# Insects as food – an option for sustainable food production?

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**SLU Future Food – a research platform for a sustainable food system**

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*Deep fried corn tortillas with garlic fried house crickets, white bean mash with smoked garlic, rocoto salsa, epazote, and avocado, salsa verde, onion and cilantro.*

# Preface

There are several reasons to learn more about insect farming and processing insects for food. For much of the world's population, insects are by tradition an important source of nutrients and appreciated as food. Quite recently, entomophagy (the practice of eating insects) has emerged as a hot topic for resource efficient food production also in our part of the world.

This report was originally written by Anna Jansson and Åsa Berggren, both researchers at SLU, and published in 2015 under the name *Insects as Food – something for the future?,* by the research platform Future Agriculture at the Swedish University of Agricultural Sciences (SLU). This platform ceased to exist in 2017. However, insects as food is a continued current and thrilling topic in which SLU has a broad and valuable competence. Therefore, the research platform SLU Future Food, launched in 2017, saw the need to update this report which is now named *Insects as Food – An option for sustainable food production?*

The report is a summary on current knowledge about insects for human consumption based on literature reviews and personal communications with experts in the field. It is suitable as reading material for students, but also as an introduction for anyone interested in insects as food and sustainable food production.

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SLU Future Food, is a strategic platform for research and collaboration to develop knowledge, solutions and innovations aimed at ensuring that the entire food system is characterized by economic, ecological and social sustainability to overcome tomorrow's challenges. The research addresses both plants and animals, from the smallest molecules to global systems.

Uppsala, August 2019

Annsofie Wahlström, programme director
SLU Future Food

# Summary


Increased world population, greater pressure on the environment, increased use of land resources globally and increased demand for nutrients and energy are predicted for coming decades. Livestock production accounts for 70 percent of all agricultural land use and, as the global demand for livestock products is expected to almost double by 2050, innovative food production solutions are needed to mitigate the environmental impacts of increasing food product demands. Insect farming has been suggested as one such solution, able to provide an alternative to conventional livestock farming for future food production.

Land clearing for agriculture is a major contributor to global warming and efficient use of land is therefore important. Insects have a high feed conversion rate, which in a rearing system limits the demand for land for feed production. Moreover, insect production appears to result in lower green-house gas emissions than conventional livestock production. It has also been suggested that the volume of water required to produce edible insects is low compared with that needed in conventional live-stock production, although empirical data on this are currently lacking. Most edible insects are herbivores and therefore plant-based feed of limited value to humans may be harvested and fed to insects. By-products from the food and forest industry are also alternatives. As insects are rich in high quality protein, fatty acids, vitamins and minerals, insect consumption is an option to reduce malnutrition in developing countries.

Insects are part of the diet of at least two billion people in the world, with more than 2100 insect species currently used as food - a practice known as entomophagy. The most common insects consumed worldwide are different species of beetles (31 percent of all insects species consumed), caterpillars (17 percent) and bees, wasps and ants (15 percent). In many countries, but not (yet) in Europe and North America, insects are considered a delicacy. In Western societies, eating insects is instead commonly regarded with disgust and as primitive behaviour. In order to promote entomophagy in Western societies, the disgust factor must be addressed. Much can be learned from the Netherlands, where entomophagy has been successfully promoted since the late 1990s.

Today, most edible insects are harvested in the wild and it is only recently that the farming of insects for direct human consumption has begun, mainly in Asia. Farmed insects can also be found in the USA and in some countries in Europe. If insects are to become a profitable commodity in Western countries, there is a need for the development of safe and efficient mass-rearing systems. Many insects reproduce rapidly and have large numbers of offspring, which can be an advantage for the development of successful rearing systems. However, through their diversity in terms of types, numbers, life cycles and habitat, insects are exposed to a wide range of pathogens.

Different parasites and diseases can regulate wild populations of insects, and can have a major impact also on farmed species. However, the risk of zoonotic infections can be expected to be low, but other pathogens carried by food insects may pose a risk for humans.

When planning food insect production systems, it is important to focus on species that are either native or have a long history in the country, in order to minimise the impacts arising from unintentional release of insects from farming systems. For feed production aimed at insects the same rule should be applied. New plant or crop types for food insects should not be introduced. In Sweden for example, possible candidates for food insect production, (of those where farming is known to be possible), are the house cricket (*Acheta domesticus*), mealworms, the larvae of the beetle *Tenebrio molitor*, and honeybees (*Apis mellifera*).

Properly managed, insect production systems can contribute to biodiversity and land conservation if sustainability measures are present in all steps of the system. Loss of natural habitat within the agricultural landscape and use of pesticides and fertilisers have negative effects on biodiversity. Possible actions to mitigate biodiversity decline are management of grazing areas, increasing small-scale heterogeneity in monoculture landscapes and, on a smaller scale, establishment of vegetated strips around crop fields. Harvesting vegetation from these type of areas would provide farmed insects with feed, while the plant material could be sustainably grown and enhance native biodiversity.
Due to the apparent resource use efficiency and good nutritional value of insects, insect rearing for entomophagy has the potential to become a modern and sustainable food production system.

# Why eat insects?

The world population is estimated to reach 9 billion people by 2050, demanding a greater output from available agro-ecosystems (FAO, 2015). Greater pressure on the environment, agricultural land, water resources, forests, fish supply and biodiversity, as well as an increased need for nutrients and energy, is predicted. At the same time studies show that even with intensification of land-use, current food production systems cannot produce the food needed for a growing population (Tilman 2011). We need to find other ways to sustain both our planet and ourselves (Rockström et al., 2017). There is an urgent need for innovative solutions.

Insects are included in the human diet in most parts of the world, with Europe and parts of North America being two exceptions (FAO, 2013). Edible insects contain high quality protein, fat, vitamins and minerals (Rumpold and Schlüter, 2013; Makkar et al., 2014) and are also considered tasty and even delicious by those accustomed to eating them (De Foliart, 1999; FAO, 2013).

