Preface

If you are searching for a comprehensive handbook for the commercial cultivation of edible insects, we highly recommend this book: The Basics of Edible Insect Rearing – a Handbook for the Production Chain.

The edible insect market is developing rapidly. In short, the demand for insect products is increasing and there is a lot of interest in rearing edible insects. Edible insect experts are increasingly being questioned by starting entrepreneurs on a wide variety of topics: what is the biology of insects like, how should I start producing insects, and how to upscale; which rearing methods are recommended; what are the optimal values of temperature and humidity; on feed and waste streams: which chemical compositions, which feeding methods, should I pre-treat waste streams or not; how should I illuminate the insects, how many larvae per cm^3; how do I maintain my insect population; how do I design a rearing facility; how do I manage optimal insect production; how do I handle and store insect eggs and insect larvae; how do I harvest the larvae; how do I prevent unwanted organisms and diseases from entering; what applications are there for insect products as feed, food and non-food purposes; what is the current state of the legal framework; and how about the economics of commercial insect operations?

Several books on edible insects have already been published. This book is unique because it is a handbook that presents the essential knowledge as well as practical techniques and engineering tips. Individuals interested in starting a business in edible insects, or students who want to know more about the practical implications of edible insect rearing, will benefit greatly from this book.

The authors are gratefully acknowledged for their contributions to the seven book chapters bringing a wealth of experience from both the industry and academia. Marian Peters and Arjan Borghuis are also acknowledged for their contribution in initiating this book. Each chapter was kindly peer-reviewed by co-editors and external scientists, and contains sound basic knowledge as well as practical experiences. The first chapter focuses on the biology, physiology, and nutritional composition of edible insects. Design principles for large-scale insect production are presented in Chapter 2, and Chapter 3 deals with insect production management issues. The practical perspective of how to run an insect farm is presented in Chapter 4. Chapter 5 looks at the careful management of unwanted organisms and provides suggestions on how to address these important challenges in insect production. An impression of applicable European (and to some extent North American) legislation for professionals involved in the insect business and current state-of-the-art is presented in Chapter 6, while in Chapter 7 the economics related to insect rearing is presented.

I am convinced that you will enjoy reading this book and that the information provided is extremely useful for the daily practice of, or education on, edible insect rearing.

Teun Veldkamp
Chief Editor

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1 Biology, physiology and nutritional composition of common edible insects

T. Spranghers[1*], D.G.A.B. Oonincx[2] and J.J.A. van Loon[3]
[1]Centre of expertise for agro- and biotechnology, VIVES University of Applied Sciences, Belgium; [2]Animal Nutrition Group, Wageningen University and Research, the Netherlands; [3]Laboratory of Entomology, Wageningen University, the Netherlands; thomas.spranghers@vives.be

Abstract

In this introductory chapter of the book, the reader is submerged into the fascinating world of the insects. A concise overview is provided to familiarise the reader with terms like hemi- and holometabolous insects. For each of these groups more detailed information is given for the orders and families containing interesting species with regard to feed and food applications. For the hemimetabolous crickets, grasshoppers and locusts, the house cricket *Acheta domesticus* and the migratory locust *Locusta migratoria* are being explored; whereas the holometabolous beetles and flies are represented by the yellow mealworm *Tenebrio molitor,* the lesser mealworm *Alphitobius diaperinus*, the housefly *Musca domestica* and black soldier fly *Hermetia illucens*, respectively. In the last part of this chapter the bridge is made towards the feed and food applications of these insects by providing information about their nutritional composition.

Keywords: insect biology, hemimetabolous, holometabolous, crickets, locusts, beetles, flies

1.1 Introduction

Insects are invertebrate animals that have an exoskeleton and six legs in the adult stage. The animal class Insecta comprises more than 1 million taxonomically described species (Grimaldi and Engel, 2005). Insects can be found in all terrestrial ecosystems and climate zones and in freshwater and coastal aquatic environments. Many insect species provide crucial ecosystem services, such as biological control, pollination of flowers and bioconversion of decaying organic material.

