requires extensive knowledge of the properties of the extracted proteins. These properties include, among others, amino acid profile, thermal stability, solubility, gelling, foaming and emulsifying capacity. Separating extracted protein groups based on their solubility in solvents produces water-soluble and water-insoluble fractions, which can be used for specific applications in both the food and feed industries. Alternative methods are enzymatic processes to obtain proteins of specific chain lengths. Alternative methods for protein separation are fluidized bed chromatography and ultrafiltration.

At present, the cost of protein extraction is prohibitive. More research is required to further develop the process and to render it profitable and applicable for industry use. Wageningen University is conducting a programme on the sustainable production of insect proteins for human consumption (in the period 2010–2013) to further explore the possibility of extracting proteins from insects to fortify human foods. Under the project, dubbed Supro2, edible insects are reared on organic side streams, after which their proteins are separated, purified and characterized in order to tailor them for specific food products. Extracted insect proteins could also be considered in feed products, although the economic feasibility would need to be established.

9.1.4 Examples of promising edible insect products for human consumption

SOR-Mite (protein-enriched sorghum porridge)

The "developing solutions for developing countries" competition, organized by the Institute of Food Technologists, promotes the application of food science and technology and the development of new products and processes with the aim of improving the quality of life of people in developing countries. The first prize of the competition, awarded during the Annual Food Expo in Anaheim, United States, in June 2009, went to the SOR-Mite project, a sorghum mixture enriched with termites. The nutritionally weak grain, frequently consumed in many African countries, is low in proteins and fats and lacks several essential amino acids, such as lysine. For this reason, fortifying the grain with highly nutritious flying termites (*Macrotermes* species), easily gathered at the start of the rainy season, makes sense. The fermented mixture can be consumed as porridge at breakfast, lunch or dinner, depending on local preferences. Both raw materials are easily obtained locally (Institute of Food Technologists, 2011).

Termite crackers and muffins in Kenya

In the Lake Victoria region in East Africa, edible insects such as termites (Isoptera: Termitidae) and lake flies (Diptera, Chaoboridae, Chironomidae and Ephemeroptera) are abundant and provide important nutrition for both humans and livestock. Although their use is limited by their seasonal availability and high perishability, processing them with conventional cooking methods could extend their shelf life considerably and contribute to promoting entomophagy throughout the region. In a recent study carried out in the cross-border ecosystem, locally available insects were roasted, sun-dried, ground and mixed with other ingredients and processed into food products. Termite-based and lakefly-based crackers, muffins, meatloaf and sausages were found to have especially high potential for commercialization (Ayieko, Oriamo and Nyambuga, 2010).

Buqadilla

Buqadilla is an innovative snack under development for the Dutch market. It is a spicy Mexican leguminoceous food product made of chickpeas and lesser mealworms (40 percent). It was well received in several restaurants and canteens, where the product was tested, for its taste and smooth structure. The sustainable, healthy and exotic snack is an example of an accessible and culturally acceptable way for Western consumers to experience and appreciate edible insects as food (van Huis, van Gurp and Dicke, 2012).

Crikizz

Crikizz is another example of European products made with insects. Developed by Ynsect and French students, Crikizz are spicy, popped snacks based on mealworms and cassava. The mealworm composition varies from 10 to 20 percent in accordance with the product line ("classic" to "extreme"). According to focus groups, the taste is very pleasing and differs from other snacks, while the texture is as crunchy as other snacks. The prototype was made without preservatives or taste enhancers, and the high fat composition of mealworms removes the need for added fat. Crikizz won a prize in the national French contest Eco-trophélia 2012 for culinary innovation.

Processed mealworms for pet food, animal feed and human food

HaoCheng Mealworm Inc. in China specializes in the farming and sale of mealworms, superworms and maggots. The farm, established in 2002, consists of 15 rearing facilities and produces 50 tonnes of living mealworms and superworms per month. HaoCheng exports 200 tonnes of dried mealworms to Australia, Europe, North America and Southeast Asia each year.

The mealworms, superworms and maggots are sold live, dried, canned and in powder form. They have elevated protein content and can be used as additives for food as well as feed:

- Food. Mealworm powder can be worked into bread, flour, instant noodles, pastries, biscuits, candy and condiments. The insects can also be consumed whole as meals and side dishes, or processed into medicinal supplements to fortify the human body's immune system.
- Feed. Entire insects can be used as direct feeds and feed supplements for pets such as birds, dogs, cats, frogs, turtles, shrimps, scorpions, chilopods, ants, goldfish and wild animals (Hao Cheng Mealworm Inc., 2012).

9.1.5 Extracted fat

The removal of fat (and ash) in the production of insect products, such as insect meal, reduces the "stickiness" of the protein concentrate and prevents fatty acids (mostly unsaturated) from exposure to undesirable oxidation processes. The extracted fat can then be used for other purposes. Traditionally, the fat (e.g. oil) of some insect species is used extensively for frying meat and other food products (Box 9.1).

BOX 9.1

Termites: processing techniques in East and West Africa

- Winged termites are often fried in their own fat. Fried termites contain 32–38 percent protein (Tihon, 1946; Santos Oliveira *et al.*, 1976; Nkouka, 1987).
- In Uganda, termites are steamed in banana leaves.
- Termites are boiled or roasted after swarming and then sun-dried or smoke-dried, or both, depending on the weather (Silow, 1983).
- Sometimes termites are crushed with a pestle and mortar and eaten with honey (Ogutu, 1986). The fat residues of fried termites can be used to cook meat (Bequaert, 1921), a time-honoured practice among Azande and pygmies in the Democratic Republic of the Congo (Bergier, 1941).
- Pygmies put the oil derived from frying or pressing dried termites into tubes and use it to treat their body and hair (Costermans, 1955).
- In many East African towns and villages, sun-dried termites can be bought at local markets when in season (Osmaston, 1951; Owen, 1973).
- In Botswana, San women harvest winged termites (*Hodotermes mossambicus*), roasting them in hot ash and sand (Nonaka, 1996).

9.2 INDUSTRIAL-SCALE PROCESSING

There is a wealth of traditional and cultural knowledge on the uses of edible insects as food in tropical countries, yet production is largely concentrated in household and small-scale operations. In temperate countries, processing technology is virtually non-existent because edible insects are not recognized food and feed sources. If insects are to become a useful and profitable raw material in the food and feed industries, large quantities of quality insects will need to be produced on a continuous basis. This requires the automation of both farming and processing methods, which remains a challenge for the development of the sector (see Table 9.1).

TABLE 9.1
Important aspects of large-scale production of edible insects

Standardization	Processing methods monitored equally
Legislation	Regulations and guidelines developed for producers. This includes feed sourcing and its standards (no waste in the EU) and as other aspects, such as welfare, biosecurity in terms of escapees, disease management etc.
Shelf life	Final product easy to store and preferably having a long shelf life
Transportation	Final product easy to transport
Tradeoffs between quality and safety	During processing (nutritional) quality maintained or increased
Costs	Product compatible to alternatives on the current market

9.2.1 Examples of industrial insect farming

AgriProtein (South Africa) and Enviroflight (United States) are examples of companies developing industrial-scale insect farming.

AgriProtein

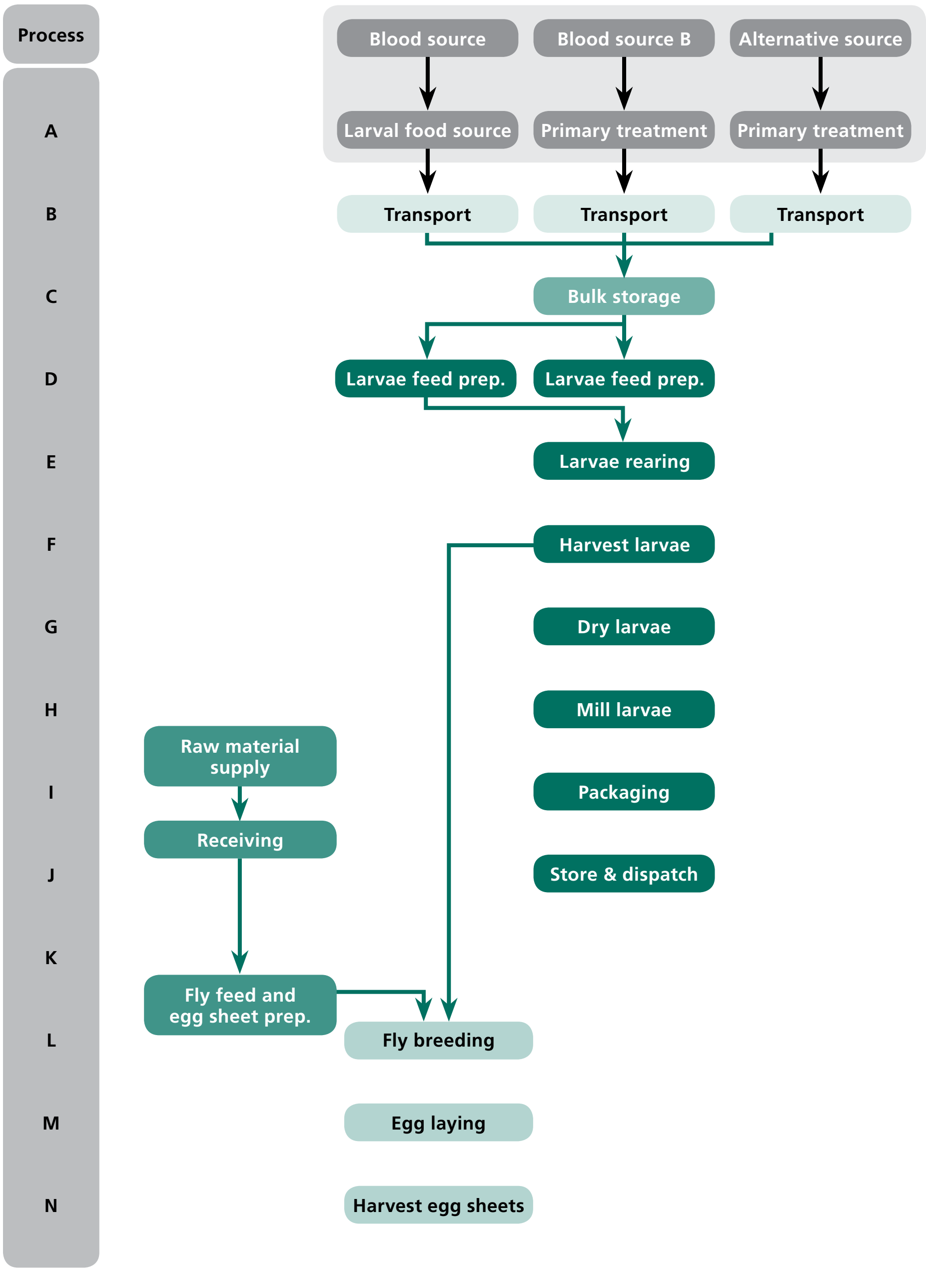
The prospect of farms processing insects for feed might soon become a global reality, due to a growing demand for sustainable feed sources. AgriProtein is leading a new industry called nutrient recycling, which uses organic waste to create protein that will help meet the increasing demand for animal feed. It is a global project focused on fish and meat farming to cater to the growing world population. By using common housefly larvae fed on abundant waste nutrient sources, AgriProtein has developed and tested a new large-scale and potentially sustainable source of protein. The bioconversion process takes low-cost waste materials and generates a valuable commodity.

The production process starts with rearing stock flies in sterile cages, each holding over 750 000 flies. Various types of waste are used, including human waste (faeces), abattoir blood and spent food. Depending on the species, a single female fly can lay up to 1 000 eggs over a seven-day period, which then hatch into larvae. Housefly larvae go through three life stages in a 72-hour period and are harvested just before becoming pupae. The harvested larvae are dried on a fluidized bed dryer, milled into flake form and packed according to customer preferences.

The product contains nine essential amino acids, with high levels of cystine and similar levels of lysine, methonine, threonine and tryptophane – similar to marine fishmeal. Potential big users would need vast quantities of the product – some pet food businesses alone could use over 1 000 tonnes per month.

The company started making only small amounts in the laboratory, but in recent years production has risen to hundreds of kg per day and will shortly exceed 1 tonne per daily production run. The end target is 100 tonnes of larvae per day. A first large factory would require an investment of US$8 million and the countries planned for roll-out are Germany, South Africa, the United Kingdom of Great Britain and Northern Ireland and the United States (see figures 9.1 and 9.2) (Agriprotein, 2012).

FIGURE 9.1
Agriprotein fly protein production process



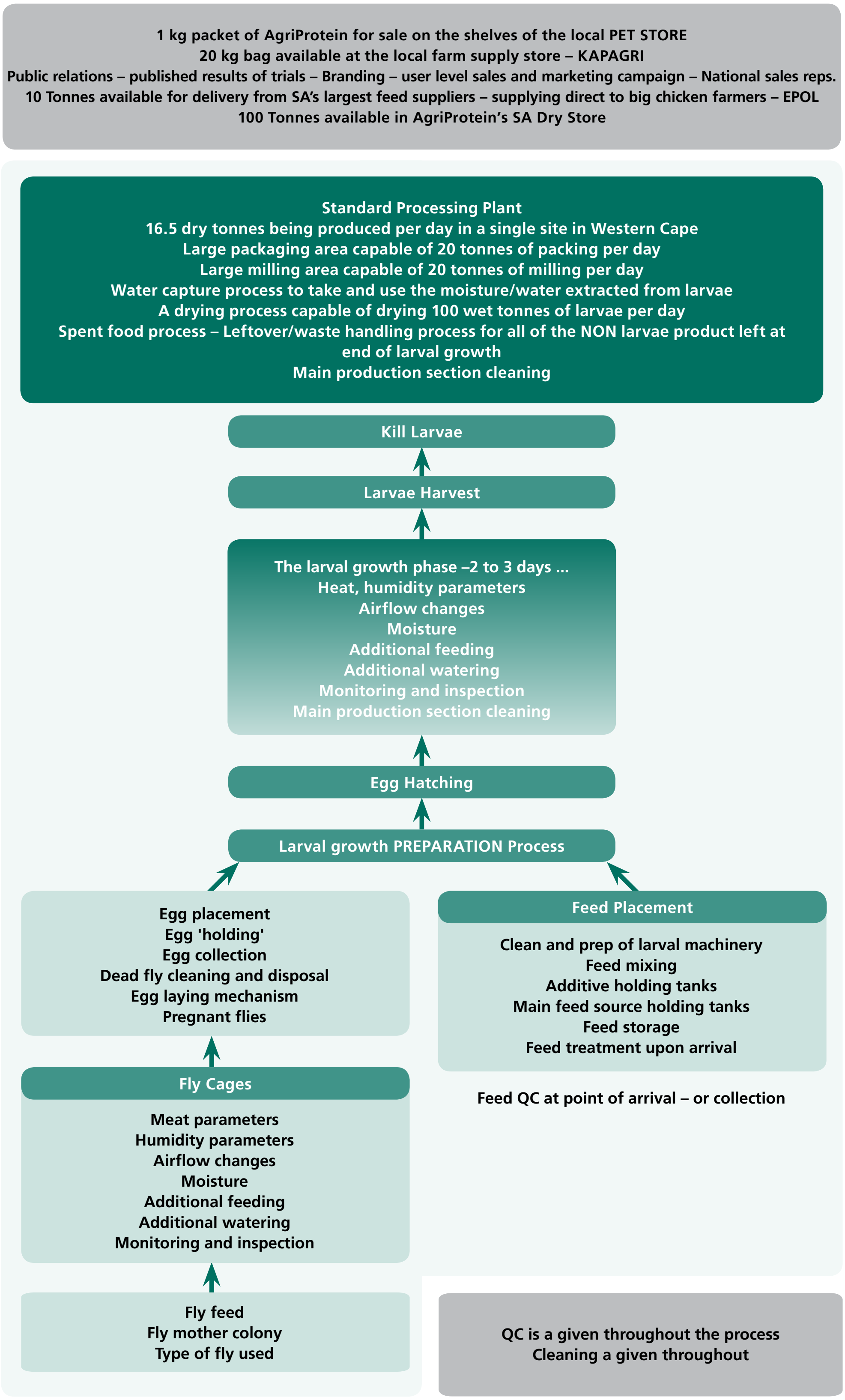
Based on: Agriprotein, 2012.

Enviroflight

Enviroflight is another producer of insects for animal feed. Enviroflight's objective is to produce animal and vegetable protein for aquaculture feeds.

Enviroflight uses dried distiller grains with solubles from ethanol plants and spent brewer grains. Black soldier flies (*Hermetia illucens*) feed off and bioconvert the grain. By doing so, the frass becomes a high-protein, low-fat feedstuff for tilapia, freshwater prawns, catfish and other omnivorous species. The material is also beneficial as a protein source for pigs and cattle.

FIGURE 9.2
Agriprotein value/production chain



Source: Agriprotein, 2012.

The larvae are used as a high-protein, high-fat ingredient for carnivorous fish such as rainbow trout, perch, bass and bluegill. They are cooked, dried and converted into a meal that is 42 percent protein and 36 percent fat. The oils can be extracted, which boosts the protein content to above 60 percent. Enviroflight has developed and tested a number of feed formulations using insect meal and other locally available ingredients for complete diets for multiple species of fish.

A key to the process is that it prevents the creation of ammonia in the frass by stabilizing the material immediately after the insect larvae consume the brewers' or distillers' grains. This keeps the nitrogen fixed and eliminates odour; it also mitigates the formation of molds and mycotoxins. The frass is also beneficial as a natural, animal-safe fertilizer. The nitrogen, phosphorous and potassium levels are 5 percent, 3 percent and 2 percent, respectively, which is very good for vegetable growing.

The system comprises a proprietary bioreactor system and a breeding chamber. It is designed to be located anywhere in the world and can be optimized for operation in developing countries. The breeding chambers are able to produce mating events and eggs in any climate. Because of this there is a continual source of eggs in all weather conditions (G. Courtright, personal communication, 2012).

9.2.2 Industrial-scale processing for insects as food and feed in the Netherlands

The Netherlands is developing an innovative supply chain that includes large-scale insect farming and marketing the insect-derived products for food and feed. Research institutes are supporting this development process.

The principles of the circular economy and theories on environmental economics (Box 9.2) are based on an interrelationship between the environment, economics and the future scarcity of sufficient, nutritious and healthy food. The design of the insect supply chain is circular (Box 9.3). It is based on farming insects on organic waste and using the insects as a food or feed ingredient. This takes place against a background of growing demand for animal protein, the negative side-effects of conventional meat production, and the increasing problem of waste disposal.

Supply-chain partners, knowledge institutes, NGOs and national and regional governmental bodies have a roadmap for creating a prosperous insect industry by 2020 (see Figure 9.3). The aim for 2020 is to introduce farmed insects as ingredients for feed and food.

BOX 9.2

Environmental economics

Balasubramanian (1984) stated that "no longer is economics merely a science of production and distribution, it has to take into account the ecological repercussions of economic activities that could affect both production and distribution". Thus, economics should not merely be the study of how goods and services are produced; it should take into consideration the impacts of the use of resources on the environment. Any study on the economic content of production, distribution and development cannot be complete without touching on issues such as externalities, pollution, damage, exhaustion and depletion, among others. Environmental economics can therefore be defined as that "part of economics which deals with interrelationships between environment and economic development and studies the ways and means by which the former is not impaired nor the latter impeded" (Sankar, 2001). It is thus a branch of economics that discusses the impacts of interactions between humans and nature and finds human solutions to maintain harmony. Insects could play an important role in finding such solutions.

BOX 9.3

Application of edible insects: insects as the missing link in designing a circular economy[12]

To satisfy the growing demand for sufficient affordable and sustainable proteins, the following innovation processes are proposed:

- **Insects as bioconverter.** The feed, food and pharmaceutical industries use ingredients from insects grown on organic waste. There are possibilities for processing insects for applications in medicine, cosmetics, alcohol, etc.
- **Alternative designs for a viable and sustainable agricultural sector.** The agricultural sector is under pressure to obtain higher yields with less input. More and more companies are being forced to cease production because they cannot cope with this competitive battle, while scaling up is not an option. Insects farmed on organic waste can be an attractive and viable alternative for entrepreneurs.
- **Opportunity for innovative modern entrepreneurs.** The Netherlands is a global leader in the field of life sciences and has many entrepreneurs with relevant knowledge. These entrepreneurs can play a leading role in developing the sector.

The potential for marketing insect-derived products depends on the following conditions:

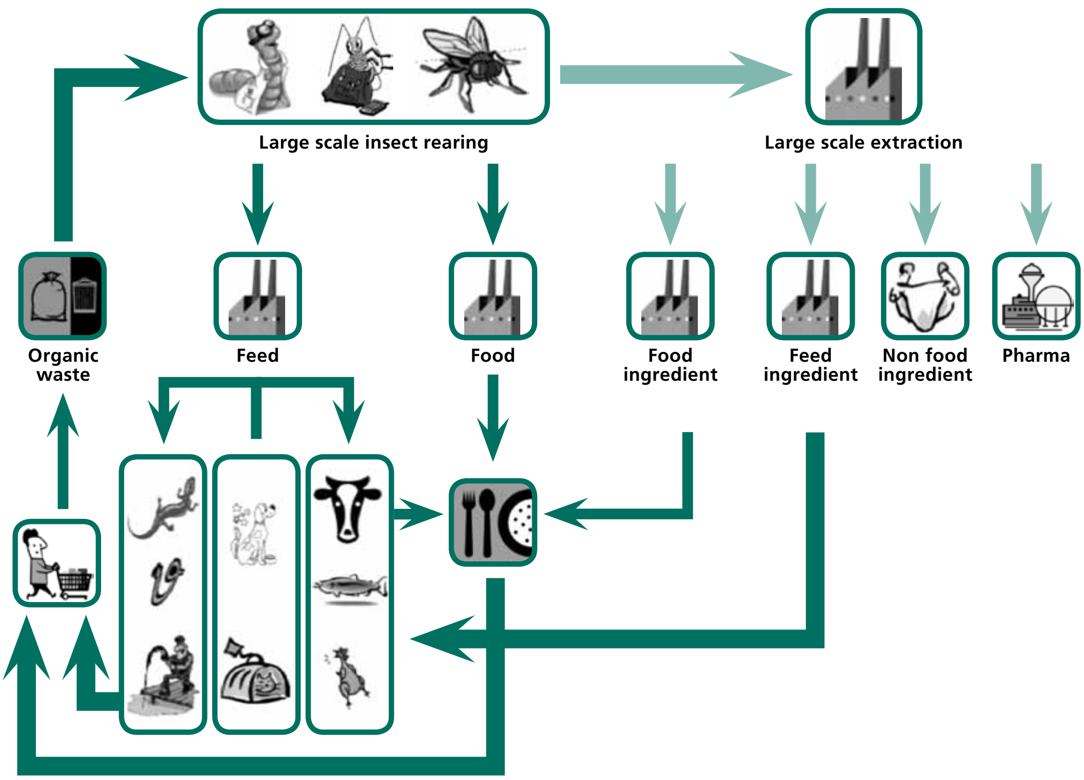
- reliable high volumes of production;
- fair and competitive market prices;
- resolutions to hurdles in legislation;
- permission to use (organic) waste or byproducts from the food and agricultural industry.

The major challenges are:

- **Scaling up.** Large-scale production units will be necessary to reduce costs. Insect products are currently substantially more expensive than regular meat products. Mealworms are approximately three times more expensive than pork and about five times more expensive than chicken. The main factor is labour and how to increase the competitiveness of alternative animal protein products. The use of insects in the feed sector in Europe costs about €100 per 100 kg. Attention must be paid to increased automation and mechanization processes in order to arrive at processed end products (i.e. insect flour instead of whole insects).
- **Increased market and consumer acceptance.** Critical factors are the development of market concepts and business cases for feed and food in close cooperation with partners in the supply chain. Market pull is needed to create a higher turnover for insect farms and enable them to invest in scaling their facilities.
- **Legislative national and international frameworks.** Legal frameworks need to allow the use of insects as ingredients for food and feed. The use of organic waste as a feed ingredient for insects is another legislative concern. Approval by the European Union (EU) Novel Food Regulation is an expensive and time-consuming procedure. In the short term, legislation does not allow for the use of protein extracts originating from insects. The Transmissible Spongiform Encephalopathies regulation at the European level also blocks the introduction of insects as an ingredient for feed.
- **Developing new cooperative and funding models.** The establishment of large-scale production facilities, pre-competitive collaboration and innovative approaches to market acceptance, as well as new forms of financing, are needed for the establishment of this new sector.

[12] Box contributed by Marian Peters of Venik.

FIGURE 9.3
Insects as the missing link: ecology designs a circular economy



Source: M. Peters, personal communication, 2012.