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Faculty of Tropical AgriSciences

Insects as Food

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Insects as Food independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague

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Julie Simády

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Abstract

Dietary change is considered a global imperative because current food systems are a major cause of climate change, land-use change, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems.

The aim of this work is a systematic review of literature, covering various aspects of insect consumption: species, nutritional profiles, farming, production, processing, food safety, ecological, social and economic approach and future prospect.

The thesis was made on the basis of primary and secondary sources retrieved from online scientific databases and libraries.

Insect farming provides employment and has the potential to reduce hunger. Insects have significantly lower greenhouse gas production than conventional livestock. It has a short life cycle and require little space and water to breed.

The most common insects consumed are beetles, followed by caterpillars, ants, bees, wasps, grasshoppers and true bugs. Due to their high in protein, fibre, vitamins and minerals and lower fat content, insects can fully replace meat from conventional farming in terms of nutritional composition. Approximately 92 % of edible insects are collected from the wild. That could be a threat of species extinction due to uncontrolled collection. Either semi-domestication or farming, is more sustainable. Semi-domestication enables partial control over reproduction, mortality or space use. Farming consists of creating a habitat for a particular species of insect with the ideal conditions for reproduction.

In insect consumption, there is a risk of contamination with pathogens, the risk of chemical pollution or allergies. These risks are controlled within the framework of food safety.

As part of the work, a comprehensive review providing information on the consumption of edible insects was developed. The bachelor thesis provides the basis for the creation of a more detailed overview for individual insect species and their developmental stages.

Key words: Entomophagy, Food safety, Insect protein, Edible insects

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1. Introduction

Dietary change is considered a global imperative because current food systems are a major cause of climate change, land-use change, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems (Springmann et al. 2018).

Insect consumption has been spotted on every continent in human history except Antarctica. In some parts of the world, specifically Europe and North America, the practice has basically disappeared. However, there are still many locations where it is very widespread (de Carvalho et al. 2020).

As a food source, insects have the potential to solve the problems associated with conventional farming. One such example is the production of greenhouse gases from livestock farming, which has been shown to be demonstrably lower with edible insect production (da Silva Lucas et al. 2020; de Carvalho et al. 2020).

Insects are seen as an alternative food source mainly on the basis of their nutritional composition, sustainability of production and availability, or their impact on health. As the population increases, the demand for animal food is also increasing, which can be compensated by the inclusion of edible insects in the diet, while maintaining the sustainability that insect farming allows (da Silva Lucas et al. 2020).

It is estimated that more than 3,000 ethnic groups worldwide consume insects in many forms (Melgar-Lalanne et al. 2019).

2. Aims of the Thesis

The aim of this work is a systematic review of literature, covering various aspects of insect consumption: species, nutritional profiles, production, processing, food safety, ecological, social and economic approach and future outlook.

3. Methodology

The thesis was made on the basis of primary and secondary sources retrieved from online scientific databases and libraries. In particular, the literature on insect as food, food safety of edible insects, edible insects farming or edible insects species. A literature review on insect consumption was conducted and specific aspects of insect consumption were described. 65 sources were used for this work.

4. Literature Review

4.1. Insect consumption

4.1.1. History

Throughout history, the consumption of insects has been practiced almost all over the world (de Carvalho et al. 2020). Alimentation in each area is influenced by culture. This is a reflection of the religion that is or has been practiced in the area (van Huis et al. 2013; Costa-Neto & Dunkel 2016). Insects were already consumed by human ancestors half a million years ago. For example, there are archaeological finds that show that Australopithecus used bone tools to dig into termite mounds (Costa-Neto & Dunkel 2016).

The Italian entomologist Ulysse Aldovani is considered the founder of modern entomophagy. In his publication from 1602, he stated that insects were an important part of the diet in ancient civilizations in the Far East for several centuries BC. It was not until the 19th century that insect consumption came to the West thanks to explorers who brought this information from tropical areas (van Huis et al. 2013). Insect consumption in the Americas was noted before the arrival of Europeans (Costa-Neto & Dunkel 2016). Today, entomophagy is practiced in 113 countries around the world. These are areas in Africa, Asia and South America where the tradition of eating insects has been preserved to this day (da Silva Lucas et al. 2020).

4.1.2. The present

There are 1.4 million described animal species in the world, of which 1 million are insects and millions more are undescribed (van Huis et al. 2013). Over the years, various estimates have been made, both global and national or regional, on the number of species of edible insects.

DeFoliart (1997) identified 1,000 edible insect species worldwide. In 2005, he recorded at least 1,681 species. Jongema (2012) created an inventory using global literature, listing 1,900 species of edible insects (van Huis et al. 2013). A 2017 study by Jongema again lists 2,111 species of edible insects worldwide (da Silva Lucas et al. 2020).

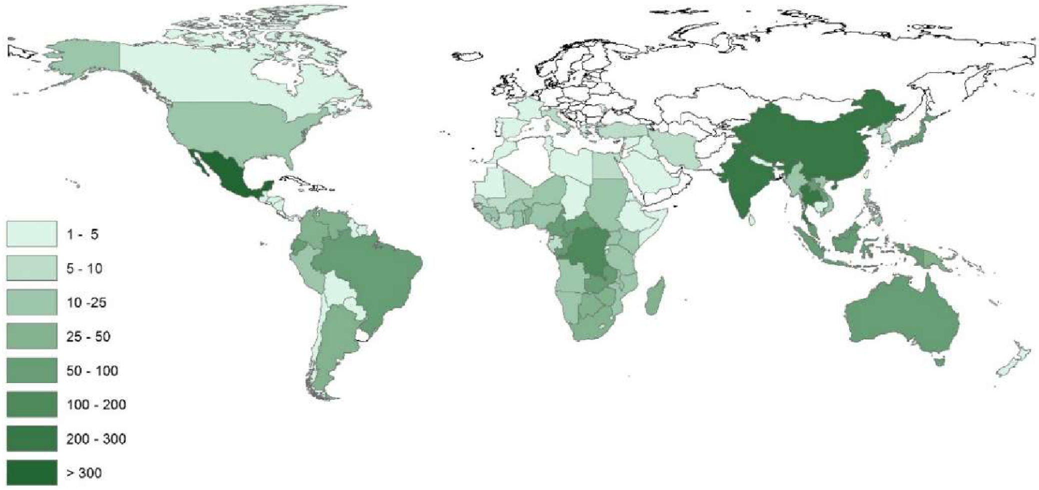

Figure 1. Recorded edible insect species (by country), data based on Jongema (2017)

(Source: Van Lammeren R. 2017. Wagenigen University & Research. Centre of Geo information, Netherlands. Available from https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm (accessed November 2021).)