The basic body structure of all adult insects consists of three parts: head, thorax and abdomen. The head of adults is equipped with compound eyes for vision, mouthparts for food ingestion, tasting and touch, and antennae for smelling odours, tasting and touch. Two basic types of mouthparts occur: biting-chewing or piercing-sucking, serving to ingest either solid or fluid foods respectively. The mouthparts carry taste sensilla, as well as sensilla to detect volatile compounds (olfaction) and touch (mechanoreception). The thorax has three segments, each bearing one pair of jointed legs that are equipped with taste and touch sensilla. Adult insects have two pairs of wings attached to the second and third thoracal segments, except the order of Diptera (flies and mosquitoes) that have only one wing pair, and Zygentoma (silverfish and firebrats) without wings. Currently some 25 different insect orders are recognised and most edible insects belong to the orders of beetles (Coleoptera), butterflies and moths (Lepidoptera), flies (Diptera), grasshoppers, crickets and locusts (Orthoptera) and ants, bees, and wasps (Hymenoptera).

In this chapter the basic biology of six commonly mass-reared edible insect species will be presented: a cricket, a locust, two beetles, and two fly species. Information about their life cycle, environmental conditions and diets can be found in Chapter 4.

1.2 Hemimetabolous insects

Insects that develop gradually from nymphal (immature, larval) stages to the adult stage without an intermittent pupal phase are called hemimetabolous and comprise circa 17% of the insect species currently taxonomically described. The most represented edible insects belong to the order of the Orthoptera ('insects with straight wings') of which over 26,000 species have been described worldwide, most of these occurring in the tropics (https://orthoptera.speciesfile.org). They rank among the larger insect species with an adult body length mostly ranging between 2 and 7 cm, and a body mass between 100-2,500 mg. Characteristic morphological features are: (1) large head with biting-chewing mouthparts; (2) a conspicuous saddle-shaped pronotum, i.e. the sclerite (plate) of the prothorax, that is often enlarged to cover also the sides of the prothorax; (3) the femurs of the metathoracic (hind) legs are enlarged allowing the typical jumping movement of this order; and (4) most adult grasshopper and cricket produce species-specific sounds through stridulation, serving a vital function in communication between conspecifics. The adults usually have two pairs of wings, the forewings being thicker and more sclerotised than the hind wings. One or both pairs of wings can be reduced or absent. In the nymphal stages the developing wings can be seen externally (exopterygote) and grow consecutively larger but are only functional in the adult stage. Both the nymphs and the adults feed predominantly on plants (herbivorous or phytophagous).

1.2.1 Crickets (Gryllidae)

The family Gryllidae, type genus *Gryllus,* comprises ca. 2,400 species and are called 'true crickets'. They have a worldwide distribution, except in Antarctica. The largest members of the family are the 5 cm-long bull crickets (*Brachytrupes* Serville), which excavate burrows as deep as 1 metre or more. The tree crickets (Oecanthinae) are delicate white or pale green insects with transparent forewings, while the field crickets (Gryllinae) are robust brown or black insects. Crickets are often seen at night, usually remaining concealed during the day on the ground in leaf litter, among vegetation or under logs and stones. True crickets are found in a variety of environments, including fields, houses, and trees. In contrast to the singing grasshoppers, true crickets are the only family able to hold a constant pitch. By rubbing their forewings together, they can create a musical tone that is used to attract or warn other crickets. Females have a long ovipositor that they use to deposit eggs in the soil. With a three-segmented tarsus and long antennae, often longer than the body, they are a distinctive family of Orthoptera.

There are several species that are produced on a small to medium scale (Caparros Megido *et al.*, 2017), three of which are most common: the house cricket (*Acheta domesticus* L.), the two-spotted or African field cricket (*Gryllus bimaculatus* De Geer) and the tropical house cricket (*Gryllodes sigillatus* Walker). Other species that are mostly produced on a small scale belong to the genera *Teleogryllus* and *Brachytrupes* (Caparros Megido *et al.*, 2017). Here we will focus on the biology of the house cricket, *A. domesticus*.

