8. Farming insects

8.1 DEFINITIONS AND CONCEPTS

Defined broadly, agriculture includes farming both animals (animal husbandry) and plants (agronomy, horticulture and forestry in part) (FAO, 1997b). The concept of insect farming, however, is relatively new in development circles, including FAO. Insects are reared in a designated area (i.e. a farm) and the insects' living conditions, diet and food quality are controlled. Farmed insects are kept in captivity, or "ranched", and are thus isolated from their natural populations. The term semi-cultivation, as it applies to insects, is defined in section 4.4.

The words *rearing* and *breeding* are often confused. The word breeding is more often used in livestock production than in entomology. Strictly speaking, *rearing* refers to tending the animals, while breeding refers to their reproduction. *Breeding* often refers to producing better offspring: that is, genetically improving the stock by selecting specimens in a population with certain desired characteristics. But keeping insects under confined conditions can also have a genetic effect on populations through inbreeding depression, founder effect, genetic drift and laboratory adaptation, such that they often no longer much resemble wild populations.

The distinction between livestock and minilivestock is not always clear: *minilivestock* implies small animals raised for domestic use or profit (not as pets), especially on a farm. These can be small mammals, amphibians, reptiles or invertebrates, including insects (Paoletti, 2005). According to Hardouin (1995), "these animal species include both vertebrates and invertebrates, which can be terrestrial or aquatic by nature, but of a weight usually under 20 kg, and that these animals must have a potential benefit, either nutritionally or economically". Conversely, *livestock* generally refers to cattle, poultry, sheep, llamas, alpacas, goats, camels, horses and other similar animals raised for domestic use or profit, but not as pets.

8.2 INSECT FARMING

Most edible insects are harvested in the wild, but a few insect species have been domesticated because of their commercially valuable products. Silkworms and bees are the best-known examples. Sericulture – the practice of rearing silkworms for the production of raw silk – has its origins in China and dates back 5 000 years. The domesticated form has increased cocoon size, growth rate and efficiency of digestion, and is accustomed to living in crowded conditions. The adult can no longer fly and the species is completely dependent on humans for survival. Both bee larvae and silkworm pupae are eaten as byproducts (Box 8.1). Additionally, some insect species are reared for the pet-food industry. For example, mealworms and crickets are reared primarily as pet food in Europe, North America and parts of Asia.

BOX 8.1

Dual production systems (fibre and food): the example of the silkworm

Colombia. In sericulture, the pupae of the domesticated silkworm (*Bombyx mori*) are considered byproducts and are good sources of food for both humans and animals. With

Continues

Box 8.1 continued

an estimated annual production of 1.2–1.4 million silkworm cocoons per ha of mulberry bushes and one pupa weighing 0.33 g (dry weight), the average yield of pupal byproduct is 400–460 kg per ha (DeFoliart, 1989). In addition, the frass (a waste that insects pass after digesting plant parts) can be used as fertilizer or as feed for pond fish.

India. Seriwaste is only used for biogas production and composting. Researchers are experimenting with feeding seriwaste to poultry (Krishnan *et al.*, 2011). The poultry industry is one of the fastest-growing agro-businesses in India, yet sustainable feed products with high conversion rates are not widely available. Krishnan *et al.* (2011) argued that seriwaste is extremely viable because silk waste is not toxic and has even better conversion rates than conventional feedstocks.

Kenya. A project in Kenya successfully linked forest conservation and livelihood improvement (Raina *et al.*, 2009). By commercializing insects such as the mulberry silkworm, local forest communities were able to sell the silk produced, which proved to be a valuable alternative source of cash income. Leftover pupae were fed to chickens. These benefits gave local communities incentives to better manage their surrounding forest habitat.

Madagascar. A local NGO, the Madagascar Organization of Silk Workers (SEPALI), along with its United States partner, Conservation through Poverty Alleviation, is implementing a programme to alleviate local pressure on the newly established Makira Protected Area by aiding local farmers in the production of artisanal silk from endemic moths. In 2013, SEPALI will develop the Pupae for Protein project. People in the Makira area eat some of the types of reared silkworms and pupae. Once farmers produce 4 000 pupae and select 200 for further rearing, the remaining 3 800 can be boiled, sautéed, dried or ground into a calcium-rich protein powder. In fact, 3 800 pupae are approximately equal in weight to one red-ruffed lemur, an endangered species.