The map in Figure 1 was created based on Jongema's list (van Lammeren 2017). The map shows that these 2,111 insects are consumed by more than 2 billion people in 80 countries in Africa, Asia and the Americas. The most of the described edible insects are found in Mexico, China, Thailand and India. Insects are consumed mostly in Africa and Asia. Jongema (2017) lists 35 African and 29 Asian countries. The lowest consumption of insects as food is in Europe, with 11 countries. In the Americas, insects are consumed in 23 countries and in Oceania in 14 countries. At lower latitudes, that is, in tropical regions, there is a greater tradition of insect consumption (Melgar-Lalanne et al. 2019).

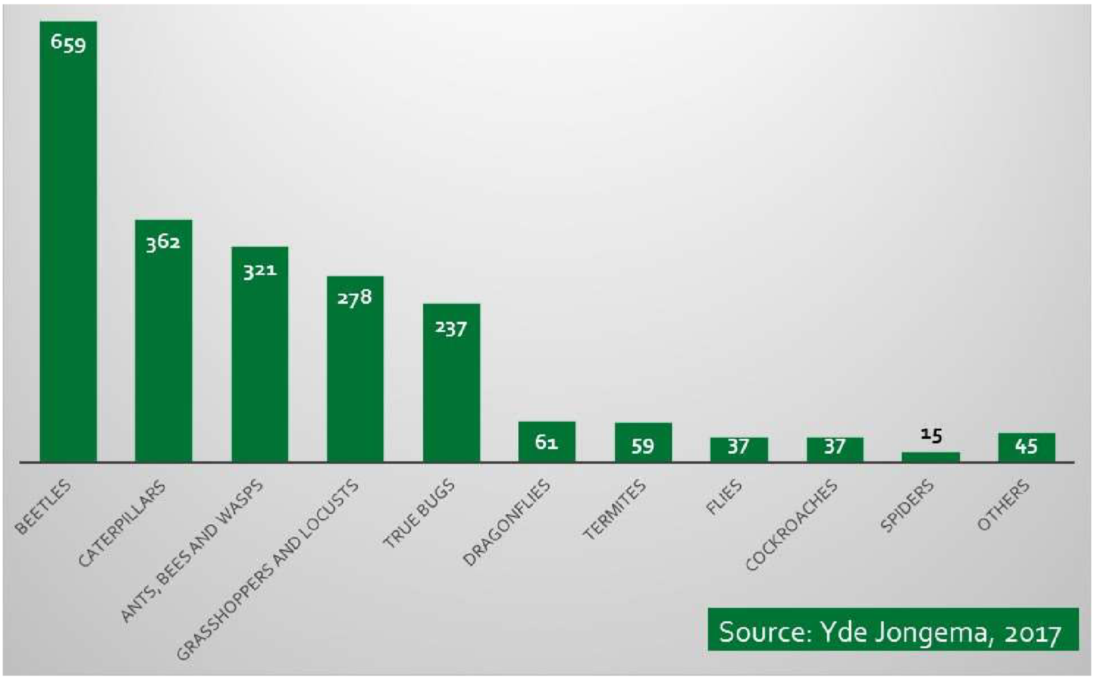

Figure 2. Number of recorded edible insect species per group in the world, data based on Jongema (2017)

(Source: Van Lammeren R. 2017. Wagenigen University & Research. Centre of Geo information, Netherlands. Available from https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm (accessed November 2021).)

The graph in Figure 2 shows the distribution of each insect species in the diet on a global scale. It shows that beetles are the most consumed, which agrees with van Huis et al. (2013) who justify this by stating that beetles account for approximately 40 % of all insects in the world. Then, according to Jongem, caterpillars, a group including ants, bees and wasps, locusts and true bugs are also widely consumed. Dragonflies, termites, flies, cockroaches, spiders and others no longer account for such a large proportion compared to the other groups.

4.1.3. Regional representation of species

The regional distribution of species is based on the biodiversity of a given region. Estimates of the number of edible insect species vary between studies. For example, Ramos-Elorduy (2008) reported 549 species in Mexico, but Cerritos (2009) recorded only 177 edible insect species there the following year. In China, Chen et al. (2009) counted 170 species of edible insects. Yhoung-Aree and Viwatpanich (2005) listed 164 species in Lao People´s Democratic Republic, Myanmar, Thailand and Vietnam. In Amazonia, Paoletti and Dufour (2005) record 428 species (van Huis et al. 2013).

Durst and Shono (2010) states that the most common orders worldwide are *Coleoptera* (beetles), *Orthoptera* (straight-winged), *Hymenoptera* (membrane-winged) and *Lepidoptera* (butterflies). This is also the case in Asia and the Pacific. Better studied is Thailand, where 81 species of insects are consumed including crickets, silkworm pupae and bamboo worms. Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines and Vietnam have a total of 150 to 200 species of edible insects. In India, Nepal, Pakistan and Sri Lanka, only 57 species of edible insects have been found to be consumed, which may be due to the vegetarianism common to Hinduism and Buddhism. Pupae of silkworm, that is used to produce silk, are commonly consumed in India. However, in Nepal, where the species is also farmed for fibre, it is not consumed. In Papua New Guinea, a total of 39 species of forest insects are consumed (Durst & Shono 2010).

Table 1. Number of recorded edible insect species per group in the world

Region	Species	Common name
Sub Saharan Africa	*Rhynchophorus phoenicis*	African Palm Weevil
	Ruspolia differens	Green Cone-Headed Cricket
	Gonimbrasia belina	Mopane Worm
	Locusta migratoria	Migratory Locust
	Gryllus bimaculatus	Two-Spotted Cricket/African Field Cricket
	Cirina forda	Emperor Shea Moth
East and Southeast Asia	*Bombyx mori*	Domesticated Silkworm
	Tenebrio molitor	Yellow Mealworm
	Rhynchophorus ferrugineus	Asian Palm Weevil
	Gryllus bimaculatus	Two-Spotted Cricket/African Field Cricket
	Acheta domesticus	House cricket
Central and South Asia	*Samia ricini*	Eri Silkworm
	Oecophylla smaragdina	Weaver Ant
	Lepidiota mansueta	Scarab Beetle
North Africa and Western Asia	*Schistocerca gregaria*	Desert Locust
	Locusta migratoria	Migratory Locust
	Gryllus bimaculatus	Two-Spotted Cricket/African Field Cricket

(Source: Smith MR, Stull VJ, Patz JA, Myers SS. 2021. Nutritional and environmental benefits of increasing insect consumption in Africa and Asia. Environmental Research Letters ***16****(6).)*

Table 1 shows the species that are consumed in each region. The data show that *Gryllus bimaculatus*, *Locusta migratoria* and palm weevil are the most commonly found species in the regions.