Insects have a comparatively efficient feed conversion, which in a rearing system limits the amount of land required for feed production. There is also evidence that insects emit less greenhouse gases and ammonia compared with conventional livestock (Oonincx et al., 2010). Due to these benefits, rearing of insects has been suggested as a promising alternative to conventional livestock production - even in Western societies (van Huis, 2013). For this to be a sustainable industry, much new knowledge is needed (Berggren et al., 2019).

## What is an insect?

Insects are a class of animals within the arthropod group. The total number of insect species on Earth is estimated to be 2-3 million and the class probably represents more than 90 percent of all animal species (Speight et al., 2008; FAO, 2013). Insects can be found in nearly all environments, although only a few species occur in the oceans. Spiders and scorpions, which can also be eaten by humans, are not insects but belong to the arthropods. The oceans are dominated by yet another group of arthropods, crustaceans (e.g. krill, shrimps, crabs and lobsters). Insects are cold-blooded and their metabolism depends on the thermal conditions in the environment.

Many insects occur naturally in high densities, which can be an advantage for the development of successful rearing systems and also from an animal welfare perspective. Some species reproduce rapidly and have large numbers of offspring, and most insects do not have parental care. Juvenile insects grow through nymphal or larval stages, shedding their skin as they grow. They then turn directly into an adult or enter a pupal stage that metamorphoses into the adult (Speight et al., 2008). Some species have diapause (a period during which growth or development is suspended) and thereby extend their development over one or several seasons. This is more common when climate conditions do not favour a full development cycle.

Adult insects have a three-part body (head, thorax and abdomen), three pairs of legs, usually compound eyes, two antennae and a chitinous exoskeleton. The digestive system consists of three parts: The foregut, the midgut and the hindgut. Digestion begins at the mouthparts, where salivary glands often provide enzymes and lubricants. The midgut is the principal site of digestion (Capinera, 2010). Methane originating from the hindgut (which could contribute to global warming) is only produced by cockroaches, termites and scarab beetles (FAO, 2013).

# The FAO perspective

The Food and Agriculture Organization of the United Nations (FAO) has been working on edible insects since 2003, in order to:

- Generate and share knowledge in the field through publications, expert meetings and a website on edible insects (http://www.fao.org/forestry/edibleinsects/en/)
- Raise awareness of insects as food through media collaborations
- Provide support to member countries through field projects
- Support networking and cross-disciplinary interactions (e.g. stakeholders working with nutrition, feed and legislation issues) with various sectors within and outside FAO.
- FAO is promoting consumption of insects in the Western world too, because of the possibilities for sustainable production in these areas and because Western food culture and gastronomy tend to influence development in other parts of the world. If a food source is rejected by Western society, it is likely that other parts of the world will follow.

## The way forward

To release the potential of insects as food, FAO (2013) has identified four key bottlenecks and challenges that must be addressed:

- Further documentation is needed on the nutritional value of insects, in order to efficiently promote insects as a healthy food source
- The environmental impacts of both harvesting and farming insects must be investigated, to allow comparisons with conventional livestock production
- The socioeconomic benefits that insect harvesting and farming can offer, particularly in poor countries, must be clarified and communicated
- Clear and comprehensive legal frameworks at national and international level are needed to pave the way for investments, development of production and trade in insect products.

## Knowledge gaps in research

In May 2014, the first international conference on insects as food, called 'Insects to Feed the World', was arranged by FAO and Wageningen University, the Netherlands. In May 2018 the second international conference was arranged in China. The first conference was considered a milestone in the recognition of a professional insect industry and participants included food entrepreneurs, animal scientists, medical scientists, entomologists, psychologists, insect breeders, members of the feed industry, food authorities and EU officials. The conclusion from the conference was that insects are a solution for the protein deficit problem in the world. The second conference had more than 180 presentations from all over the world covering a range of topics, from ethno-entomology, farming, diseases, environmental impact, food and feed aspects, ethics to economics and consumer attitudes.

# Entomophagy – The practice of eating insects

Insects maintain an ancient connection with mankind. Though insects have long provided cultural, religious and economic inspiration to human societies, it is their use as a food resource that has been critical to the development of the human species (Costa-Neto and Dunkel, 2016) having been consumed continuously by humans since pre-agricultural times (Raubenheimer et al., 2014). The practice of consuming insects is called entomophagy, from the Greek *éntomon*, insect, and *phagein*, to eat. It is estimated that edible insects are part of the diet of at least two billion people, with more than 2100 insect species currently used as food worldwide (Jongema, 2017) (Figure 1). The insects most commonly consumed worldwide are beetles (Coleoptera, 31 percent of all insect species consumed), caterpillars (Lepidoptera, 17 percent) and bees, wasps and ants (Hymenoptera, 15 percent). Moreover, grasshoppers, crickets and locusts (Orthoptera, 13 percent) and cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera, 11 percent) are consumed. Termites (Isoptera), dragonflies (Odonata), flies (Diptera) and other insects each comprise less than 3 percent of insects consumed (Jongema, 2017).

