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Preface

In tropical countries, insects have been a food source for a very long time, and the local population has an intricate knowledge about which species can be eaten, when and how they can be harvested, and which methods to use for conserving, preparing and consuming the insects. In the western world, this knowledge is absent as insects were never considered as food. However, insects are farmed by private companies as feed for pets, birds, fish, reptiles, etc. This utilisation is only a small niche market and the volumes produced are rather limited.

There is an increasing awareness that with the growing world population and increasing welfare that business as usual for the production of animal proteins in not an option. The land area available on our planet to satisfy the increasing demand for animal proteins is not enough. Besides, there are concerns about the environmental footprint of producing livestock (greenhouse gas and ammonia emissions), about infectious diseases of vertebrate animals that can naturally be transmitted to humans (zoonosis). For those reasons, society is receptive to the idea of searching alternative protein sources. Although it was known in the western world that insects are eaten in the tropics, only now they are considered as an option to be used both as human food and animal feed. Only since the last ten years there is an increasing interest to farm insects as a new source of protein for humans and for animals. This in particular when considering the lower environmental impact when compared to the conventional protein products.

However, to go from a niche market to producing edible insects at an industrial level is new. The only examples of mass rearing insects are those used in pest control. One example is the sterile insect technique in which large numbers of sterile insects are released into the wild. The sterile males compete with wild males to mate with the females. Females that mate with a sterile male produce no offspring, thus reducing the next generation's population. Insects that have been controlled (eradicated) this way are screw-worm flies, fruit flies and tsetse flies. Biological control companies have experience in rearing insects to control agricultural

pests (i.e. natural enemies, such as predators and parasitoids). However, the companies that produce insects as feed for animals are rather small with a lot of labour involved making it too expensive to be competitive to conventional feed products.

So, the field of rearing insects for either human food or animal feed is new. Companies are engaged in automating the system in order to bring the price down. However, there are many challenges. To make it interesting to rear insects, such approaches have to be done sustainably and environmental impact should compare with the farming of common production animals. What kind of production design and what kind of facilities are needed to farm the insects in an optimal way? Can we fine tune the rearing technique to respond to the biological requirements of the target species? What about using different strains of insects and how can we maintain a high quality of the insects (genetics). What kind of diets are we going to use taking into account the price and the large influence substrates have on the development of the insect and on the nutritional value of the end product. Of particular interest is the use of organic side-streams as this would largely contribute to a circular economy. Other factors of importance to the nutritional quality are for example the abiotic conditions and the stage of the insects to be harvested. Also, we have a lot of knowledge about entomopathogens to kill pest insects, but very limited knowledge about diseases and pests that occur in insect rearing. Wat about insect welfare? Does the killing of thousands of insects for food or feed morally equal the slaughtering of one cow? Then after harvesting the larvae, what is done with the substrate and how to process the insects? How to deal with chitin, protein and oil? Finally, the product needs to marketed. When insects are used as food then consumer attitudes play an important role and what kind of strategies to use to convince the consumer? Another very important issue in such an innovative sector is the legislative framework which is often not conducive. What kind of enabling conditions are required for the edible insect industry to thrive?

Finding answers to all these questions served as the impetus for bringing together a diverse group of researchers and practitioners from around the world to develop this book dealing with all aspects of farming insects and developing methods for efficiently bringing insect-related products to the consumer.

In order to improve the quality of the book most chapters have been subjected to a peer review process. We tried to find the best independent subject experts around the globe to do so. Most chapters have been checked for accuracy and readability by at least one reviewer, most often two and sometimes even three reviewers. The detailed feedback, from a range of expert reviewers, ensures that that we deliver relevant, cutting edge, and high quality information useful for students, teachers, practitioners, and researchers. We wish to thank all reviewers, listed on the next page for the willingness to check the chapters and provide their valuable comments.

The editors and Wageningen Academic Publishers want to thank the Uyttenboogaart-Eliasen Foundation (UES; http://tinyurl.com/y77pkj6b) in the Netherlands for their generous grant to develop the e-learning module attached to this book (https://e-insects.wageningenacademic.com). The grant also allowed the incorporation of specially made high quality photographs both for the book and the e-learning module. The module enables readers to test whether they have learned from the book and to get feedback.