1.2.1.1 The house cricket – *Acheta domesticus*

Biology

The house cricket is supposedly native to Southwestern Asia but currently has a cosmopolitan distribution. It has 8-9 nymphal stages that take about 45 days at 30 °C and 60% relative humidity (RH) depending on feed nutritional quality (Figure 1.1). It probably evolved from an originally biting-chewing plant-feeding species, and it accepts a wide range of feed sources including living plants (e.g. grasses or leaves of cabbage, melon, pumpkin, cassava), residues of beer production (e.g. spent grains), fruit waste, etc. (Durst and Hanboonsong, 2014; Lundy and Parrella, 2015; Oonincx *et al.*, 2015; Sorjonen *et al.*, 2019). The neonate nymphs that hatch from the eggs are called pinheads due to the large size of the head relative to the rest of the body. The early nymphal instars (i.e. until three weeks of age) are often fed protein-, starch-, mineral- and vitamin-rich cereal-based diets such as commercial chicken feed, while during the last four weeks of nymphal development they can be fed with residual organic materials such as discarded food and agricultural by-products. When fed dry feed, a source of free water is often offered separately (e.g. in bottles plugged with cotton wool). Due to their nocturnal lifestyle and preference for concealed habitats, shelters made of egg cartons are commonly provided in rearing containers. Females produce 1,200 eggs in the first four weeks at 34 °C (Parajulee *et al.*, 1993) whereas Woodring *et al.* (1979) reported a lifetime egg production of 2,800 eggs/female (longevity 60 days) at 28 °C. Eggs are deposited a few cm deep into soil or another material of suitable particle size and moisture content. At optimal conditions the egg develops in about 13 days.

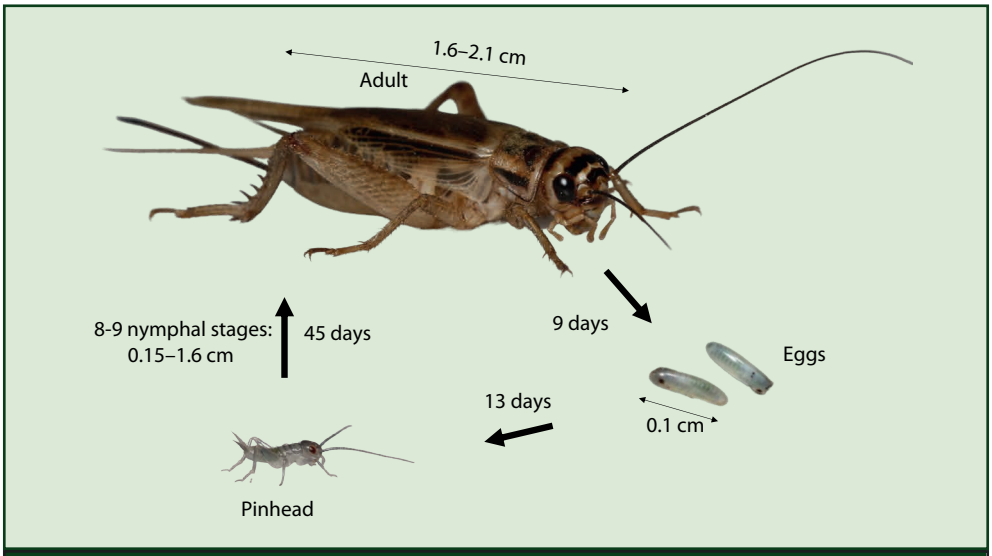

Figure 1.1. Life cycle of *Acheta domesticus* at 30 °C and 60% RH (Inagro).

Physiology

The digestive system of house crickets consists of the (1) foregut – pharynx, oesophagus, crop, gizzard; (2) midgut with caeca (blind sacs), and (3) hindgut – the anterior ileum and posterior hindgut, colon and rectum (Kirby *et al.*, 1982). In the ileum in particular, pockets filled with bacteria are found that most likely fulfil functions in feed digestion.