4.2. Examples of species

4.2.1. Beetles (*Coleoptera*)

The larvae of the palm weevil are consumed in Asia, Africa and Latin America. Their hosts are palm trees damaged, for example, by other insects. Fallen palms can serve as breeding sites. Often palms are deliberately felled for this reason (Anankware et al.

2015). Palm weevil can reach up to four centimetres in length and can be over two centimetres wide. Adult larvae are fleshy and have a high fat content (Elemo et al. 2011).

Figure 3. Red palm weevil (*Rhynchophorus ferrugineus*)

*(Source: Ferry M, Gomez S. 2002. The red palm weevil in the Mediterranean area. Palms **46**(4):172-178.)*

Mealworms (*Tenebrio molitor*) are distinguished by their easy availability and simple breeding. The mealworm is one of the largest beetles that attacks stored food and feeds on plant products. Its adult larva is 25-35 mm long and weighs about 0.2 g. It is these that are consumed (Siemianowska et al. 2013). Mealworms are already bred on an industrial scale (Anankware et al. 2015).

4.2.2. Caterpillars (*Lepidoptera*)

The mopane caterpillar (*Imbrasia belina*), known as mopane worm, is the most popular and economically important caterpillar consumed. The caterpillar is endemic to mopane forests in southern Africa and its habitat covers an area of about 384 037 km^2 (Nyoka 2003). Ghazoul (2006) estimates that 9.5 billion of these caterpillars are harvested annually (van Huis et al. 2013).

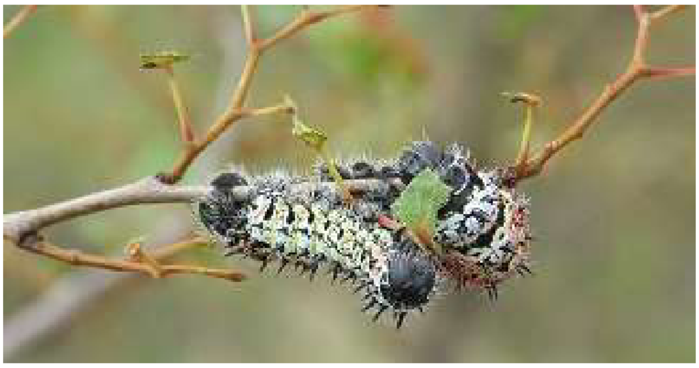

Figure 4. Mopane caterpillar (*Imbrasia belina*)

(Source: Nethavhani Z, Veldtman R. 2016. Mopani Worm. SANBI: South Africa National Biodiversity Institute. SANBI – KABR/ECOS. Available from: https://www.sanbi.org/animal-of-the-week/mopani-worm/ (accessed February 2022).)

Other species of caterpillars are consumed in smaller quantities. Malaisse (1997) documented 38 species in the Democratic Republic of Congo, Zambia and Zimbabwe. Latham (2003) identified 23 edible caterpillar species in Kongo Central, Western Province of the DRC alone (van Huis et al. 2013).

In China and Southeast Asia, the silkworm has been popular as a food for centuries. Its larvae are traditionally used for consumption (Zhou & Han 2006).

4.2.3. Ants, bees and wasps (*Hymenoptera*)

Ants are consumed in many parts of the world. For example, the larvae and pupae of the weaver ant (*Oecophylla spp.*) are widely consumed in Asia. The black weaver ant (*Polymachis dives*) is popular in southeast China, Bangladesh, India, Malaysia and Sri Lanka (Anankware et al. 2015). Black ants are a traditional food in Kenya. More than 200 species of black ants live in the Lake Victoria basin and only two of them have been proven to be edible (Ayieko et al. 2012).

In Japan, the larvae of yellowjackets (*Vespula and Dolichovespula spp.*) are commonly consumed (Anankware et al. 2015).

4.2.4. Locusts and crickets (*Orthoptera*)

About 80 species of locusts are consumed worldwide. Their collection is facilitated by the fact that they can occur in swarms. In Africa, desert, migratory, red and brown locusts are commonly consumed. The most famous locust eaten in Latin America is the Chapuline, which has been part of the local diet for centuries and is still eaten in some parts of Mexico. The problem with the consumption of locusts is that they are considered agricultural pests and insecticides are therefore used on them (Anankware et al. 2015). Saeed et al. (1993) found high concentrations of organophosphorus pesticide residues in locusts collected for food in Kuwait.

4.2.5. True bugs (*Hemiptera*) and others

Cicadas are found on tree trunks. They are harvested using long reeds or grasses, which have remnants of the glue that remains on the wings of cicadas. The wings are removed before consumption. They are important as food in Malawi, for example (Anankware et al. 2015).

Termites of the genus *Macrotermes* are the most commonly consumed. These are large winged termites emerging from holes near termite nests at the end of the dry season after the first rains. In Africa, they are collected by simulating rain. Locals pound the ground around termite mounds, forcing the termites to come out (van Huis 2003). Termites of the genus *Syntermes* are the largest consumed termites in Amazonia. During collection, a palm leaf rib is introduced into the galleries of the nest, the soldier termites begin to nibble on it, and together with the leaf are then fished out (Anankware et al. 2015).

4.3. Nutritional composition of insects

In general, edible insects are considered to be very rich in protein, vitamins and minerals (Hanboonsong et al. 2013; de Carvalho et al. 2020). The specific nutrient distribution depends on the type of insect and the method of preparation for consumption (Azmi & Taib 2020). For commercially reared insects, it may be the case that their nutritional composition will differ from that of wild insects (de Carvalho et al. 2020).

4.3.1. Proteins and lipids

Compared to conventionally reared livestock meat, insects contain more protein (Anankware et al. 2015). Its ratio is estimated at 20–70 % (Azmi & Taib 2020). The protein contained in insects is considered to be of high quality and well digestible (Kouřimská & Adámková 2016; de Carvalho et al. 2020).

Insects contain less lipids than conventional livestock (Anankware et al. 2015). Their content in dry matter ranges between 10–50 %, making them the second largest part of the nutritional composition of edible insects (Xiaoming et al. 2010; Azmi & Taib 2020). Their content is highest in larvae (Xiaoming et al. 2010; Hawkey et al. 2021).

Agbidye et al. (2009) reported that 100 g of caterpillars provide 76 % of the recommended daily protein intake. According to Mitsuhashi (2010), three silkworm pupae contain 50 % of the recommened daily allowance of protein and 30 % of that of lipids.