Arnold van Huis and Jeffery K. Tomberlin

credits

The photographs at the beginning of each section and of each chapter have been made and are copyrighted by Hans Smid (bugsinthepicture.com), except for the photograph in Chapter 2, which was made by Nina Fatouros (bugsinthepicture.com). The photographs of Hans Smid were optimized for increased depth of field by making multiple images taken at various distances with a camera (Canon M5, Tokyo, Japan) mounted on a Stackshot automated macro rail (Cognisys, Traverse city, MI, USA). Resulting stacks of images were processed in Zerene stacker software vs 1.04 (Zerene systems, Richland, WA, USA). The following insect species are shown:

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1.

Lucilia sericata

The potential of insects as food and feed

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Abstract

Insect production has gained recognition globally as a viable economy in terms of protein production for food and feed. While many tropical countries have practiced entomophagy for millennia, western nations are just now tapping into this tremendous resource. The purpose of this text is to review the many facets related to insect production ranging from examining the diversity of arthropods currently being mass-produced, ethics of such systems, to industrialized processes currently employed to meet the growing demand. While the architecture from production of the insect to packaging is still in its infancy, this growing sector of agriculture is presented with a unique opportunity to address potential hurdles prior to their encounter through communication, education, and practice.

Keywords: edible insects, insects as food and feed, animal protein, alternative protein sources, environment, organic side streams

1.6.4 Ability to convert organic side streams

FAO (2011) estimated that 'roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tonnes per year'. The value of the lost and wasted food has been estimated to be 750 billion US$ (The Economist, 2014). Most of it is vegetables (23%), followed by meat (21%), fruits (19%) and cereals (18%) (Figure 1.3). Besides, this loss and waste is associated with approximately 173 billion cubic meters of water consumption per year and 198 million hectares of cropland per year (Lipinski *et al.*, 2013).

The use of side streams to grow insects is of course a very interesting option. Most considered as insects as feed are the black soldier fly and the house fly. The capacity to live on organic side streams seems to be somewhat larger for the black soldier fly. Both have quite different life cycles in which the advantage of the house fly is their tremendous reproductive capacity (Figure 1.4). However also other fly species such as the blow fly, *Lucilia sericata*, and face fly, *Musca autumnalis*, can be considered (Čičková *et al.*, 2015). For insects for human consumption the yellow mealworm and crickets can also be grown on organic side-streams, in particular fruit and vegetable remains as well as dried distillers grains with solubles can be considered. An overview of these species grown on different types of organic side streams is given in Table 1.5. Also, a list is given of references indicating which insect species can be fed to pigs, poultry, to animals in general and to a number of fish species (Table 1.6). As alternatives for fish meal plant proteins (soya protein, corn gluten, pea meal and wheat gluten) have been and will probably continue to be the main choice when replacing fishmeal in aquaculture. However, these products have limitations due several nutritional drawbacks compared to fishmeal (Lock *et al.*, 2015; Olsen and Hasan, 2012) particularly in diets for carnivorous species, which are not adapted to plant feed. Besides, there is a relative low content of proteins, the amino acid profile is unbalanced, and the fibre content is high. Anti-nutritional components are present, reducing digestion or absorption of nutrients, counteract the function of vitamins and may even induce toxicity. Plant proteins also compete with use for human consumption.

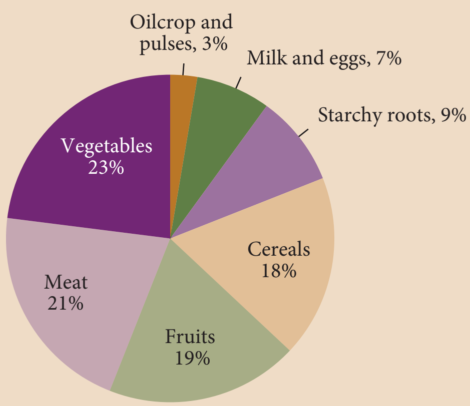

Figure 1.3. Global economic costs of food wastage (750 billion US$), by commodity, 2007 (The Economist, 2014).

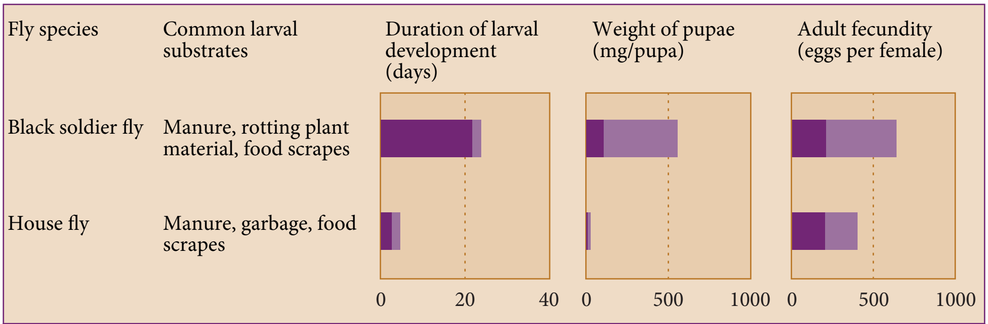

Figure 1.4. Comparison of life histories (under optimum conditions) of some fly species used for biodegradation (Ĉiĉková *et al.*, 2015).

Table 1.5. Insects species able to convert certain types of organic waste streams and references.

Insect species	**Organic side streams and references**
Black soldier fly	• organic waste (Čičková *et al.*, 2015; Diener *et al.*, 2011b; Leong *et al.*, 2015; Oonincx *et al.*, 2015a; Pastor *et al.*, 2015; Surendra *et al.*, 2016) • manure (Lalander *et al.*, 2015; Li *et al.*, 2011; Newton *et al.*, 2005a; Oonincx *et al.*, 2015b; Zhou *et al.*, 2013); pig manure (Newton *et al.*, 2005b; Wang *et al.*, 2013); cattle manure (Liu *et al.*, 2008; Myers *et al.*, 2008; Rehman *et al.*, 2017); chicken manure (Erickson *et al.*, 2004; Sheppard, 1983; Sheppard *et al.*, 1994); kitchen waste (Driemeyer, 2016) • coffee pulp (Lardé, 1989, 1990) • vegetables (Pineda Mejia, 2015; Rehman *et al.*, 2017; Spranghers *et al.*, 2016; Supriyatna *et al.*, 2016) • catering waste (Jeon *et al.*, 2011; Spranghers *et al.*, 2016; Zheng *et al.*, 2012a,b) • municipal organic waste (Diener *et al.*, 2009, 2011a; Gabler, 2014) • straw (Manurung *et al.*, 2016; Nicks *et al.*, 2003; Zheng *et al.*, 2012a) • dried distillers grains with solubles (Spranghers *et al.*, 2016; Webster *et al.*, 2015) • sorghum and cowpea (Tinder *et al.*, 2017)
House fly	• organic waste (Čičková *et al.*, 2015; Pastor *et al.*, 2015; Ramos-Elorduy and Morales, 1989) • manure (Shah *et al.*, 2016); pig manure (Čičková *et al.*, 2012a,b; Roffeis *et al.*, 2015; Wang *et al.*, 2013; Zhang *et al.*, 2012); poultry (El Boushy, 1991; Teotia and Miller, 1974); cattle (Hussein *et al.*, 2017) • municipal organic waste (Ocio *et al.*, 1979)
Yellow mealworm	• organic waste (Oonincx *et al.*, 2015a) • vegetables (Ramos-Elorduy *et al.*, 2002; Van Broekhoven *et al.*, 2015) • dried distillers grains with solubles (Van Broekhoven *et al.*, 2015)
Crickets	• organic waste (Oonincx *et al.*, 2015a) • vegetables/cereals (Caparros Megido *et al.*, 2015; Miech *et al.*, 2016) • weeds (Miech *et al.*, 2016)
Cydia pomonella	• wastewater sludges (Brar *et al.*, 2008)