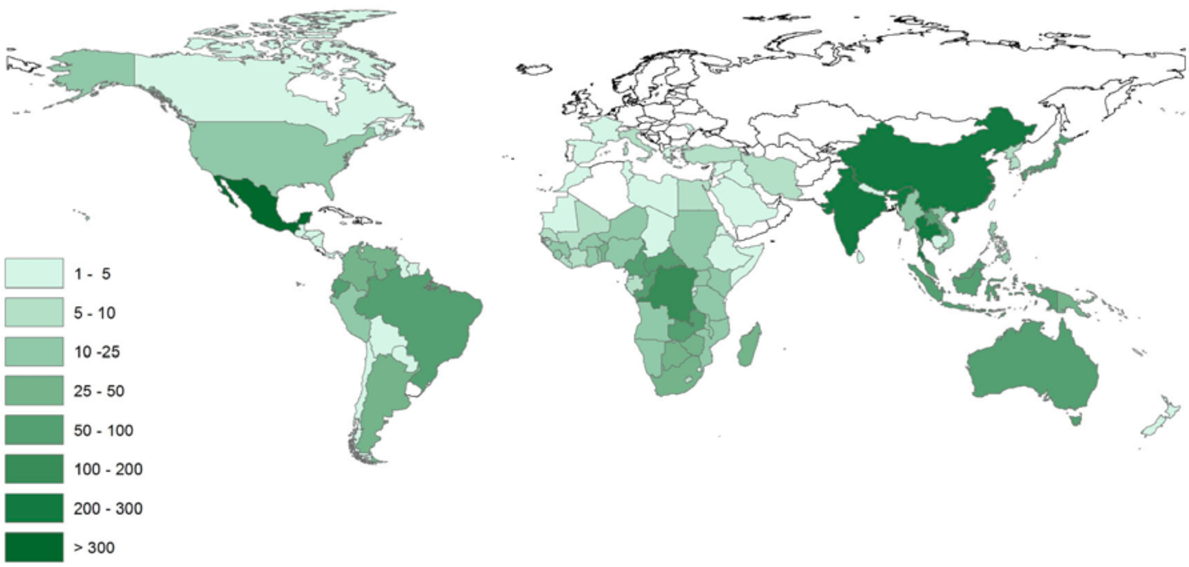


**Figure 1.** Recorded numbers of edible insect species, by country. (Source: Jongema, 2017)

## Attitudes, market and communication

The acceptance of entomophagy is predominantly influenced by culture and religion. Western societies are largely alone in rejecting entomophagy, with insect consumption widespread in most other parts of the globe (van Huis, 2016). However, the recent explosion of interest in the insects as food and feed field has led to a greater understanding of the impact of psychology, culture and marketing on this acceptance. In Western societies the consumption of insects is often viewed with disgust (Payne, 2016), likely a major reason why insect rearing has been neglected in Western agricultural research.

Western society remains reluctant to change meat consumption patterns, with consumer awareness of the impact of meat consumption and willingness to change dietary habits surprisingly low (Hartmann, 2017). As the American psychology professor Paul Rozin has said: "the last and critical step in promoting insects as food is getting people to eat them". Rozin et al. (2014) predicted insect acceptance in Americans using both demographic and psychological variables. The predictions included traits such as:

- Disgust sensitivity
- Beliefs about the risk of consuming insects
- Beliefs about the benefits of consuming insects
- Desire to have new and stimulating experiences
- Risk tolerance, food neophobia (resistance to try new foods)
- Gender

Understanding the 'disgust factor' is a serious issue when promoting entomophagy in Western societies. Disgust is often the result of negative taste and consistency expectations, expectations that can be changed if insects are processed and presented as part of a familiar combination of foods (Tan et al., 2016). These expectations also vary between countries and regions. For example, while mealworms are the preferred edible insect in the Netherlands they are associated with rotting and decay in Thailand, leading to a Thai preference for giant water bugs (Hartmann, 2017). Consideration of these local attitudes, expectations and even language is very important to the successful marketing and communication of edible insects (Ali, 2016).

Disgust can also be a result of a lack of previous exposure to insect consumption culturally or socially (Wilkinson, 2018). This is evident in the Netherlands for example, where an ongoing promotion of entomophagy since the 1990s has resulted in a greater acceptance of edible insects among the public (Dicke et al., 2014). The key to success has been collaboration among the research community, the private sector, government institutions, foundations and non-profit organisations. Dicke et al. (2014) believe that these success factors may also be relevant for promotion of edible insects in other countries. Communicating the benefits of insect production has been shown to a very effective method of influencing consumer attitudes towards entomophagy (Barsics et al., 2017). Once exposed to insect consumption, consumers are far more accepting of the practice (Hartmann, 2016). As such, overcoming the disgust factor is a matter of increasing familiarity and influencing consumer expectations through effective communication of the benefits of edible insects and their applicability to existing local food combinations.

## Preparation and processing of edible insects

Insects are often consumed whole, but can also be peeled and processed. Western societies are generally reluctant to consume whole insects and therefore insect-based flour, granules and pastes that are included in other products can offer alternatives (Gmuer et al., 2016). It is also possible to extract protein, fats, chitin, minerals and vitamins from insects. Insect processing techniques are developing rapidly (de Castro et al., 2017), though further development is still needed to make them applicable for industrial use (FAO, 2013). Products such as protein-enriched porridge, taco bread, muffins, protein bars and snacks have been developed, and advances towards the better preservation of insects and insect products are now being made (Kamau et al., 2018). However, from the perspective of sustainability, extensive processing should be considered from a resource use perspective, since it will increase energy consumption and costs. In addition, there is a risk of over-consumption of protein if insect meal is included in products not generally considered as protein foods (like snacks and bakery). Although this may not pose a health risk to humans, it is a waste of resources.

## Nutrient composition and nutritional value of insects

The nutrient content of insects varies considerably, both between species and also between the different development phases. Due to this variation it has been suggested that the term "insects" is not a useful term for discussions on nutrition (Payne et al., 2015). The crude protein and fat content is high in several species (Table 1), while the amino acid profile of many insect species appears to be highly applicable to a human diet, even for very small children (Table 2).

**Table 1.** Examples of crude protein and ether extracts of fats ( percent of dry matter) in house cricket, silkworm and mealworm (Source: Makkar et al., 2014; Williams et al., 2016)

| | House cricket *(Acheta domesticus)* | Silk worm *(Bombyx mori)* | Meal worm *(Tenebrio molitor)* |
|---|---|---|---|
| **Crude protein** | 55-67 | 52-71 | 47-65 |
| **Fats** | 10-22 | 6-37 | 14-43 |

**Table 2.** Amino acid content (g/16 g N) in insects produced as animal feed. (Source: Makkar et al., 2014)

| | House cricket | Mormon cricket | Meal worm | Black soldier fly | FAO reference protein for 2-5 year old child |
|---|---|---|---|---|---|
| **Methionine** | 1.4 | 1.4 | 1.5 | 2.1 | 2.5 (meth. + cyst.) |
| **Cysteine** | 0.8 | 0.1 | 0.8 | 0.1 | |
| **Lysine** | 5.4 | 5.9 | 5.4 | 6.6 | 5.8 |