4.3.2. Amino acids

According to Azmi & Taib (2020), edible insects can supply 30–60 % of amino acids. They contain 10–30 % of all essential amino acids (see Figure 5) (de Carvalho et al. 2020). As with proteins and lipids, amino acid abundance depends on the life stage of the insect (Hawkey et al. 2021)

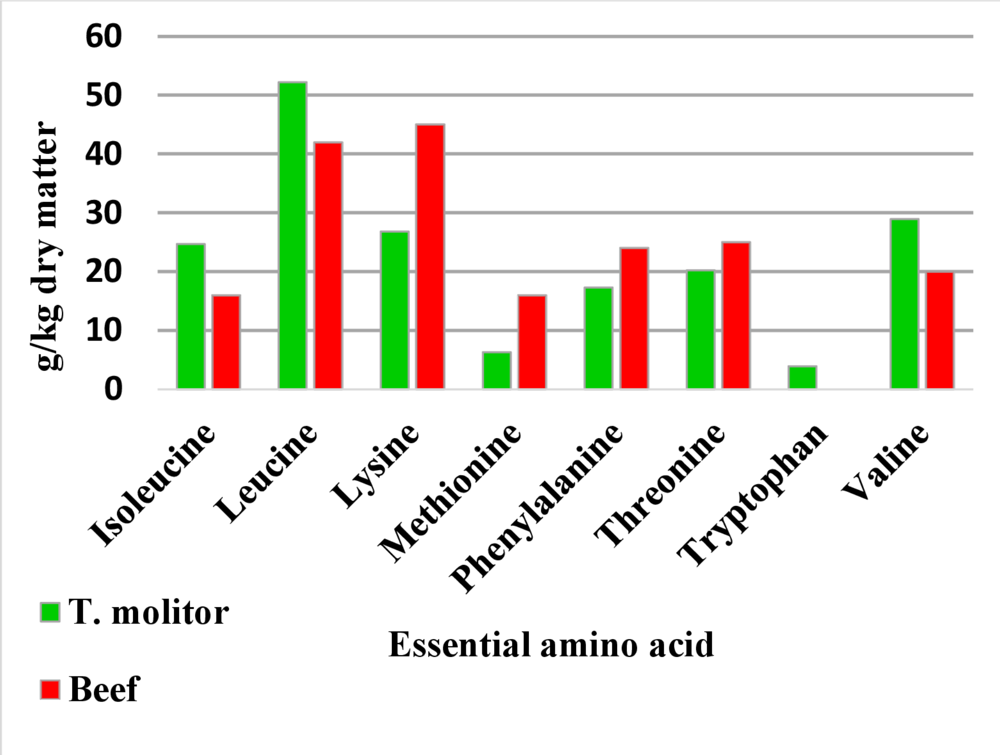

Figure 5. Content of essential amino acids in minilivestock vs. conventional livestock

(Source: Van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P. 2013. Edible insects: future prospects for food and feed security. Food and agriculture organization of the United Nations ***171****:75.)*

4.3.3. Vitamins and minerals

In general, edible insects contain high levels of potassium, calcium, iron and magnesium (Zielińska et al. 2015), selenium (Finke 2002), zinc (Anankware et al. 2015) as well as manganese and phosphorus (Hawkey et al. 2021). Iron and calcium content is higher than in traditional meat according to some sources (DeFoliart 1992; Sirimungkararat et al. 2010).

In terms of vitamins, insects contain high levels of B vitamins, riboflavin (B2), pantothenic acid (B5), and biotin, but lack niacin (B3), thiamine (B1), as well as vitamins A, C, and D (Hawkey et al. 2021).

Even in the case of minerals and vitamins, their content in insects varies across species and orders, insect life stages, and depending on the season and the feed provided (Hawkey et al. 2021).

Hawkey et al. (2021) notes that the mineral content of insects is sufficient to meet the nutritional requirements of most people. Caterpillars contain almost 100 % of the recommended daily allowance of vitamins (Agbidye et al. 2009). Mitsuhashi (2010) reports that three silkworm pupae are as rich in nutrients as one hen's egg. Black soldier larvae contain more calcium and phosphorus compared to yellow mealworms. The latter contain more potassium and sodium. The highest levels of vitamin B12 are found in mealworms (Hawkey et al. 2021).

4.3.4. Nutritional profiles

Table 2. Nutrition profiles of edible insects (100 g of dried insect sample)

	House Cricket (*Acheta domesticus)*[1]	Green Long horned Grasshopper (*Ruspolia differens)*[2]	Termite/White ant (*Macrotermes subylanus)*[3]	Black ant (*Calebara vidua)*[4]
Protein (g)	59	43	39	40
Fat (g)	25	48	44	47
SFA (%)	52.6	38.3	35.1	-
MUFA (%)	40.5	26.6	52.8	-
PUFA (%)	6.8	34.4	12.2	-
Crude fibre (g)	8.0	3.9	-	6.9
Ash (g)	4.0	2.8	7.6	1.6
Calcium (mg)	5.0	27.4	58.7	22.2
Magnesium (mg)	10.0	33.9	-	10.4
Iron (mg)	6.3	16.6	53.3	10.6
Zinc (mg)	15.0	17.5	8.1	5.6

* SFA – Saturated Fatty Acids; MUFA – Monounsaturated Fatty Acids; PUFA – Polyunsaturated Fatty Acids

[1] Münke-Svendsen et al. 2016; Rumpold and Schluter 2013; [2] Kinyuru et al. 2010; [3] Kinyuru et al. 2013; [4] Ayieko et al. 2012

*(Source: Münke-Svendsen C, Ekesi S, Ayieko M, Kinyuru J, Halloran A, Makkar H, Roos N. 2016. Nutritional properties of insects for food in Kenya. Greeinsect Technical Brief **5**. Copenhagen, Denmark.)*

Insects contain large amounts of fibre. Its most common form in insects is chitin, which is an insoluble fibre that comes from the exoskeleton (Klunder et al. 2012).

4.4. Production of edible insects

There are two ways to breed and raise insects, namely full or semi-domestication. Full domestication means breeding insects in captivity. In semi-domestication the environment of the insect is manipulated to increase its production, but there is no separation from its wild population (Baiano 2020).

4.4.1. Free breeding

Collecting insects in the wild is the most traditional way of insect acquisition (Melgar-Lalanne 2019). Worldwide, approximately 92 % of edible insects are collected from the wild, and only a small amount of insects are specially reared (Baiano 2020). Local collectors have the necessary knowledge to estimate the appropriate time, conditions and host vegetation to produce specific edible insect species with environmental conservation (Melgar-Lalanne 2019).

Many species (e.g. species of *Orthoptera*, *Coleoptera* or *Lepidoptera*) are pests that threaten agricultural crops. For this reason, they are chemically controlled. Their hand-picking can lead to saving crops while reducing the use of pesticides. However, the disadvantage of such collection is that the quality and safety of insects collected from the wild cannot be guaranteed. There is also a risk of species extinction (Baiano 2020).

4.4.2. Semi-domestication

Semi-domestication has emerged as a response to the environmental and health risks posed by the free collection of insects. It is a more sustainable, less time-consuming and more consistent way of rearing insects whose populations are characterised by morphological and physiological characteristics and behaviours that are the result of human actions. These include partial control over reproduction, mortality, space use and food supply and aim to increase economic profit (Melgar-Lalanne 2019).

This breeding is practiced for locusts, wasps, bamboo caterpillars, palm weevil larvae and dragonflies (Baiano 2020). Insects are reared in old trees, sawdust or forest waste (Melgar-Lalanne 2019). For example, when water hemiptera are collected, artificial oviposition sites are created from which the eggs are then collected. Palm weevil collection is done by deliberately felling palm trees. The aim is to induce oviposition by this insect species and subsequently collect its larvae (Baiano 2020).

4.4.3. Farms

Currently, three insect species are considered fully domesticated, namely the bee, the silkworm and the cochineal. There are also several other species that are partially domesticated. Domestication of insects is neither difficult nor economically challenging (Melgar-Lalanne 2019).

In Thailand, 20,000 farms produce approximately 7,500 tonnes of insects annually. Two species of crickets (*Gryllus bimaculatus* and *Acheta domesticus*) are commonly bred in backyard sheds in Thailand, Vietnam and Laos. In the temperate zone, mainly mealworms, crickets and grasshoppers are kept. Breeding takes place in family-run farms. These are enclosed spaces where it is important to control the climate, which must be set so that the soft bodies of the larvae do not dry out. Industrial insect farming already requires a broader knowledge of biology, rearing conditions and diet composition (Baiano 2020).

Feeding, water provision, environmental control (especially temperature and humidity) and cleaning are essential components of edible insect rearing (Hawkey et al. 2021). Insects have low technical requirements, high production densities, and some life stages do not require sunlight (Melgar-Lalanne 2019).

Certain components of husbandry can be automated, such as feeding and irrigation. For example, a system similar to that used in commercial greenhouses could be considered as a method of irrigation (Hawkey et al. 2021). Most species can be reared in small ventilated plastic containers at ambient temperatures of up to 30°C and relative humidity of up to 70% (Melgar-Lalanne 2019). Both temperature and humidity are specific to the species being reared. The solution would be to use growth rooms, incubators, air conditioning units, fans or heaters (Hawkey et al. 2021).

Insects can be sustainably reared on a variety of organic substrates such as manure, farmyard manure or compost. Some insects, such as the black soldier fly (*Hermetica illucens*), the housefly (*Musca domestica*) or the yellow mealworm (*Tenebrio molitor*), are capable of biodigesting organic waste. Together, these three insect species could convert 1.3 billion tonnes of biological waste annually (Baiano 2020). It is the substrate on which the insects are reared that can serve as food. In addition to organic waste, this can also be cereals, for example. The most suitable diet is one high in protein and fat (Melgar-Lalanne 2019).

It is assumed that captive breeding would be suitable for mass production. However, the problem at present is the dependence on manual labour. This causes high costs. Automation could be the solution. There are two potential sectors for mass production of insects, namely breeding and large-scale production. Breeding involves several stages: harvesting, processing and packaging. The processing stage involves the removal of pathogens (Hawkey et al. 2021).

The problem is, for example, the spread of pathogens in the population of insects bred this way (Baiano 2020).

4.5. Processing

Some insects are eaten alive, but more often they are processed (Liu & Zhao 2018). Processing is done by drying, boiling, frying or baking (Baiano 2020). Processing is intended to improve taste or increase shelf life and safety. The processing method can also affect the nutritional value and functional properties of edible insects (Liu & Zhao 2018).

Cooking improves the sensory quality of insects. Cooking extends the shelf life of the product and increases the digestibility of the insects. Cooking causes degradation of proteins, oxidation of lipids and fatty acids or dissolution of vitamins and minerals (Melgar-Lalanne 2019).

The blanching method can be used to pre-treat insects. This is a process in which the food is first immersed in boiling water for a short time and then in ice water or under cold running water to stop the heating process. This type of treatment reduces the number of mesophilic bacteria, yeasts and moulds and inactivates the degrading enzymes that are responsible for spoilage and food toxicity. However, it is not capable of removing them (Melgar-Lalanne 2019).

Drying is the most commonly used technology for extending the shelf life of food. Drying reduces the total water content, which is a major factor in degradation reactions. The most traditional is sun drying, which is the least demanding in terms of energy and is therefore mainly used in households. Another method of drying is smoking. This involves the action of enzymes and heat, which promotes changes in proteins and lipids. Lyophilisation is carried out at low temperature and involves the sublimation of water. Microbiological and oxidative degradation is stopped and the resulting product retains its nutritional value and long shelf life. For this reason, this method is used for laboratory analysis of the nutritional properties of insects. However, it is expensive to use at industrial level. Lower energy costs are incurred in oven drying. The resulting product is comparable to that produced by freeze-drying. The difference is reduced lipid oxidation and high protein solubility (Melgar-Lalanne 2019).

Therefore, the processing method should be chosen taking into account the insect species and the desired properties of the final products (Liu & Zhao 2018).

4.6. Food safety

Like the consumption of other foods, eating insects carries risks, especially in the form of pathogens, chemicals or allergies (Belluco et al. 2013).

Nutrient and water contents are high in insects the same way as in other meat products, which leads to the development of microbes as they thrive in this kind of habitat (Klunder et al., 2012).

Furthermore, as some species of mealworms have revealed, insects have allergenic potential (van der Fels-Klerx et al. 2018). Allergies have been reported, for example, when eating caterpillars or silkworm pupae (Belluco et al. 2013).

Microbiological risk is related to the ability of insects to transmit pathogens (Belluco et al. 2013). Insects host many microorganisms and they may contain pathogenic bacteria. Insect species, substrate, and rearing and processing conditions will mostly determine the potential contamination witch microbial threats to human health (van der Fels-Klerx et al. 2018). The level and severity of this risk in insect consumption is assessed by Belluco et al. (2013) to be equivalent to the risk in livestock meat consumption.

Furthermore, insect consumption poses a risk in the context of the use of pesticides that are used against it (Belluco et al. 2013). Factors connected to the breeding stage, such as insect species, life stage, and contamination source, influence the accumulation of pollutants in insects. With the exception of veterinary medications and pesticides, which can have negative production impacts, the majority of pollutants for which experimental data has been collected have had no effect on insect growth and survival. Some pollutants, such as heavy metals, cadmium, and lead, can accumulate in the body, and differences in bioaccumulation between species have been noted (Meyer et al. 2021).

The insects are mainly exposed to chemical hazards from the substrate on which they are bred. Essential heavy metals do not accumulate in insects, whereas non-essential heavy metals and arsenic may accumulate and the degree of that accumulation will again depend on the element, the type of insect and the growth stage. Cadmium in black soldier fly and arsenic in yellow mealworm larvae are concerning because of their high accumulation potential in these high interest insects used in food and feed (van der Fels-Klerx et al. 2018).

Human health complications have occurred for this reason, for example, in Thailand or Kuwait in the last century (Belluco et al. 2013). According to Belluco et al. (2013), this can be prevented by selecting appropriate insect species and banning species that pose a risk of bioaccumulation of chemicals and by selecting appropriate feeds focusing on their composition and contamination (Belluco et al. 2013).

The goal of conventional processing techniques such as boiling, frying, baking and drying is not only to improve taste, but to ensure food safety. The chosen processing technique is based on cultural inclinations and sensory factors and a variety of these techniques exists. However, the selection of a conservation method should be based also on the insect species, since the different biological compositions of these may require different treatment to guarantee food quality and safety. Defining the optimal treatment will be a key aspect in the global commercialisation of edible insects for food and feed (FAO/IAEA 2001; van Huis et al. 2013).

The Hazard Analysis and Critical Control Point (HACCP) system identifies threats and introduces control systems to ensure food safety (FAO/WHO 2001; van Huis et al. 2013). HACCP is a globally acknowledged system identifying, evaluating and controlling physical, chemical and biological hazards during the whole production process from primary production to final consumption. The work of authorities controlling food products may be facilitated by the application of this system, as well as the confidence in the safety of the produce based on a worldwide recognition of these standards may enhance its international trade. Adoption of this system throughout the whole supply chain of edible insects will be a key factor to the success of this industry. According to FAO, "any HACCP system is capable of adapting to changes such as advances in equipment design, processing procedures or technological developments" (FAO/IAEA 2001; van Huis et al. 2013).

4.7. Aspects of edible insect production

4.7.1. Ecological

4.7.1.1. Global warming

One of the biggest problems humanity faces is the production of greenhouse gases, which is a major contributor to climate change. The main anthropogenic source of greenhouse gas emissions is livestock. Livestock produce greenhouse gases directly as well as ammonia, which undergoes a process of conversion to the greenhouse gas nitrous oxide in the soil (Alrifai & Marcone 2019).

Oonincx et al. (2010) examined the difference in greenhouse gas and ammonia production between five species of edible insects and conventional livestock. The values of four insect species were significantly lower than those of pigs while accounting for only 1% of the GHG emissions produced by ruminants. Ammonia values were lower for all five insect species than for livestock.

According to Hanboonsong et al. (2013), the reason is that insects are several times more efficient than livestock in converting ingested food into material that can be consumed by humans. For beef, for example, this conversion efficiency is up to six times lower, according to him.

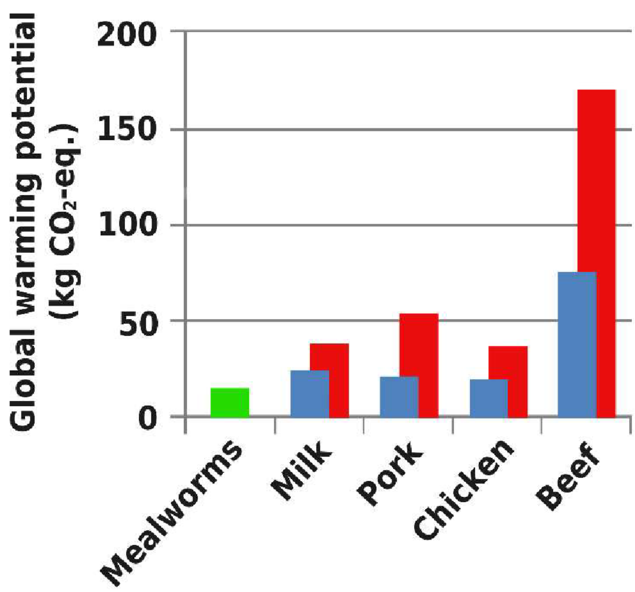

Figure 6. Global warning potential of minilivestock vs. livestock – minimum (blue) and maximum (red)

(Source: Oonincx DG, De Boer, IJ. 2012. Environmental impact of the production of mealworms as a protein source for humans – a life cycle assessment. PLoS ONE 7 (e51145).)

4.7.1.2. Land use

The way the landscape is managed is space consuming. The world is facing an ever-increasing demand for meat and a loss of agricultural land (Alrifai & Marcone 2019). Raising edible insects is also less demanding on the space provided to livestock by deforestation (Anankware et al. 2015; da Silva Lucas et al. 2020).

According to de Vries and de Boer (2010), beef production is the most space-intensive. Alrifai and Marcone (2019) report that insects occupy up to 50–90% less land per kg of protein than conventional livestock.

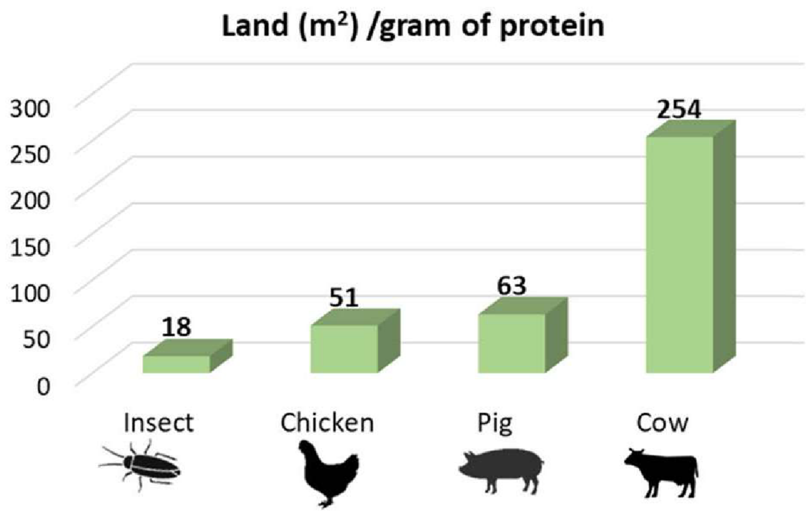

Figure 7. Land use – minilivestock vs. livestock

*(Source: Guiné RP, Correia P, Coelho C, Costa CA. 2021. The role of edible insects to mitigate challenges for sustainability. Open Agriculture **6(1)**:24-36.)*

4.7.1.3. Water use and feed conversion ratio

Agricultural production is threatened by increasing water scarcity. As a result, 1.8 billion people will not have access to meet vital human needs by 2050 (Alrifai & Marcone 2019).

Water consumed by the livestock sector accounts for more than 8% of total water consumption (Abbasi & Abbasi 2016).

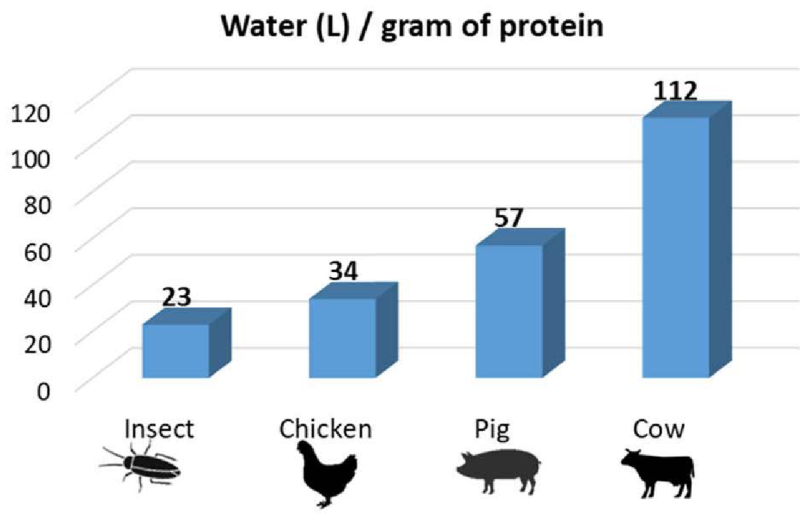

Figure 8. Water use – minilivestock vs. livestock

(Source: Guiné RP, Correia P, Coelho C, Costa CA. 2021. The role of edible insects to mitigate challenges for sustainability. Open Agriculture ***6****(1):24-36.)*

The solution could be to produce insects as food instead of conventional livestock, as the water requirements of insects are much lower. This is because insects are cold-blooded and therefore have a high feed conversion efficiency, allowing them to obtain water from their food. Water requirements are also reduced by the insect's rearing on organic by-products, which it is also fed (Alrifai & Marcone 2019).

Most water is used for feed in livestock production (Abbasi & Abbasi 2016). Figure 9 shows how many kilograms of feed are consumed per kilogram of live weight. Cattle consume the most feed, while insects consume five times less.

Insects also have a much higher reproductive capacity and rapid growth, making large-scale production easier than other animals (Anankware et al. 2015; de Carvalho et al. 2020).

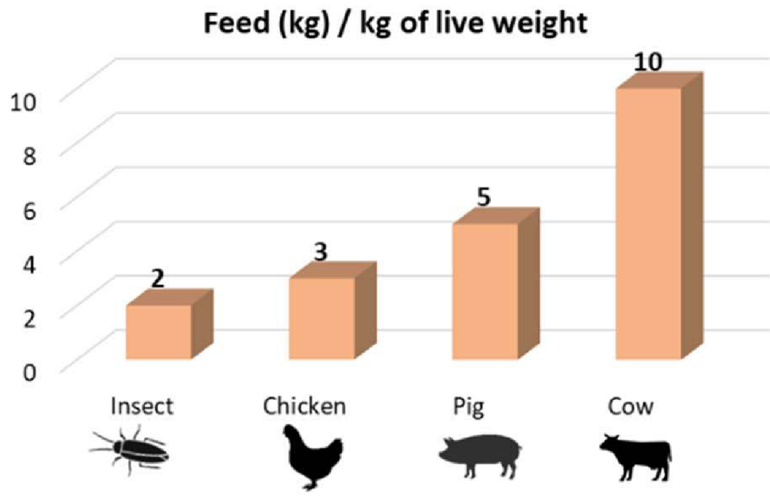

Figure 9. Feed – minilivestock vs. livestock

*(Source: Guiné RP, Correia P, Coelho C, Costa CA. 2021. The role of edible insects to mitigate challenges for sustainability. Open Agriculture **6**(1):24-36.)*

Due to the necessity to regulate body temperature, energy requirements for insect production might be significant (Hawkey et al. 2021).

Ooninex and de Boer (2012) carried out a comprehensive LCA of mealworm production, that revealed a reduction of land use of 43 % for equal energy input and a lower GHG generation than for 1 kg of traditional meat protein (chicken, pork, beef).

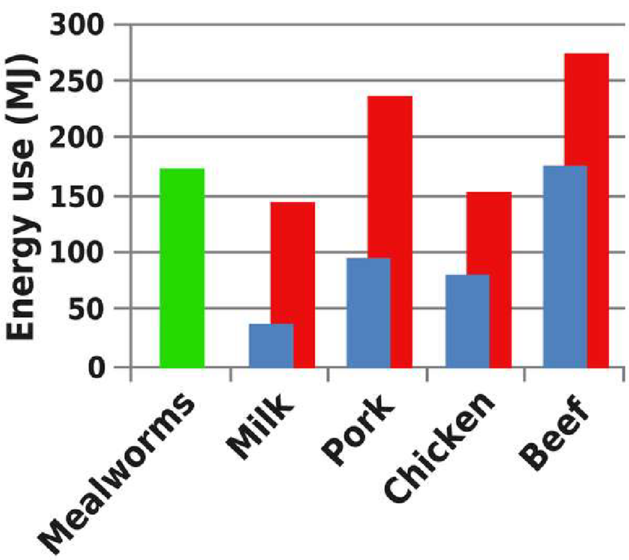

Figure 10. Energy use – minilivestock vs. livestock – minimum (blue) and maximum (red)

(Source: Oonincx DG, de Boer, IJ. 2012. Environmental impact of the production of mealworms as a protein source for humans – a life cycle assessment. PLoS ONE 7 (e51145).)

4.7.2. Economic

Anankware et al. (2015) describe insect farming as a low-capital investment option. It provides employment, thus giving opportunity to the neediest social classes (Hanboonsong at al. 2013; Anankware et al. 2015). This group includes, for example, individuals who do not own land or women. Insect farming has the potential to supply both urban and rural areas. Ordoñez-Araque and Egas-Montenegro (2021) in his publication cites the positive impact of insect consumption on global food security in the form of reduced hunger.

The high reproductive capacity, rapid growth and size of the distribution area increase the economic potential of insect farming (Sun-Waterhouse et al. 2016; de Carvalho et al. 2020).

There are surveys pointing at the price of edible insects being higher than that of traditional meat (Agea et al. 2008; de Carvalho et al. 2020). It is assumed that with the expansion of industrial production of insects within a sustainable economy (breeding, farming, agricultural processing technologies), the availability of edible insects on the market will increase and thus reduce their price (de Carvalho et al. 2020).

In developing countries, collecting and rearing insects is one of the ways to gain income. In Thailand, for example, insect farming is carried out both through family farms and industrially (Alrifai & Marcone 2019; Baiano 2020). Prices of edible insects in markets are usually higher than the prices of the crops from which they are derived, and sometimes even higher than the prices of fish and meat (Baiano 2020). Wholesale buyers purchase insects from farms and then supply them to street vendors, from whom they go to consumers. Street food stalls and local restaurants, sought after not only by locals but also by tourists, are a successful and popular market in developing countries (Alrifai & Marcone 2019).

Insects have a short life cycle and require relatively little space and water to breed, which is very limited in many areas of the world. Another advantage of rearing edible insects is the rapid return on investment and high financial return. Management of insect farms is simple and does not require in-depth training (Govorushko 2019). The ease of importing edible insects to market, rearing and harvesting them is easily achievable for most small enterprises in Southeast Asia and Central Africa (Alrifai & Marcone 2019).

Farmers and local inhabitants have poor access to information technology and services due to their lack of integration into the developed world. This causes extreme competition and limits them from selling good-quality products. Market prices are controlled by larger industries, which eliminates small farmers from participating in this trade. Thus, the sale of insects in markets takes place only within communities. For this reason, there are associations of farmers or producers of insect products. Their aim is to enter new markets, but also to develop and innovate. There is then a better use of the local trade network involving producers and collectors, middlemen, sellers and processors (Alrifai & Marcone 2019).

4.7.3. Social

The consumption of insects as food is influenced by factors such as culture and religion. These findings could explain the geographical spread of insect farming. An important social implication of insect farming is that, particularly in developing countries, the poorest or outcast members of society may be involved in the collection, cultivation, processing and sale of insects. Indeed, insects can easily be collected in the wild or cultivated with minimal technical or capital costs (Baiano 2020).

4.7.4. Ethical

Recently, the welfare of insects reared for food purposes has been debated. Currently, there is a lack of structured knowledge on how insects should be kept in conditions that respect their well-being. Two perspectives are conflated - animal welfare advocates use the capacity to suffer and animal rights advocates use the presence of certain cognitive capacities as the basis for granting moral status. From an ethical perspective, animal protection legislation can be divided into two types: pathocentric, which considers only sentient animals, and biocentric, which considers all animals (Baiano 2020).

4.8. Future outlook

Katayama et al. (2008) state that entomophagy can play a key role in solving the world's food shortage problem. Currently, 6,000 tonnes of insect protein is produced in Europe, with production expected to reach 3 million tonnes by 2030 (Hawkey et al. 2021).

Katayama et al. (2008) investigated the potential for using insects in space agriculture. They created a model diet that included rice, soybean, sweet potato, green-yellow vegetable, silkworm pupae, and loach fish, and concluded that insect consumption has the potential to meet the nutritional needs of humans in space. In the context of space agriculture, insects can be used not only for consumption, but also as feed or for recycling materials.

Although insects are generally considered to be a sustainable food source, there is also the threat of unsustainable collection, which could subsequently cause habitat alteration and pollution (van Huis & Oonincx 2017; de Carvalho et al. 2020).

As insects are not recognised as a food source in Mexico, no regulations are in place to protect the natural populations from exploitation. Field studies in Hidalgo, Mexico, have shown that approximately 14 out of 30 insect species used as food are threatened due to the current level of commercialisation. In the past, insects were only consumed for small-scale local subsistence needs and the consumption expansion is a challenge for the ecosystem balance (Durst & Shono 2010).

Pesticide use, tree felling and mechanisation are typical consequences of agriculture intensification and present a risk to many insect species. Invertebrate populations globally declined by 67 % in the last 40 years due to pesticides. Aggressive insect harvesting methods provoked by increasing demand pay no attention to sustainability, mainly harvesting during the reproductive season. This reduces local biodiversity and risks eradicating completely some species. Honey ants and caterpillars in Australia are an example of endangered species, since they are in demand in local restaurants and ecotourists (Melgar-Lalanne 2019).

5. Conclusions

The consumption of insects has its roots in prehistoric times. Today, insects are used as food in 80 countries around the world, most notably in Africa, Asia and Latin America. The most commonly consumed insects are beetles, which are consumed at almost twice the rate of caterpillars, which are second in consumption.

As a food source, insects have the potential to solve the problems of food shortages related to population growth, global warming, water scarcity, and those of low living standards in developing countries, reflected, for example, in unemployment rates. Many studies have shown that insects can fully replace conventionally farmed meat in terms of nutritional composition. It is rich in protein, fibre, vitamins and minerals and contains essential amino acids and lower levels of fat.

An important issue in insect production is the way of breeding. The most widespread is the collection of insects in the wild, which traditionally occurs within households for self-consumption. However, this method is difficult to control and can lead to species extinction. For this reason, so-called semi-domesticated farming has been adopted, which allows a certain degree of control over reproduction, mortality or space use. Farms where insects are bred under artificial conditions are another option. This means creating a living space for a specific insect species. The temperature, humidity or light is adapted to the individual species to create the conditions for reproduction. The substrate on which the insects are reared is also an important component of such rearing. This can take the form of, for example, biological waste, adding a waste management aspect to insect farming.

Like other foods, edible insects are subject to food safety controls. Insects can contain pathogens and chemicals and cause allergies. Chemical contamination can be prevented by choosing a suitable substrate or collecting in an uncontaminated environment. The removal of pathogens is most often done by heat treatment of the collected insects. As regards food safety, edible insects have not been shown to pose a higher risk than conventional livestock.

In this work, comprehensive overview was developed providing information on the consumption of edible insects in terms of their nutritional composition, production and processing or food safety. Many of these aspects are related not only to the specific species of insect, but also to whether it is a larva or an adult. Some species are consumed at all developmental stages, some only at the larval stage. The life stage defines also allergies or contained pathogens. This is then reflected in the procession method. Differences can also be seen in husbandry, as not all insects are suitable for captive breeding.

The bachelor's thesis thus provides the basis for a more detailed overview of individual insect species and their developmental stages. So far, the potential of insect consumption has been mainly addressed in scientific works. More detailed studies could then be used to develop proposals for specific insect farms that would operate locally, provide employment opportunities for local people and address more than just food shortages.

The thesis also deals with ecological, economic, social and ethical aspects of insect consumption, which touches on a large number of global issues. These are therefore important to bring to the attention of the wider public. These aspects have not been the subject of much research and, given their importance, a detailed evaluation would be appropriate. One possibility, for example, is the development of models that show the potential of insect consumption to address global problems if it were to become widespread not only in poor areas but also in the rest of the world.

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