In-depth studies on *A. domesticus* nutrition, growth and metabolism were performed by Woodring *et al.* (1979) and Roe *et al.* (1980). The diet was a mix of plant and animal-derived ingredients: alfalfa, soybean and corn meal, sorghum, wheat-oat screenings, fish meal, dried-ground meat scraps. In addition, poultry premix (vitamins and trace elements) and NaCl were added. Total dietary protein content was 20% and total lipid content 5%. Growth during the last nymphal stage was entirely somatic and resulted in a fat body containing 65% lipids. Net growth during the first 10 days of adult life was entirely invested in gonad growth. Total protein content of the diet was sufficient for all somatic and ovarian growth. Both nymphs and adults synthesised additional lipids from carbohydrates to supplement absorbed lipids for growth demands. The absorption efficiency (72%) and growth efficiency (28%) were similar for both the last instar nymphs and virgin females consuming the same food. However, the nymphal metabolic efficiency (42%) was higher than that of females (37%), indicating that more of the absorbed feed was converted to tissue during larval growth (somatic) than during adult growth (ovarial). On a commercial cricket diet containing 18% crude protein, 4% crude fat and 4% crude fibre, efficiency of conversion of ingested food (ECI, on dry matter basis) was 20-23% during the nymphal stages and was similar for groups kept at 27 or 29 °C (Morales-Ramos *et al.*, 2017). House crickets perform nutrient self-selection, a capacity that can be applied to determine which nutrients limit growth. Micronutrients (vitamins B1, B5, and C; sterols and manganese) were most limiting for live biomass growth, and improved

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Insect production for feed, food and technical applications: current status and legal framework

A. Paul[1*], J. Mathew[2], C. Muraru[2], L. Gasco[3], I. Belghit[4], G. Vandenberg[5], L. Star[6,7], S. Zibek[8], T. Hahn[8] and C. Derrien[2]

[1]Protix B.V., Industriestraat 3, 5107 NC Dongen, the Netherlands; [2]International Platform of Insects for Food and Feed, Avenue Adolphe Lacomblé 59, 1030 Brussels, Belgium; [3]University of Turin, DISAFA, Largo Paolo Braccini 2, 10095 Grugliasco, Italy; [4]Institute of Marine Research, Nordnesgaten 50, 5005 Bergen, Norway; [5]Department of Animal Science, Faculty of Agriculture and Food Science, Université Laval, 2425 rue de l'Agriculture, Quebec City, QC G1V 0A6, Canada; [6]Schothorst Feed Research B.V., Meerkoetenweg 26, 8218 NA Lelystad, the Netherlands; [7]Aeres University of Applied Sciences, De Drieslag 4, 8251 AJ Dronten, the Netherlands; [8]Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB, Nobelstraße 12, 70569 Stuttgart, Germany; amanpaul@mail.com

Abstract

Insects are recently gaining popularity as food and feed ingredients in Western countries. This chapter is written with the objective to provide an impression of applicable European (and to some extent North American) legislation to people involved in the insect business. It provides information regarding legislative frameworks concerning the following aspects: (1) insect production including feed for insects, rearing, processing, and animal welfare; (2) applications of insect products including whole insects, proteins, fats, chitin derivatives and frass. Moreover, this chapter also provides recent information about regulatory developments expected in the near future and some challenges that need attention from regulators. Finally, it shows that transparency in the national and international legislative framework will be critical for the future of insect farming and use of insect products in feed, food, and technical applications.

Keywords: insect breeding, legislations, proteins, fats, chitin, frass

6.1 Introduction

The commercial rearing of insects started thousands of years ago with the cultivation of *Bombyx mori* for silk production. Silk became a highly valued commodity, and its popularity led to the development of the Silk Route stretching from eastern China to the Mediterranean Sea in 139 B.C. (Cherry, 1987). Commercial farming of insects for biocontrol purposes started in the early 20th century. In 1903, the California State Horticulture Commission constructed a facility to produce natural enemies (Van den Bosch *et al.*, 1982). Commercial farming of insects to feed exotic pets and zoo animals in North America started during the 1950s (Cadinu *et al.*, 2020). The large-scale production of insects for nutritional applications initiated in Western countries mainly during the last decade (IPIFF, 2020a). Currently, insects are being considered as mini-livestock, with multiple applications in fibre, biocontrol, and nutrition industries (Van Huis and Oonincx, 2017). In Western countries, insect production is mainly being promoted due to the sustainability aspects (Paul *et al.*, 2016; Smetana *et al.*, 2016; Star *et al.*, 2020).