Rumpold and Schlüter (2013) list published data on the nutrient content of 236 edible insects. Compared to FAO (2013) nutritional data, it is clear that many of the insects listed meet the amino acid requirements of humans and are also high in mono- and poly-unsaturated fatty acids. For example, the content of unsaturated omega-3 fatty acid and six other fatty acids in mealworms is comparable to that in fish. The study by Rumpold and Schlüter (2013) also shows that many insects are rich in micro-minerals such as copper, iron, magnesium, manganese, selenium and zinc, as well as vitamins such as riboflavin, pantothenic acid and biotin and, in some cases folic acid, all of which are valuable in terms of human nutrition. Payne et al. (2015) conclude, based mainly on comparisons of micronutrient contents, that certain insects may be superior to conventional meat products in situations of undernutrition.

However, it is possible that insect nutritional content varies based on feed, development stage and processing procedures (Churchward-Venne et al., 2017). For example, the nutrient data available are from samples of animal feed where intact insects are likely to have been used. When consumed by humans, insects are sometimes peeled (wings and legs are removed). This can result in a loss of protein and an increase in the fat ratio content (Miech et al., 2017). There have been suggestions that a removal of chitin (exoskeleton of insects) may improve digestibility and palatability (Kourimska et al., 2016), but in a study by Miech et al. (2017) no effect on digestibility or nitrogen retention was seen with the removal of legs in crickets. These results imply that 100 percent of the crickets shall be used for food and feed.

Little is known about the digestibility and nutrient utilisation of insects by humans, though a number of studies on animals show that dietary inclusion of insects, instead of conventional protein sources such as soybean and fishmeal, does not adversely affect growth. Finke et al. (1989) concluded that cricket protein is equivalent or superior to soya protein as a source of amino acids for young rats. In a study with chickens, no significant differences in weight gain were found between animals fed corn-soybean meal diets and animals fed corn-cricket diets (Nakagaki et al., 1987). Mealworm has been substituted successfully with soybean in the diets of poultry (Bovera, 2016) and with fishmeal in the diets of shrimp (Panini, 2017), as well as up to 50 percent of fishmeal in the diets of fish (Sanchez-Muros et al., 2016; Gasco et al., 2017). A broiler study using the black soldier fly showed growth and egg production rates similar to those obtained with soybean-based feed (Maurer et al., 2016). Studies on the growth and performance of monogastric animals (e.g. laying hens and pigs and rats) on mealworm diets seem to be lacking (Makkar et al., 2014). A recent study using pigs as human models showed high values in digestibility and nutrient uptake (Miech et al., 2017), with other recent studies are optimistic of insects as feed for pigs (Poelaert et al., 2016; Ji et al., 2017).

## Entomophagy and human health

There is very little doubt that entomophagy can be an important solution in decreasing malnutrition in developing countries, but it may also help to improve health in Western societies. Iron deficiency is the world's most common nutritional disorder, according to the World Health Organisation (WHO).

This condition not only occurs in developing countries but also in Western societies, e.g. in Sweden, 45 percent of adolescent girls are at risk of iron deficiency (Sjöberg and Hulthén, 2015). Many insects have a high iron content (Bukkens, 1997; Bukkens, 2005; Oonincx et al., 2011), even higher than red meat (FAO, 2013), and entomophagy could therefore be recommended from that perspective. If red meat consumption is reduced in the future, as recommended by the Swedish National Food Agency (Livsmedelsverket, 2015), iron deficiency could become even more common than it is now unless appropriate substitutes are used. Miech et al. (2018) suggested that a child (1-2 years) would fulfil its iron requirement by consumption of about 100 grams of field crickets reared on a weed (*Cleome rutidosperma*).

Chitin is a main component of the exoskeleton in insects and consists of a polymer of N-acetyl-glucosamine. Chitinase (the enzyme that breaks down chitin) has been found in human gastric juices (Paoletti et al., 2007), but it is not clear to what extent chitin is actually digested by humans (Muzzarelli, 2012). The effects of chitin intake seem to be complex and both negative and positive impacts on the immune system have been documented (FAO, 2013). The effect of chitin consumption in humans is actively being investigated, with the maximum safe intake of chitin in humans an important factor of insect consumption (Schluter, 2017).

It has been proposed that consumption of locusts and grasshoppers without removing their legs can cause intestinal constipation and therefore removal of legs, and perhaps also wings, prior to consumption is recommended (FAO, 2013). The removal of legs before consumption is not universal (Halloran, 2017), and not practised in many areas where crickets are traditionally eaten. A recent study using pigs (used as human model), showed that much nutrients are lost, if legs are removed from the crickets (Miech et al., 2017).

Studies indicate that patients allergic to house dust mites and crustaceans may be at risk when consuming mealworm protein (Broekman et al., 2014), and that patients allergic to prawns may be more susceptible to cricket allergies (Srinroch et al., 2015). The effect of different insect processing methods on allergenicity is also tentatively under investigation (Broekman et al., 2015), though more studies regarding insect allergic potential have been called for (Testa et al., 2017).

As with all nutrient-rich food, there is a risk of contamination and growth of microbes during processing and storage of insect products. This may, of course, adversely affect product quality, but it may also cause food-borne illness. Stoops et al. (2016) recently concluded that a microbiocidal (bacterial pathogen-reducing) processing step is required to minimize risks when consuming mealworms and grasshoppers produced for human consumption. Fernandez-Cassi et al. (2019) recently published a review and a risk profile for *Acheta domesticus*. They identified as main hazards: (1) high total counts of aerobic bacteria; (2) presence of spore-forming bacteria post thermal processing; (3) accumulation of cadmium and other heavy metals; and (4) a possible increase of allergenic reactions due to exposure to insects and insect derived products.

## Entomophagy and nature conservation

In countries where insects are traditionally used as food, the main way of obtaining insects is by gathering them in the wild (van Huis, 2013). As a consequence, the insect species and their habitats may become at risk. In all systems when humans harvest natural resources, over-exploitation and destruction of habitats and species can be the result (Yen 2015; van Huis and Oonincx, 2017). It can also have positive affect on species communities and habitats, when people utilising the insects protect the area to safeguard the resources (DeFoliart, 1997). In some countries the use of pesticides has been reduced in areas as a response to harvesters noting a decrease in insect populations (DeFoliart, 1997).

## Legal obstacles

Insects are not yet fully approved as food within the EU, since risk assessments are lacking (EU 2015; 2017). The Dutch and Belgian food authorities have published some risk assessments (EFSA, 2014a, b, c), which they use to regulate their own industries. Countries within the EU interpret the laws differently which has resulted in insects being sold as food in some countries, but not in others.

# Insect farming for food production

Although humans have used insects for different purposes for many thousands of years, only honeybees, cochineals and silkworms have been domesticated. The reason for this is probably multifactorial and includes biological, historical and cultural aspects (FAO, 2013).

Today, most edible insects are harvested in the wild and farming of insects for direct human consumption began only recently (FAO, 2013). Rearing of insects for food is found in south-east Asia as well as in central and southern Africa (Durst and Hanboonsong, 2015; Kelemu et al., 2015; Gahukar 2016). These facilities are often small-scale businesses and run as family companies or by farmer groups that generally rear insects for local markets (Figure 2), some facilities export to close-by regions (van Huis, 2013). Insect farms can also be found in the USA and the Netherlands (FAO, 2013). The cricket pet food industry in the USA is described as a multimillion-dollar business, with as many as 50 million crickets produced weekly (Weissman et al., 2012). Most insect farming in Western countries consists mainly of family-run enterprises with the main focus on pet and zoo animals, although some farms produce small amounts for human consumption (FAO, 2013). The species most farmed are crickets (*Gryllodes sigillatus, Gryllus bimaculatus, Acheta domesticus*), mealworms (*Zophobas morio, Alphitobius diaperinus, Tenebrio molitor*), locusts (*Locusta migratoria*), sun beetles (*Pachnoda marginata peregrina*), wax moths (*Galleria mellonella*), cockroaches (*Blaptica dubia*) and house fly maggots (*Musca domestica*).

If insects are to become a profitable dietary component for humans, large quantities of insects need to be produced on a continuous basis. This means that both farming and processing need to be highly automated (Berggren et al., 2018). Accordingly, there is a need for development of efficient and safe


Figure 2. A typical Asian smallholder rearing system for crickets. The crickets usually stay inside the cardboard egg boxes. Harvesting is done using a brush and a bag, or by shaking the boxes over a water trough. To prevent crickets from escaping, the tray is covered with a net and the walls may be covered with a slippery surface, e.g. tiles.

mass-rearing systems in Western countries. Development of mass-rearing systems for some insect species is currently underway in the Netherlands (FAO, 2013; van Huis, 2013).

## Breeding

As already mentioned, only honeybees, cochineals and silkworms are considered to be domesticated. The fruit fly (*Drosophila melanogaster*) and other insects are often used as model animals in genetic studies and other species (such as mosquitoes) are used in breeding programs for pest control (Scott et al., 2017), but applied research and breeding programs for farmed insects other than honey bees and silkworms seem to be lacking (Berggren et al., 2018). Breeding could alter e.g. insect growth rate and feed conversion, reproduction, behaviour, disease resistance and flavour.

## Feeding

Most edible insects are herbivores (van Huis, 2014) and feed resources of limited value to humans therefore have potential to be used when farming insects. So far, little attention seems to have been paid to sustainable feeding of farmed insects, but see Miech et al. (2016). Mealworms are typically fed on wheat bran or flour supplemented with soybean flour, skimmed milk powder or yeast (Makkar et



*Roasted house crickets, butterfried chanterelles, dill, pickled onion rings and mustard seeds.*

al., 2014) and crickets are typically fed commercial chicken feed (Miech, et al., 2016). Such strategies cannot be considered sustainable, since some of these ingredients have high food quality and originate from production systems that cause major environmental and ecological problems. There is therefore an urgent need to find sustainable feed resources for insect rearing systems.

Studies on the nutrient requirements of insects are scarce, but data exist for some species (Neville et al., 1961). Studies on how diet affects the nutrient composition of insects are also scarce. In one study, the amino acid profile of field crickets was altered by diet, resulting in a higher methionine content in crickets fed cassava tops and a weed than crickets fed commercial chicken feed and another weed (Miech et al., 2018). In one study on locusts, protein content decreased and fat content increased when wheat bran was included in a grass-based diet, but the content of retinol (a form of vitamin A) was not affected by inclusion of carrots (Oonincx and van der Poel, 2011). However, the nutrient composition of the diets offered was not analysed and the true intake of protein and energy might therefore have had a greater effect than the feed ingredients per se. Another study indicates that the fatty acid composition of insects is affected by the plants included in their diet (Bukkens, 2005). A recent study also showed that mealworms could be grown successfully on diets composed of organic by-products and that diet composition did not influence larval protein content, but did alter larval fat composition to a certain extent (van Broekhoven et al., 2015). Further studies are needed to increase knowledge on the nutrient requirements of selected insect species and on how feed and nutrient intake affects mortality, growth, nutrient composition and flavour of the insects.

## Feed production

Since farming of insects for direct human consumption began only recently, dedicated or commercial large-scale feed production for insects is not yet taking place. By-products from the food, agricultural and forest industry are interesting alternatives and this area needs further investigation. Human food waste and animal manure have been used to rear flies for animal feed, but it is unlikely that such feed resources will be approved in the production of insects for direct human consumption. Feed preservation methods are likely to affect both nutrient availability for the insects and also the need for extra water intake. Preservation of feed for insects is a research area where there is a great lack of knowledge.

## Health, disease and hygiene

Through their diversity in terms of types, numbers, life cycles and habitats, insects expose themselves to a wide range of pathogens. Different parasites and diseases can regulate wild populations of insects, but can also have a major impact on farmed species. In silkworms and honeybees there are records of diseases from the seventh century B.C. Epizootics and infectious diseases develop - or are most evident - at high host densities (Tanada and Kaya, 1993). Such events can be seen in intensive animal production as a potential cause of losses in both animals and production. Little is known about these potential problems when it comes to insect farming for food purposes (Maciel-Vergara and Ros, 2017), but some pathogens have the potential to affect both crickets and consumers (Marshall et al., 2016). For example, recent epizootic outbreaks of a densovirus affecting the cricket *Acheta domesticus* have devasted the American insect-based pet food business (Weissman et al., 2012). In general, FAO recommends that when starting mass rearing (irrespective of insect species), a parental line should always be preserved in case of culture crashes (FAO, 2013).

A zoonosis is an infection or infestation that is shared by humans and animals. Insect rearing for food and feed has not yet been practised long enough to determine the risk of disease transmission (FAO, 2013). However, since insects are taxonomically quite distant from humans compared with conventional livestock, the risk of zoonotic infections is expected to be low. Nevertheless, according to FAO (2013), particular attention should be paid to pathogens that initially have animals as their host, but could then shift to humans as their preferred host. The lack of studies on safety issues and hygienic handling of insects highlights the need for more research in this area.

## Environmental aspects

According to FAO (2006), livestock production accounts for 70 percent of all agricultural land use. As the global demand for livestock products is expected to double between 2000 and 2050, innovative solutions are needed. Land clearing for agriculture is one of the largest contributors to both global warming (Makkar et al., 2014) and devastating biodiversity losses (Chaudhary et al., 2017) and efficient use of land is therefore a high priority. Greenhouse gas emissions are a global concern. Data on greenhouse gas emission from insect rearing are scarce. As with other livestock production systems it is important to distinguish between biological greenhouse gas emissions from those produced directly or indirectly from the use of fossil fuels. To this date no such studies have been performed. A few small-scale experiments by Oonincx et al. (2010) indicate that the endogenous greenhouse gas emissions and ammonia production from insects are low compared to some conventional livestock, while favourable greenhouse gas emission results have been found for cricket production in comparison to poultry production (Halloran et al., 2017). Water is another crucial element and scarcity of water is predicted in the future (FAO, 2012). There are suggestions that insects may need little or no water to drink if the feed contains enough water (Jozefiak, 2016). As water requirement are likely to differ between insect species, more knowledge and studies are needed in this area.

### *Life cycle analyses*

Studies on LCA of different insect species are scarce. There are two on mealworms (Oonincx and de Boer, 2012; Thevenot et al., 2018), house flies (van Zanten et al., 2015; Roffeis et al., 2017) and black soldier flies (Smetana et al., 2016; Salomane et al., 2017) and only one on house crickets (Halloran et al., 2017), and black soldier flies, so more LCAs are urgently required.

Previous LCAs show that land use is the most common benefit of insect production, with insect production often requiring very little land in comparison to conventional livestock production. There is a risk of high energy use when producing insects from them being cold-blooded and the growth and reproduction are dependent on thermal conditions. For production of house crickets and mealworms, for example, a temperature higher than 20°C is feasible and 25-30°C is ideal (Makkar et al., 2014). For insect production to be sustainable all year around in colder climates, waste energy or renewable energy sources must therefore be used. However, this applies for all livestock production systems.

Halloran et al. (2017) suggest that future LCAs of insect production systems take the following into account: (1) clear definition of the insect species and life stages, (2) use of at least two of the following types of functional units: nutritional, mass, or economic-based, (3) collection of empirical data in situ (e.g., on farms/production sites), (4) comparative analysis where production systems produce products that are realistic alternatives to the insect species under investigation, (5) inclusion of additional or previously unconsidered unit processes, such as processing and storage and waste management, and (6) use of a wide range of impact categories, especially climate change, resource consumption, nutrient enrichment potential, acidification potential, and impacts on land and water consumption in order to allow for comparison between studies. There are other aspects of sustainability that are not yet considered in LCAs that needs to be incorporated, such as the impact on biodiversity and risk of escapees (Berggren et al., 2019).

## *Feed conversion rates*

Insects are generally considered to have a low feed conversion ratio (defined as kg feed/kg growth), which corresponds to high feed efficiency (kg growth/kg feed). In the few studies carried out to date, the feed conversion rate for insects has been shown to vary depending on the feed offered (Oonincx et al., 2015; van Broekhoven et al., 2015; Miech et al., 2017) and that it can be considerably lower than for most conventional livestock animals, fish and chicken being exceptions (see Table 3). When feed conversion figures are adjusted for edible weight (approximately 40 percent in cattle, 55 percent in

**Table 3**. Examples of feed conversion rate (FCR) in insects and conventional livestock.

| | FCR (kg feed/kg growth) | Reference |
|---|---|---|
| **Cricket** | 1.5-3.9 | Lundy and Parella, 2015 ; Miech et al., 2017 |
| **Chicken** | 1.8 | Sheppard et al., 2009; Patricio et al., 2012 |
| **Mealworm** | 2.0 | Thevenaut et al., 2018 |
| **Pigs (conventional crossbred pigs)** | 2.6 | Smit et al., 2014 |
| **Pigs (Moo Lath breed, Laos)** | 4.5 | Chittavong et al., 2013 |
| **Beef** | > 4.5 | NRC, 2000 |

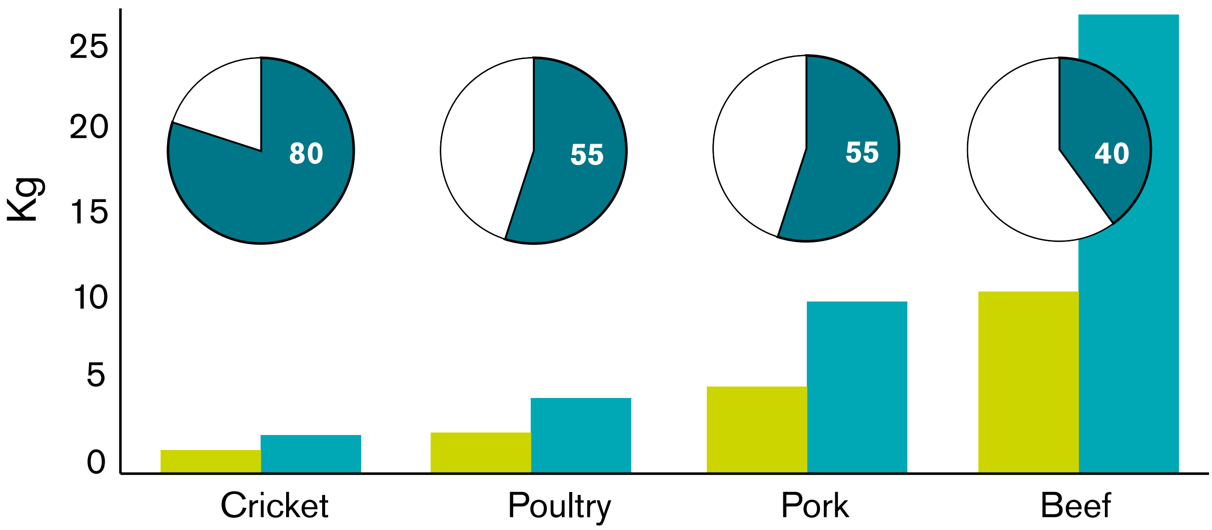


**Figure 3.** Efficiency in converting feed into live weight and edible weight (green bars = kg feed/kg live weight and blue bars = kg feed/kg edible weight) for crickets and some conventional livestock species. The edible proportion of cricket and of poultry, pork and beef animals is 80, 55, 55 and 40 percent, respectively (see pie charts). (A. van Huis, pers. comm. 2014; FAO, 2013).

chicken and pigs and 80 percent in crickets (Nakagaki and DeFoliart, 1991), the advantage of insects is even greater (van Huis, 2013). Crickets then are twice as efficient in converting feed to meat as chickens and more than 12 times as efficient as beef (Figure 3). When reared at optimal temperature, crickets need six times less feed than cattle, four times less than sheep and half the amount compared with pigs and broiler chickens to produce approximately the same amount of protein (FAO, 2015). However, cattle are able to maintain on very low quality products (i.e. high cellulose material and urea) which is not the case for the edible insects we know. Termites may be one exception and attempts have been made to create rearing systems. As far as we know, attempts have failed (Kinyuru et al., 2015), possibly due to the complex ecology and life cycle of this species.

## Animal welfare

Little is known about discomfort and pain experiences in insects (Erens et al., 2012;  FAOs (2013) suggestion that welfare issues are few are probably based on the fact that that some edible insects occur in the wild in crowded conditions and do not perform parental care. Erens et al. (2012) advise that farmed insects be provided with an ample quantity of appropriate quality nutrients, freedom to express natural behaviour, freedom from discomfort, pain, injury and disease and a breeding environment that imitates the natural conditions as closely as possible. Accurately replicating the natural breeding conditions of an insect species can be challenging, requiring comprehensive knowledge of the species' ecology and life-history. Welfare issues for mass-reared insects may also differ from the ones that exist for livestock and as such, guidance on welfare questions needs to be developed (Gjerris et al., 2016). How different insect species should be killed to ensure no suffering is unclear. Techniques such as freezing or deep-frying are commonly used to kill insects, but studies on the impact on animal welfare and food quality are scarce (Erens et al., 2012; Gjerris et al., 2016).

# Interest from society

## Interest from entrepreneurs

There has been a sharp increase in companies producing food made from insects the last few years. Many of the products are snackbars, but there are also a number of flours and shakes (http://www.bugburger.se/foretag/the-eating-insects-startups-here-is-the-list-of-entopreneurs-around-the-world/). Some restaurants serve insects e.g. Noma in Copenhagen, Denmark (http://noma.dk/), the Fat Lizard, Esbo Finland (http://ravintolafatlizard.fi), Viking Line, Finland and the Grub Kitchen, Pembrokeshire, UK. Nordic Food Lab, a non-profit organisation working on the development of gastronomy, supports entomophagy (http://nordicfoodlab.org/). A group of Swedish insect companies have started an organisation called "The Insect companies", promoting e.g. insect eating, development of new knowledge and the interests of the businesses (http://www.insektsforetagen.se). The idea of insects as a human foodstuff also reaches in to architecture A Swedish architectural firm (Belatchew architects) recently won an international prize for its concept "BuzzBuilding", which integrates building of flats with rearing of crickets and bees in and around the building (BuzzBuilding, 2015a, 2015b).

## Interest from media and the public

The interest from media around the world has grown significantly in the last few years, with articles on a variety of aspects related to the use of insects as food published in newspapers and magazines such as ABC News, The Telegraph and The Wall Street Journal. In Sweden, national news media coverage has also been significantly increased, with information from the Swedish University of Agricultural Sciences (SLU) regarding entomophagy appearing in a number of different types of media over recent years (e.g. Swedish Television "World of Science" program, Swedish Television "Morning news", Swedish Television local news, National radio "Science radio", National radio P1 and P4, Uppsala Nya Tidning, Land). This has sparked huge interest and positive responses from other branches of the media and the public. Students from different educational levels have done projects and theses driven by their interest in the field. Several have been linked to nutrition and digestion (Håkansson, 2018; Thorsson, 2018) and to attitude and markets of insects as food (e.g. Bechter, et al., 2014; Aspholmer and Gellerbrandt, 2014).

# Use of insects in a wide perspective

Although the present report focuses on the use of insects as food, it should be mentioned that the human use of insects is wider and is an ancient practice. Honey and silk are the most commonly known insect products. A common dye (carmine) used to colour food and textile red is also by insects. A rubber-like protein called resilin that enables insects to jump has been suggested to have both industrial and biomedical applications (Elvin et al., 2005) and chitosan, a material derived from chitin in the exoskeleton, has been considered as a potential polymer for food packaging (FAO, 2013). Fats from insects can be extracted for mechanical use, since these fats may possess valuable properties like extremely low freezing points. Some insects are used in biological pest control and bees are used for pollination of crops. The rearing of crickets and mealworms for the pet and zoo market has been carried out for quite some time. Insect production for inclusion in feed for conventional livestock is an alternative use of reared insects (Makkar et al., 2014, Miech 2017). Systems using organic waste and rearing of black soldier fly and housefly are currently being developed and American patents are pending.

# Insect farming for food in Sweden – risks and possibilities

## Ecological aspects

### *Importance of using native species for mass rearing*

Intended or unintended introduction of new species is one of the greatest threats to natural systems and production systems today. Invasive species are estimated to reduce food production by 14 percent globally, while 30-45 percent of the pests in agricultural and forest systems are non-native (Pimentel, 2007; Kenis and Branco, 2010). New species are being introduced to ecosystems as a result of increased transport and travel and imports of goods.  Non-native species establishment is expected to increase due to changes in land use and climate, factors that can increase the competitiveness of new species. There are around 2200 non-native species in Sweden today, of which 392 are regarded as invasive and 84 as potentially invasive, while for 993 species there are currently no estimates (Nobanis, European Network on Invasive Alien Species 2019). World-wide, the monetary costs of non-native species that have become invasive are enormous and escalating. At a conservative estimate, these costs amount to around 5 billion Swedish crowns per year in Sweden (Gren et al., 2009). It is very important not to contribute further to this existing problem, as any species brought in to a new region becomes a risk (Berggren et al., 2019). Insect species that do not exist in Sweden should therefore not be used in production systems. However, although there is the potential for Swedish native insects to be used as "mini-livestock" for food production, there is unfortunately very little knowledge on how this potential can be achieved at present. This attitude must also extend to feed production, to ensure that only native feeds are applied in any insect-based food system.

### *Sustainable use of the agricultural landscape*

The loss of natural habitats within the agricultural landscape is believed to be the main driver of biodiversity declines on arable land (Senapathi et al., 2015; Duflot et al., 2017). The use of pesticides and fertilisers has negative effects on biodiversity and biological control (Rundlöf et al., 2015). Possible actions to mitigate biodiversity decline based on landscape composition and management can be increasing small-scale heterogeneity in monoculture landscapes, reduce the use of fertilisers and pesticides and establishing vegetated strips (e.g. grassy edges) around crop fields (Josefsson et al., 2013; Fried et al., 2018). Harvested vegetation from areas with biodiversity enhancing actions (e.g. grassy strips) could be used as feed in insect production according to what is suitable for the reared species. This approach would provide feed for farmed insects and the plant material would also be grown with a purpose to benefit native biodiversity. Thought out and planned this way, large-scale feed production for insects could also contribute to biodiversity.

## Potential insect species for farming in Sweden

### *House cricket*

The house cricket (*Acheta domesticus*) has been part of the Swedish fauna for several hundred years and can today be considered native. Crickets are considered easy to farm (Mott, 2017) and that is probably one important reason why there are very large numbers of cricket farmers in countries such as Thailand (20 000 farmers; FAO, 2013). Crickets can eat a large range of organic material, reared in crowded conditions (2 000 insects per square meter) and prefer temperatures in the upper level of 20°C (Neville et al., 1961; Parajulee et al., 1993; Makkar et al., 2014; Cortes Ortiz et al., 2016). Unfortunately, large populations of the house cricket farmed today seem to be affected by a virus (Maciel-Vergara and Ros, 2017), which may have devastating effects on populations (Weissman et al., 2012).

### *Mealworm*

Mealworms, the larvae of the beetle *Tenebrio molitor*, can be a promising option for mass rearing in Western countries as this insect is endemic in temperate climates, has a short life cycle and is easy to farm. Farming expertise is already available in the pet feed industry and the species is one of the predominantly used in the growing entomophagy industry (Cortes Ortiz et al., 2016; Berezina 2017). There are a growing number of studies on the nutrient requirements, feeding and rearing of this insect. Moisture in the feed seems to be critical to the mealworm and may affect productivity and fat content (Urs and Hopkins, 1973; Makkar et al., 2014) while different feed might affect fatty acid composition (Dreassi et al., 2017). Mealworms are omnivores but are typically fed on wheat bran or flour supplemented with soybean flour, skimmed milk powder or yeast (Makkar et al., 2014). Rearing mealworms on wheat flour, soya and skimmed milk cannot be considered sustainable, since these products could be considered more suitable for direct consumption by humans. According to Makkar et al. (2014), mealworms have the ability to recycle plant waste material of low quality into high quality feed.

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*Meal worms at the event Matologi in Sweden.*

### *Honey bee*

The honeybee (*Apis mellifera*) is a potential species for breeding. There is a vast amount of knowledge on honeybee ecology, breeding and population health. Varroa mites (*Varroa destructor*) have major impacts on bee health and the survival of bee colonies. Varroa is more often found in drone broods and one method to reduce varroa mites is to make the queen lay the drone larvae in special combs that are later harvested (Calderone, 2005). This reduces the amount of varroa mites in the population without adversely affecting the worker population or honey production. Today these drones are usually not used, but studies on flavours of drone larvae and pupae show that the species has a potential as food and that flavour is dependent on life stage (Evans et al., 2016).

# Insects as food – something for the future?

It is well known that many current food production systems are not sustainable in a global perspective. The struggle to mitigate the effects of land clearing for agricultural use, loss of natural habitats, global warming, use of fossil fuels, use of pesticides and health and welfare issues in animal production systems will continue unless major changes are made. There are good indications that insects are a viable source of food for humans, and that they have the potential to be utilised as food to a much higher degree than is evident today. Developed countries should take their responsibility in acknowledging this resource, thereby giving it a status that inspires others to continue and develop sustainable production systems. The biological traits coupled to insects provide a potential basis for the development of a sustainable food industry, but only if we are able to gather the knowledge that is needed and concerted efforts are applied to enable this potential to be realised.

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