Another commercially viable product obtained from farmed insects is carminic acid. Carminic acid derives from the cochineal insect (*Dactylopius coccus*), which is domesticated on the cactus *Opuntia ficus-indica* var. Atlixco (see section 2.4). The acid is used as red dye in human food and in the pharmaceutical and cosmetic industries.

Insects are also reared in agriculture to either combat insect pests or for pollination. In biological control, large rearing companies mass-produce beneficial insects such as predators and parasitoids (Box 8.2). These insects are often sold to fruit, vegetable and flower farmers to combat insect pests and are also used in large estate crops, for example egg parasitoids (*Trichogramma* spp.) and larval parasitoids (*Cotesia flavipes*) to combat sugarcane borers. Bumblebees (*Bombus* spp.) and honeybees (*Apis* spp.) are reared worldwide to help farmers pollinate crops and fruit orchards.

BOX 8.2
Biological control and natural pollination

The large-scale production of natural enemies to combat agricultural pests and bees to pollinate crops is a global business. Koppert Biological Systems is the international market leader in the field of biological crop protection and natural pollination. The company develops and markets pollination systems (bees and bumblebees) and IPM programmes for protecting high-value crops.

Natural enemies of insect pests, also known as biological control agents, include predators, parasitoids and pathogens. Predators (e.g. ladybirds) feed on their prey, resulting in the death of the organism. A parasitoid develops inside the host insect

Continues

Box 8.2 continued

and eventually kills it (e.g. parasitic wasps). Predators and parasitoids can be mass-reared and then released in the field or in glasshouses to contain agricultural pests, thereby minimizing damage to crops. Insects are also reared for the *in vivo* production of pathogenic nematodes and viruses. These insect products are excellent examples of non-chemical, non-toxic, non-hazardous and environmental friendly plant protection measures. They are commonly included in IPM strategies applied to control major insect pests in a large number of food and fibre crops.

A common method used in IPM is the sterile insect technique, in which large numbers of sterile insects are released into the environment, competing with wild males for female insects. When a female mates with a sterile male it will bear no offspring, thus reducing the next generation's population. Repeated release of sterile insects can eradicate or contain a population. The technique has been used successfully to eradicate the screw-worm fly (*Cochliomyia hominivorax*), a livestock pest in areas of North America, and to control the medfly (*Ceratitis capitata*) in Central America, which has caused extensive damage to a range of fruit crops.

In temperate regions there are companies that produce large numbers of insects as pet food and fish bait. The species most used are crickets (*Gryllodus sigillatus*, *Gryllus bimaculatus* and *Acheta domesticus*), mealworms (*Zophobas morio*, *Alphitobius diaperinus* and *Tenebrio molitor*), locusts (*Locusta migratoria*), sun beetles (*Pachnoda marginata peregrine*), wax moths (*Galleria mellonella*), cockroaches (*Blaptica dubia*) and maggots of the housefly (*Musca domestica*). Some companies even produce Mighty Mealys™, or giant mealworms, which are *T. molitor* larvae treated with juvenile hormones. The hormone suppresses pupation and allows the larvae to grow to a size of about 4 cm, making them ideal as pet food and bait.

In addition, some insects serve medicinal purposes. The common green bottlefly (*Lucilla sericata*), for example, is produced for use in maggot therapy. Live, disinfected fly larvae are introduced into soft tissue wound(s) of humans or animals to clean out the necrotic tissue (debridement) and disinfect the traumatized area. House dust mites are also produced commercially for allergy-testing. The Research Institute of Resource Insects of the Chinese Academy of Forestry in Kunming has conducted extensive research on the rearing of insects for medical applications (Feng *et al.*, 2009), and the use of insects as food in space is also being examined (Box 8.3).

Other reasons for rearing insects include research into plant breeding and chemical control (e.g. screening of pesticides and testing side-effects on non-target arthropod species). Insects are also produced for educational and recreational purposes, for example in zoos and butterfly gardens. In some countries, insects serve as pets – such as walking sticks and singing or fighting crickets in Chinese culture (see section 2.1), and scarab beetles, such as stag beetles (Lucanidae) and rhinoceros beetles (Dynastinae) in Japan, Thailand and Viet Nam.

The potential uses of insects are vast. Recently, the use of insects for the bioconversion of manure and waste has been explored (see section 7.4). It would be useful to engage industries already producing insects, for example as pet food, to promote production for animal feed and human consumption (e.g. mealworm, locusts and crickets).

8.3 INSECT FARMING FOR HUMAN CONSUMPTION

8.3.1 Tropics

The best example of rearing insects for human consumption in the tropics is cricket farming. In Thailand, two species are produced: the native cricket (*Gryllus bimaculatus*) and the house cricket (*Acheta domesticus*). The native cricket is interesting from an economic standpoint, but the taste and quality of the house cricket is generally thought to be superior (Y. Hanboonsong, personal communication, 2012).

The methods used in cricket farming in the Lao People's Democratic Republic, Thailand and Viet Nam – veteran producers of crickets – are very similar. In these countries, crickets are reared simply in sheds in one's backyard, and there is no need for expensive materials. In the Lao People's Democratic Republic and Thailand, concrete rings approximately 0.5 m in height and 0.8 m in diameter are used as rearing units, while plastic bowls are used in Viet Nam. In each "arena", a layer of rice hull (or rice waste) is placed on the bottom. Chicken feed or other pet food, vegetable scraps from pumpkins and morning glory flowers, rice and grass are used for nourishment. Plastic bottles are used to provide water; a plate of water filled with stones can also be used, with the stones preventing the crickets from drowning. Sticky tape or plastic tablecloths are stuck on the inner side of the walls just below the edge to keep the crickets from crawling out of the arena. Cardboard egg cartons, tree leaves and hollow logs are also used to create a larger amount of space for the crickets. Females lay their eggs in small bowls filled with sand and burned rice husks. After a time, these bowls are moved to another receptacle, where a new generation is reared. Each bowl is covered with a layer of rice hull to maintain a suitable incubating temperature. Crickets are kept from escaping by covering the arena, for example with mosquito netting; this also prevents other animals, such as geckos, from entering. The rearing areas are surrounded by a "moat" – a narrow strip of water containing very small fish – that prevents ants from entering (Yhoung-Aree and Viwatpanich, 2005; J. Van Itterbeeck, personal communication, 2008).

8.3.2 Temperate zones

In temperate zones, insect farming is largely performed by family-run enterprises that rear insects such as mealworms, crickets and grasshoppers in large quantities for pet food. Because the species are frequently reared in close, confined spaces, climate control is often applied, as high temperatures may cause the desiccation of soft-bodied larvae.

The rearing of high quantities of insects, either for consumption as whole insects and/or as protein extracts, is possible in industrialized countries. Critical elements for successful rearing include greater knowledge of biology, rearing conditions and artificial diet formulation (Wang *et al.*, 2004, Feng and Chen, 2009; Schneider, 2009). Diets can be altered to increase nutritional value (Anderson, 2000) and adapting the light regime can optimize production; for example, exposing crickets to 24 hours of light per day can increase cricket production (Collavo *et al.*, 2005). Such issues warrant further research.

BOX 8.3

Insect proteins in space

It has been suggested that insects could be used as a protein source in space flights. Scientists in China, Japan and the United States are looking seriously into this food resource for space travel and use in space stations. China is planning to build a terrestrial model of a bio-regenerative life support system that makes use of silkworms (DeFoliart, 1989; Katayama *et al.*, 2008; Hu, Bartsev and Liu, 2010). Species like *Agrius convolvuli*, *Stegobium paniceum* and *Macrotermes subhyalinus* have also been proposed (Katayama *et al.*, 2005).

Cohen (2001) criticized the lack of professional appreciation for insect rearing and proposed formalizing insect rearing and insect food science and technology as academic disciplines. High-quality rearing is essential for the widespread use of insects as human food.

Another major challenge is rearing insects in large numbers, which requires the development of automation processes. These are being explored for silkworms

(Ohura, 2003). Robert Kok and colleagues at McGill University, Canada, are conducting research on the optimal design of insect farms for large-scale production (Kok, 1983; Kok, Shivhare and Lomaliza, 1990) (see Table 8.1). Nevertheless, major impediments to full-scale rearing include cost and the still uncertain nature of the supply of waste streams and the ability to guarantee a consistent, high-quality product.

TABLE 8.1
Favourable characteristics of insects for automated production systems

Social structure of populations	Reaction to humans
Gregarious	Readily habituated
Small territories	Little disturbed
Males affiliated with female groups	Non-antagonistic, no disagreeable odour
Intra and interspecies agonistic behaviour	Parental behaviour
Non-agonistic to con-specifics	Egg guarding
Non-agonistic to non-specifics	Precocial young
Altruistic	Young easily separated from adults
Sexual behaviour	Ontogeny
Male initiated	Short developmental cycle
Sex signals via movement or posture	High survival of immatures
Pheromonally induced	High oviposition rate
Promiscuous	High potential of biomass increase/day
Easy to propagate	Low vulnerability to diseases/parasites
Feeding behaviour	Locomotory activity and habitat choice
Generalist feeder	Non-migratory
Feeds on common items	Sessile or small home range
Non-cannibalistic	Limited agility
Accepts artificial diet	Wide environmental tolerance
Endogenous feeding satiation	Ecological versatility

Source: Kok, 1983; Gon and Price, 1984.

8.4 INSECT FARMING FOR FEED

Insects are much more efficient in converting feed to body weight than conventional livestock and are particularly valuable because they can be reared on organic waste streams (e.g. animal slurries). Research into rearing insects as food and feed on a large scale remains a priority. Current production systems are still too expensive. A study in the Netherlands (Meuwissen, 2011) suggested that the production of mealworms is still 4.8 times as expensive as normal chicken feed. In particular, labour and housing costs for large-scale feed production facilities are much higher for insects than for the production of chicken feed.

8.5 RECOMMENDATIONS ON INSECT FARMING

The Expert Consultation Meeting on Assessing the Potential of Insects as Food and Feed in Assuring Food Security, held at FAO headquarters in Rome in January 2012, made recommendations for rearing insects, including suggestions on species and strain collection; household production; training in insect farming; the choice, cost and reliability of feedstock; safety, health and environmental issues; and strategic issues for industrial-scale insect farmers.

8.5.1 Species and strain collection for food and feed

The Expert Consultation Meeting agreed that rearing practices in tropical countries should employ local species because they pose virtually no risk to the environment, there is no need for climate control, and such local species are likely to be more culturally accepted. Selection criteria should involve ease of rearing, taste, colour and whether they can be used as feed. In temperate zones, cosmopolitan species like the house cricket (*Acheta domesticus*) should be used, or those that do not pose environmental risks.

Industrial-scale production was defined in the meeting as a minimum reach of 1 tonne per day of fresh-weight insects. Species destined for mass production, moreover, should possess certain characteristics, including a high intrinsic rate of increase; a short development cycle; high survival of immatures and high oviposition rate; a high potential of biomass increase per day (i.e. weight gain per day); a high conversion rate (kg biomass gain per kg feedstock); the ability to live in high densities (kg biomass per m^2); and low vulnerability to disease (high resistance). Good candidates were considered to be the black soldier fly (*Hermetia illuscens*) for feed and the yellow mealworm (*Tenebrio molitor*) for both food and feed. Because of the vulnerability of production systems, heavy reliance on a single species is discouraged (Box 8.4). Finally, it was recommended to preserve parental genetic lines in case of culture crashes.

Other questions identified and discussed at the Expert Consultation Meeting included:
- Is the species amenable to large-scale automation (thereby reducing labour costs)?
- Can the species be contained in non-native areas? What are the biodiversity consequences if they are introduced to non-native areas?
- Is there a possibility of genetically improving species by selective breeding to obtain high-quality strains?
- What is the ecological footprint of the insects (e.g. GHG production)?
- What are the water requirements?

8.5.2 Household production

In the tropics, the emphasis should be on maximizing the productivity of traditional management systems. Procedures for small-scale farming should be developed – such as kits for home-use – so that people can easily start small-scale rearing facilities. Feed for insects should be obtained locally. The possibility of using available organic waste (or rest streams), for example, should be evaluated.

BOX 8.4

Difficulties in rearing crickets in the Netherlands

The insect-rearing company Kreca used to sell more than 10 000 boxes of crickets (*Acheta domesticus*) each week. In 2000, 50 percent of the crickets reared by the company died within 8–12 hours, a population crash never previously experienced. A densovirus was suspected to be the cause of cricket mortality, and a very thorough sanitation regimen followed. All diseased crickets were removed, the entire rearing facility was cleaned, and strict hygiene measures were imposed. In addition to the sanitation programme, the location of rearing was moved and the cricket eggs were washed thoroughly. These efforts, however, proved futile. As a consequence, cricket rearing was terminated. Heavy reliance on a single species is strongly discouraged, for many of the same reasons that monocultures should be avoided in agriculture – their high vulnerability to diseases and pests. Kreca now rears three cricket species: *A. domesticus*, *Gryllus bimaculatus* and *Gryllodus sigillatus*, with the latter showing the most economic promise.

8.5.3 Training in insect farming

Farmers can learn from each other's experiences. Cooperatives can be effective for information-sharing and should be promoted in both tropical and temperate countries. Workshops for sharing knowledge and to increase networking should also be organized.

In tropical countries, moreover, training could be conducted using the "farmer field school" approach, which has proven successful in other agricultural development settings and requires the involvement of local extension services. Insect farming should be incorporated into formal educational systems, including elementary and secondary schools and universities, with the aim of making people aware that insects can be farmed just like other livestock.

The Faculty of Agriculture at the National University in the Lao People's Democratic Republic already teaches cricket farming to its students (see Chapter 12). In Thailand, the Faculty of Agriculture, Khon Kaen University, has an undergraduate teaching course in industrial entomology, including edible insect farming. In addition, cricket farming, processing and marketing is taught in an annual international training course on using indigenous food resources for food security.

8.5.4 Choice, cost and reliability of feedstock

In choosing a feedstock it is important to know whether the insects are destined for feed or food. For insects to be used as feed, different (organic waste) side streams need to be evaluated. Insects intended for human consumption need to be fed feed grade or even food grade food if the insects are not to be degutted. Waste streams might not be a viable option for human consumption; this area demands further research. Finally, the feedstock needs to be inexpensive, locally available, of consistent quality and supply, and above all free of pesticides and antibiotics.

8.5.5 Safety, health and environmental issues

In food production, safety is paramount. The mistakes made in the livestock industry (e.g. the overuse of antibiotics) should serve as a lesson for insect rearers. Disease management strategies need to be preventive in nature. Human hazards related to production should be circumvented, such as passive vectoring of pathogens and the development of allergies among personnel in production units. The rearing system design should also minimize sensitivity to disease. Risk guidelines as well as sanitary standards need to be developed and implemented for each species.

8.5.6 Strategic issues for industrial-scale insect farmers

The success of the industry will hinge on its ability to set up a reliable and consistent production chain and, above all, on its ability to produce high-quality feed and food with high nutritional value. The following developments are recommended:

- creating an international society of producers of insects as food and feed to complement the existing Association of Insect Rearers for Biocontrol, with the possibility of a society publication;
- developing a code of practice/standards (possibly modelled on those of the mushroom industry) and product quality metrics to garner credibility;
- adopting a common language in the industry to assist communication with the general public;
- developing a marketing strategy that establishes which industries and consumers to target;
- creating a list of species that are "society approved" for use as human food;
- centralizing information, literature, methods and practices;
- liaising with relevant policymakers and researchers.