This chapter deals with aspects related to the status of insects for the food and feed industries and applicable legislative framework. Insects are recently gaining popularity as food and feed ingredients in Western countries (Collins *et al.*, 2019; Schmitt *et al.*, 2019; Star *et al.*, 2020). However, in order to become mainstream ingredients, insects still need to be integrated into Western society. The integration is linked to the fulfilment of the following criteria: (1) nutritional sufficiency; (2) safety; and (3) consumer acceptance (Van der Meulen, 2010). Nutritional sufficiency of insects for human and animal nutrition is well established (Belghit *et al.*, 2019c; Bosch *et al.*, 2014; Paul *et al.*, 2016; Star *et al.*, 2020). On the other hand, consumer acceptance of insects depends on a wide range of factors, with food safety also playing one of the central roles (Caparros Megido *et al.*, 2016; Paul *et al.*, 2016). The safety of food and feed ingredients is mainly guaranteed by compliance to legislation (Van der Meulen, 2010). This indicates that development of specific regulatory framework in Western countries will enable the consumers to trust in the product, which will facilitate consumer acceptance.

This chapter is written with the objective to provide an impression of applicable legislation to people involved in the insect business, but not as an attempt to systematically summarise the regulations. The chapter first deals with the legal framework concerning rearing and processing of insects, and welfare (Section 6.2). Following this, Section 6.3 focusses on: (1) applications of insects in human and animal nutrition; applications of by-products arising from insect production, e.g. insect frass and chitin, are also discussed. (2) Overview of the legal framework concerning use of live insects, proteins, fats, frass, and chitin derivatives. Section 6.4 provides information about the regulatory developments that are expected in the near future and some of the current challenges that need attention from regulatory authorities. The scope of this chapter will mainly be limited to EU legislations but will also provide suitable examples from other countries (mainly North America) to facilitate readers in making a bridge between global legislations.

6.2 Legislative framework concerning insect production

6.2.1 Insect rearing

Overview of EU food and feed legislations relevant for insect industry is indicated in Figure 6.1. Insects intended for food and feed purposes are considered 'farmed animals' according to EU animal by-products legislation, i.e. Regulation (EC) 1069/2009 (EC, 2009a). Therefore, insect producers should comply with animal health and biosecurity measures on transmissible animal diseases enlisted in Animal Health Law, i.e. Article 10 of Regulation (EU) 2016/429 (EC, 2016).

Additionally, the insect species (and derived products) should not be pathogenic or have any other adverse effects on plant, animal, or human health. The insect species intended for food and feed should not have a protected status or be defined as an invasive alien species in accordance with food and feed hygiene legislation (see Figure 6.1). These provisions apply to all insect producers rearing, processing, handling (e.g. transport, storage) or distributing insects along the food or feed chain. Insects, being farmed animals, may only be fed with feed of vegetal origin and/or animal origin materials in compliance with:

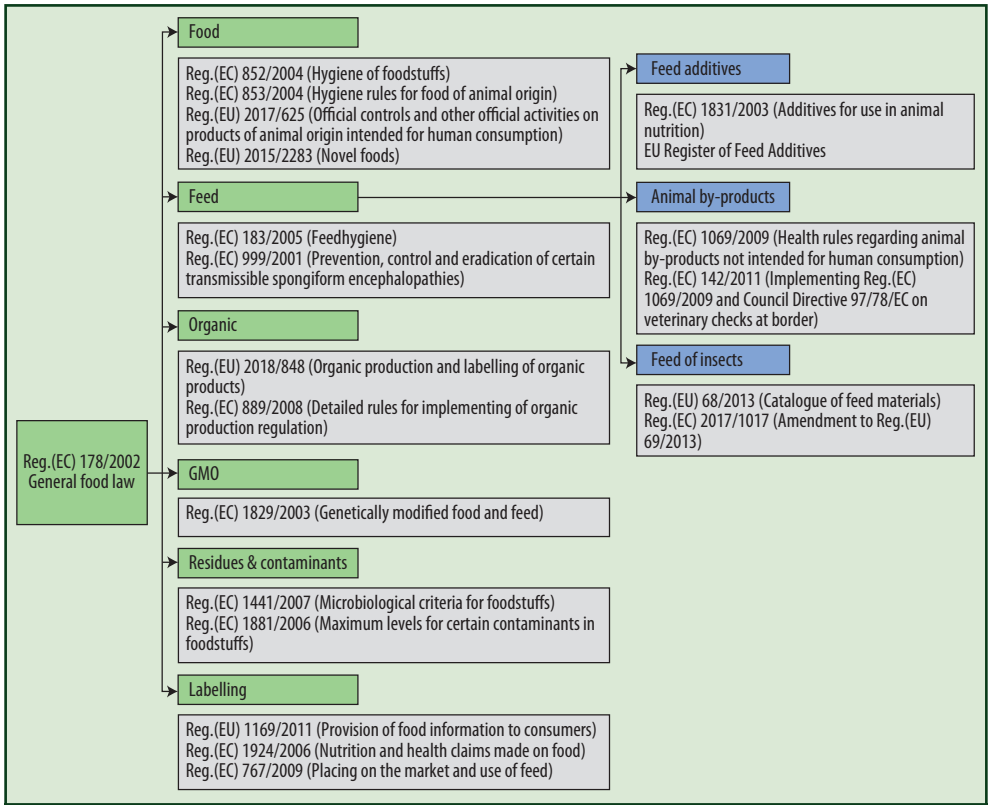

Figure 6.1. Overview of the EU food and feed legislation, relevant for the insect industry.

- Regulation (EU) 2017/1017 (catalogue of feed materials) (EC, 2017a);
- Regulation (EC) No 999/2001 (hydrolysed proteins derived from parts of non-ruminants or hides and skins of ruminants, fishmeal and compound feed containing fish meal, dicalcium phosphate and tricalcium phosphate, blood products derived from non-ruminants and compound feed containing such blood products) (EC, 2001c);
- Regulation (EC) No 142/2011 (former foodstuff namely milk and milk-based or derived products, eggs and egg products, honey, rendered fat, collagen, and gelatine) (EC, 2011).

Whereas, feeding insects with former foodstuffs other than those found on the above list, such as manure/animal faeces and catering waste is currently prohibited in the EU. The companies rearing insects for food/feed applications, and as suppliers of insect feed materials should comply to registration, hygiene, traceability, and facility requirements as indicated in the GFL, and food and feed legislations as indicated in Figure 6.1. Additionally, the undesirable substances in insect feed materials should not exceed the limits indicated in Directive 2002/32/EC (EC, 2002a).

6.2.2 Insect processing for human and animal nutrition

The slaughter of insects and onwards activities could change the primary nature of product and hence are not considered as primary activities. Therefore, insect producers involved in processing activities must align with hygiene requirements concerning facility, equipment, personnel, transportation, sampling plan, record keeping measures, complaints and product recall plan as indicated in food and feed hygiene legislation (Figure 6.1).

Producers of processed animal proteins (PAP) from insects intended for animal feed and pet food applications must be approved by national competent authorities in accordance with the animal by-product legislation (Figure 6.1). Slaughter and further processing shall be done in accordance with the animal by-product legislation and its implementing Regulation (EU) 142/2011 (EC, 2011). Insects and derived products are treated as 'category 3' material and may be used in production of feed for food-producing animals without adhering to the restrictions mentioned in TSE legislation (Regulation (EU) 999/2001). Within the provisions of Regulation (EU) 142/2011, establishments handling category 3 material must: (1) be specifically approved for processing of dead animals into PAPs; (2) choose between methods 1 to 5 or 7 for thermal processing of insect ingredients as mentioned in Annex IV of Regulation 142/2011; (3) adhere to general requirements laid in GFL, food and feed legislation as indicated in Figure 6.1.

6.2.3 Animal welfare

Welfare of farmed insects is a complex topic. With the recent emergence of the insect industry, this topic is becoming increasingly significant. In 1998, the Directive 98/58/EC regarding the welfare of animals kept for farming purposes came into force (EC, 1998). However, the directive explicitly mentions that invertebrates are outside the scope of this document. Therefore, in the current situation, European insect producers do not have to comply with any legal requirements with regards to insect welfare. In this section, we will mainly focus on the good practices used in commercial settings and summarised in literature. Researchers have indicated three philosophical approaches that people use to deal with invertebrates: