46 Edible Insects

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Abstract

In the tropics more than 2000 insect species are eaten. Most are only seasonally available, and the local population uses a number of techniques to harvest them. In the western world, insects are not known as food. However, alternative protein sources are needed as the agricultural land available in the world is not enough to satisfy the growing demand of meat. Among those sources are algae, mycoproteins, cultured meat, plant proteins, and insects. The nutritional value of insects is comparable to meat products. The environmental impact from rearing insects is much less than livestock production: insects emit less greenhouse gases and need much less land and water. When insects are promoted as food, harvesting more from nature is not an option and they need to be farmed as mini-livestock. The interest in the western world to use insects as food is growing. This is exemplified by the exponential growth of the number of publications as

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well as the number of start-up companies. Major hurdles in western countries are the creation of a legislative framework, automation to reduce the cost price, and the development of strategies to convince consumers. Consumer strategies are: an affordable price, developing tasty products, incorporating insect ingredients in familiar products and to give consumer a taste experience. Producing insects as food may become a new agricultural sector.

Introduction

The increased demand for meat products cannot be satisfied in the future because the area available for livestock will be insufficient. Eighty percent of all agricultural land is already used for livestock (3,400 million ha as pastures and 500 million ha as crop land). Livestock also decreases food supplies, since the grains used as feed could be used for human consumption (Van Huis and Oonincx 2017). About a third of the world's cereal production is fed to animals. On environmental impact, a comparative study between mealworms and livestock showed that a gram of edible protein from beef requires 8–14 times as much land and approximately 5 times as much water, while broiler chickens are associated with 32–167% higher greenhouse gas emissions, and beef cattle emit 6–13 times more CO_2 equivalents (Oonincx and de Boer 2012).

Research on alternative protein sources is concentrated in vitro cultured meat, seaweed, duckweed, canola/rapeseed, microalgae, mycoproteins, and insects. In this chapter, we focus on insects.

The Consumption of Insects Worldwide

Insects can be used either as human food or as feedstock for pets, fish, poultry, and pigs. One could argue whether it is a good idea to feed insects to production animals, which are then in turn eaten by humans (two conversion cycles). When the insects are fed with the same substrate as the production animals, the conversion process is probably prohibitively expensive. In this chapter, we will only deal with insects as human food.

Often when referring to the eating of insects the word "entomophagy" is used, derived from the Greek words "entomon" (insects) and "phagia" (to eat). It is a somewhat derogatory word for a food habit which is often considered primitive by western people. Probably because the practice is alien to western people while it is customary in tropical countries. However, more and more, people in western countries discover the benefits of eating insects as a sustainable, nutritious, and healthy food source. More and more the eating of insects is considered a normal food habit and not much different from eating shrimps, which are very closely related to insects. This is exemplified by the growing number of private enterprises rearing and marketing edible insects and the increasing number of articles in the popular press and in peer reviewed scientific journals (Shockley et al. 2017).

In general the consumption of insects by early humans has been undervalued in comparison to food plants and wild meat. It seems that insects were an important dietary component, because (1) insects are eaten by virtually all nonhuman primates; (2) insects are an important part of the diet of many traditional societies; and (3) there is archaeological evidence of insectivory by hominids (Van Huis 2017).

It is estimated that there are about 5.5 million insects species in the world and only 1 million of those have been described (Stork 2018). Most of these species are beneficial: producing honey and silk and providing ecological services such as pollination, decomposition, recycling, and biological control of pests through parasitoids and predators. Only 5,000 (less than 0.1%) are considered harmful for humans, animals, pets, and plants (Van Lenteren 2006). Concerning edible insect species, there are worldwide more than 2100 species and most of those occur in tropical countries where they are collected and harvested from nature. The species can be divided into the following categories: beetles (31%), caterpillars (17%), ants, bees and wasps (15%), grasshoppers (13%), true bugs (11%), dragonflies (3%), termites (3%), cockroaches (2), spiders (1%), and others (2%) (Fig. 1) (Jongema 2019). Some countries have a very high number of recorded species. This may be a matter of more extensive research, for example, in Mexico, where one person authored many publications on the topic (Pino Moreno 2016). Most insect species are harvested from nature. But there have been examples where the local population enhanced their occurrence before harvesting. One example is the palm weevil, which is a snout beetle of the genus *Rynchophorous*. If you deliberately cut the tree, palm weevils are attracted by the rotten odor, lay their eggs in the trunk, and the hatched larvae develop on the trunk tissue which can then a few weeks later be harvested as food by the local population (Van Itterbeeck and van Huis 2012). This palm weevil is considered a delicacy in Africa, Asia, and Latin America.

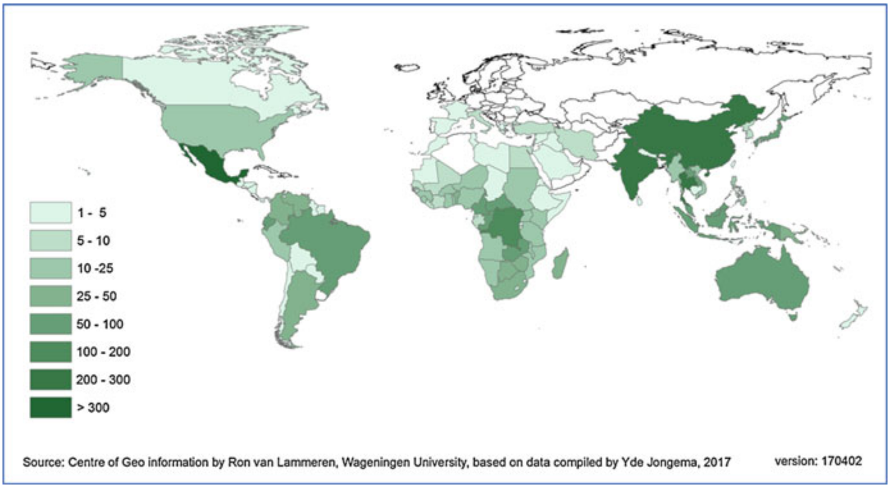

Fig. 1 Recorded edible insect species in the world (Jongema 2019)

Collection is often done by hand, but some insect species like the grasshopper *Ruspolia differens* in East Africa are collected during a certain time of the year by using light. Attracted by street lights they are often collected by women and children, because of the traffic a dangerous undertaking. Commercially they can also be collected, such as in Kampala Uganda by using electric lights shining into the sky. The attracted grasshopper falls on corrugated iron sheets folded to a cone shape and leading to a large collection bucket (Mmari et al. 2017). Light is also used to collect winged termites, which emerge from holes near the termite hill after the first rains following the dry season. The most common way to collect them is by placing a light above a receptacle with water. The attracted termites fall into the water, loose their wings, and are then scooped out.

However, procurement of insects by harvesting from nature is likely to become less common. The causes are: urbanization, limited availability because of seasonal occurrence, unpredictability, diminishing occurrence due to overharvesting and pollution, in particular of waterways (Van Huis and Oonincx 2017). To become a regular food source, insects need to be reared like livestock ("mini-livestock"). Experience in the large scale rearing of insects is mainly available in pest management, either by companies that rear insects as biocontrol agents or for the production of males in the sterile insect technique. In March 2019 there were 241 companies listed worldwide to produce edible insects (Bug Burger 2019).

The scientific interest in edible insects is growing exponentially. Searching the Web of Science (consulted March 2019) using "edible insects" resulted in the number of 196 publications in 2017 and 2018 compared to 162 for the preceding 10 years (2007–2016).

Which Insect Species Are Consumed in Western Countries

A number of companies that started to rear edible insects were already producing insects as feed for birds, reptiles, and aquaria fish. In order to comply with food laws, they needed to modify rearing techniques and procedures, like producing under more stringent hygienic conditions and to install a track and tracing system. For newcomers on the market, the problem is that they have to start from scratch, as most companies do not reveal how they produce the insects and which kind of substrates they are using. The most common insect species reared for human consumption are the following:

Beetles. Three mealworm species of the family Tenebrionidae are often used: the yellow mealworm (*Tenebrio molitor*) (Fig. 2), the lesser mealworm (*Alphitobius diaperinus*), and the superworm (*Zophobas morio*). Palm weevils, curculionid beetles, are popular food throughout the tropics.

Crickets, locust, and grasshoppers. The most common reared cricket is the house cricket (*Acheta domesticus*) (Fig. 3). However, other cricket species can also be considered such as the tropical house cricket (*Gryllodes sigillatus*) and the two-spotted cricket (or African or Mediterranean field cricket) (*Gryllus bimaculatus*).

Fig. 2 The larvae of the yellow mealworm, *Tenebrio molitor* (Coleoptera: Tenebrionidae). (Photo-credits and copyright: Hans Smid – www.bugsinthepicture.com)

Fig. 3 The house cricket, *Acheta domesticus* (Orthoptera: Gryllidae). (Photocredits and copyright: Hans Smid – www.bugsinthepicture.com)

The migratory locust (*Locusta migratoria*) and the desert Locust (*Schistocerca gregaria*) are both reared for human consumption. These insect species can also be consumed by Muslims and Jews.

Caterpillars. The greater wax moth or honeycomb moth (*Galleria mellonella*) is considered by some a delicacy (Martin 2014; pp. 35 and 232) (Fig. 4). Also, the pupae of silk worms (such as *Bombyx mori*) are consumed as food.

Bees and wasps. In the Central region of Japan, the wasp *Vespula flaviceps* is a seasonal delicacy, which can be captured in the wild but they can also be raised in people's backyard (Payne and Evans 2017). Also bee drones are used as food and even a cookbook is based on this (Ambühl 2017).

Fig. 4 Caterpillar of the greater wax moth or honeycomb moth, *Galleria mellonella* (Lepidoptera: Pyralidae). (Photocredits and copyright: Hans Smid – www.bugsinthepicture.com)

Maybe there are other insects around that can be reared for food and we can choose from the list of more than 2100 (Jongema 2019). The major criteria of selection will be how appetizing they are, how easy they can be reared, and whether a cheap feeding substrate can be found.

Nutrition

Because of the many species that are eaten it is difficult to generalize. However, some studies have reviewed the literature. Rumpold and Schlüter (2013) concluded from more than 200 edible insect species that many provide sufficient energy and protein, meet amino acid requirements for humans, and are high in monounsaturated fatty acids (MUFA) and/or polyunsaturated fatty acids (PUFA) and rich in several micronutrients such as copper, iron, magnesium, manganese, phosphorous, selenium, and zinc as well as riboflavin, pantothenic acid, biotin, and in some cases folic acid. Payne et al. (2016) using the Nutrient Value Score found that crickets, palm weevil larvae, and mealworms were significantly healthier than beef and chicken. The high iron content of some insect species like crickets and caterpillars is beneficial considering that one quarter of the world population is at risk of iron deficiency anemia. However, bioavailability remains an issue to be studied (Mwangi et al. 2018). Bauserman et al. (2015) administered a caterpillar cereal to infants in the Democratic Republic and found that fewer were anemic.

The nutrient content of edible insects not only depends on the species but also on diet, developmental stage harvested, and environmental conditions (Finke and Oonincx 2014). The fatty acid content, unlike the protein content, can be very much influenced by the diet. For mealworm it was shown that saturated fatty acids (SFA) and PUFA percentages and an n-6/n-3 ratio could be made more suitable for human consumption (Dreassi et al. 2017). For example, Francardi et al. (2017) added linseed as a source of n-3 acid to the diet of yellow mealworm to lower the n-6/n-3 ratio in order to make it more suitable for human consumption. This is more useful for the secondary prevention of cardiovascular diseases. Recently it was found that insects like migratory locusts, house crickets, and yellow mealworms can synthesize vitamin D de novo and that the amounts depend on ultraviolet irradiance and exposure duration (Oonincx et al. 2018).

The taste of caterpillars tends to be close to the plants that they eat. For example, the taste of the cassava caterpillar *Elaphrodes lactea* is like that of its leaves (Malaisse 1997; p. 209). We know that diets can influence the nutritional value of insects (Finke and Oonincx 2017); however, there is not much research about the possibility to influence the taste of insects by feeding them special substrates.

Health Benefits

The exoskeleton of insects is composed of chitin, a modified polysaccharide that contains nitrogen. Humans and other mammals have chitinase and chitinase-like proteins that can degrade chitin. Humans do not synthetize chitin and thus it is considered as a potential target for recognition by the immune system (Elieh Ali Komi et al. 2018). Chitinases seems to play a crucial role in regulating the immune response in relation to bacterial infections and inflammatory diseases and can be used as diagnostic and prognostic markers for numerous diseases (Di Rosa et al. 2016).

Stull et al. (2018) evaluated the effects of cricket powder on gut microbiota composition. They found that cricket powder supported growth of the probiotic bacterium, *Bifidobacterium animalis*, which increased 5.7-fold, while levels of a pro-inflammatory cytokine were reduced. Therefore, eating crickets may improve gut health and reduce systemic inflammation; however, more research is needed to understand these effects and underlying mechanisms.

Other health effects have been summarized by Roos and van Huis (2017). Some insect species stimulate angiotensin-converting enzyme (ACE) inhibitors which may reduce blood pressure. There are also indications that some insect species, like yellow mealworm, have bioactive compounds to induce weight loss and that silkworms reduce symptoms of Parkinson’s disease.

Food Safety

What are the risks for human health when consuming insects? They could be chemical, microbiological, and allergenic hazards and prions. The risks have been reviewed by Van der Fels-Klerx et al. (2018). This review deals with insects as food and feed. When insects are used as feed, several species are of particular interest when grown on low quality substrates. We will deal only with insects used as food.

In yellow mealworm several heavy metals, like cadmium, lead, and arsenic, accumulate with increasing concentration in the substrate, although for the first two not beyond permissible levels. Their levels seem to decrease during molting and metamorphosis. Several studies showed that mycotoxins are metabolized by the yellow mealworms but do not accumulate. Few studies deal with the accumulation of resides of pesticides, veterinary drugs, and hormones.

Microbiological hazards for human health in insects are affected by a combination of the substrates used and the processing steps applied after rearing.

Proper heat treatment before consumption may eliminate most microbiological hazards and has been shown to be effective in particular against Enterobacteriaceae, although bacterial spores are not affected (Van der Fels-Klerx et al. 2018). Particular attention should be paid in the storage of processed products and in the household treatment of fresh insects. It is possible to produce end products with low microbial numbers that could be kept low during storage, especially by the use of modified atmosphere packaging (Stoops et al. 2017).

Concerning allergic reaction when eating insects, cross-reactivity may occur in patients allergic to house dust mites and crustaceans. The main allergens identified are the protein tropomyosin and arginine kinase (Verhoeckx et al. 2014). van Broekhoven et al. (2016) showed that heat-processing might decrease, but not eliminate, the risk for allergic responses when consuming mealworm species. Evidence for the association between consumption of insects and allergenic effects of chitin is lacking.

When insects are reared on organic by-products, one should be aware of contaminants. Some insect species can deal with chemical contaminants. For example, Van Broekhoven et al. (2017) showed that the yellow mealworm degraded and excreted the mycotoxin deoxynivalenol, although it remains to be studied whether possible resulting metabolites would be toxic.

Insect Food Products

Insects as food can be brought on the market as whole insects such as the bamboo caterpillars in the Lao People's Democratic Republic (Fig. 5). In the western world, they are often disguised in insect products such as pastas from mealworm or cricket flour (Fig. 6), jungle bars, protein bars, cricket flours, snack packs, insect candies, and biscuits, among others.

In South Korea, a high-protein yoghurt was prepared by adding different concentrations (0%, 0.5%, 1%, and 2%) of powder of the grasshopper *Oxya chinensis sinuosa* (Kim et al. 2017). However, except for color and texture, taste, flavor, and overall acceptability decreased with increasing proportions of the powder.

Manufacturing 3-D printed snacks from wheat flour dough enriched with ground yellow mealworm larvae has also been attempted (Severini et al. 2018). Baked under certain conditions, the enrichment with the insects significantly increased the total essential amino acid and protein digestibility corrected amino acid score. There was no adverse impact on quality.

In Mexico, the grasshopper *Sphenarium purpurascens* is a pest of corn, bean, and alfalfa and it can be controlled by pesticides, but the insects can also be captured and used as food (Cerritosa 2008). Extruded snacks have been made based on nixtamalized maize enriched with grasshopper meal (8/100 g of maize) without

Fig. 5 Packed bamboo caterpillar, *Omphisa fuscidentalis* (Lepidoptera: Crambidae) on the Tlat Dong Makkhai market near Vientiane, Lao People's Democratic Republic. (Photo by author)

Fig. 6 Cricket pasta. (http://tinyurl.com/yyhdvrk4)

affecting the physicochemical properties and acceptance of the snack (Cuj-Laines et al. 2018).

A patent was filed for the consumption of a scorpion in a novelty drink form (Turner 2019). The edible scorpion is suspended in a mixture of alcoholic or nonalcoholic fluid. It is prepared in a fashion that poses no health risk if consumed, either swallowed with the beverage or consumed thereafter once the beverage is finished. There are also websites that recommend which kind of wine or beer pairs with an insect snack (Jimini's 2019). Also red wood ants (*Formica rufa*) have been used to make a gin, the ants bringing the citrus flavor (Evans et al. 2017; p. 222).

The cockroach *Diploptera punctata* does not lay eggs but larvae. The developing offspring are nourished directly by the mother from the brood sac wall. This assures a rapid development of embryos that are able to drink and, importantly, store complete nutrients (protein, carbohydrate, and lipid) concentrated in crystalline form (Banerjee et al. 2016). Researchers isolated in vivo-grown crystals from the mid-gut of an embryo. A single crystal is estimated to contain more than three times the energy of an equivalent mass of dairy milk. Researchers have the sequence and hope to be able to produce the crystal in much larger quantities, making it more efficient than extracting crystals from cockroach's guts.

There are companies that produce ice creams from insect milk, apparently made from the black soldier fly (Bessa 2018).

Consumer Attitudes

There are several strategies that have been proposed to increase the acceptance of insect based products (van Huis 2016): (1) deliciousness; (2) providing information about nutritional value, sustainability and food safety; (3) stressing the proximity between crustaceans and insects; (4) giving people a taste experience, such as bug buffets; (5) using role models like political figures, film stars, or cooks, such as those of the world famous insect serving restaurants like NOMA in Denmark and D.O.M. in Brazil; (6) writing cookbooks for insects available in the country; and (7) targeting children as they are not biased yet. A study by Hartmann and Siegrist (2017), reviewing 38 articles dealing with alternative proteins, showed that the sustainability angle may not be convincing enough to motivate people to eat insects: their willingness to reduce or substitute meat (e.g., by insects) was not very high. Consumers apparently are not very much aware that meat production has a high environmental impact. But consumers are able to enumerate manifold substitutes for meat, as studies in Germany, France, and the Netherlands showed. However, traditional eating habits (liking the taste of meat) and lack of knowledge how to prepare meat-free meals seem to be major impediments to reducing meat consumption (Weinrich 2018). Therefore, it seems that substituting meat once or twice a week is a more realistic option. Tan and House (2018) suggested to focus on demand-side factors (changing consumer perceptions) and supply-side factors (creating tasty, usable, distinctive, and accessible products). They emphasize that initial motivations to eat insects and repeated consumption are two different things, and the two should be distinguished in future scholarly and commercial efforts. Interestingly, consumers of insect and vegetarian products are perceived as more health conscious, environmentally friendly, imaginative, brave, interesting, and knowledgeable than meat consumers (Hartmann et al. 2018).

In a representative survey in Belgium, about 80% of the people were aware of the fact that foods with insects can be bought, 11% had already eaten foods with processed insects, 32% had no experience but were willing to try, and 57% had no experience or interest in tasting such products (Van Thielen et al. 2018). Of potential consumers and depending on the product about 50–60% accepted invisible processed mealworms in energy shakes, energy bars, burgers, soup, sandwich spreads, unfried snacks, and fried snacks. Consumers indicated that the presence of insects should be clearly declared on the package and that they wanted to be able to buy these products primarily in the supermarket. In the same country, an experiment was conducted in which consumers were asked to taste insect burgers and rate them for quality and nutritiousness (Schouteten et al. 2016). This was done by giving a control group no information while the treatment group received information about insects having high-value proteins and their production being beneficial in terms of sustainability and the food safety. The liking for the insect-based burger was significantly higher among the informed than the noninformed consumers. The main conclusion of this study is that deliciousness is crucial. When consumers are willing to try the insect burger, but do not like the taste, they might not be willing to eat it again.

A study in Germany using mealworms suggests that higher prices lead to higher willingness-to-pay (Berger et al. 2018b). This is based on the assumption that introducing insect-based foods by means of "luxury consumption" may actually help to kick-start (initial) demand. The same authors (Berger et al. 2018a) also looked at motivations to eat insects: utilitarian benefits (environment and health) or hedonistic (taste). Their results show that hedonic claims of insect-based products lead to higher expectations, which then result in higher consumption probability and higher taste ratings. Based on these findings, they propose when marketing insect-based foods to use hedonic instead of utilitarian messages.

One has to be careful with the term "insect eating." This because of the large variety of insect species that can be eaten and the preferences of certain consumer groups. Van Huis (2003) already showed that neighboring ethnic groups in sub-Saharan Africa may eat different insect species. A nice example of cultural differences is given by Tan et al. (2015). They conducted focus group discussions to explore the different consumer perceptions and expectations regarding insects as food in two different cultural contexts – one where insects are eaten (Thailand) and one where insects are generally not eaten (The Netherlands). One of the insects studied was mealworms which are sold as food in the Netherlands but not in Thailand. The Thai participants were strongly repulsed by mealworms, due to the association with larvae that they often see in decaying matter. This shows that the preference towards certain species depend on cultural background and individual experience.

Challenges

In addition to the "general food hygiene requirements," the production and marketing of insects as food in Europe is governed by the so-called "Novel Foods" legislation – i.e., Regulation (EU) No 2015/2283 (IPIFF 2019). This legislation applies to all categories of foods that "were not used for human consumption to a significant degree" within the European Union before 15 May 1997, which is the case of insects and insect-derived products. Novel food applications have to be submitted to the European Commission. In several EU countries, insect producers may continue to commercialize their products, even in the absence of EU novel food authorization. This is a transitional measure that aims to ensure that products which were lawfully commercialized in a Member State of the EU before 1 January 2018 – i.e., date of application of the "new" novel food legislation – may remain on the market of this particular country for a given period of time, subject to certain conditions.

Another challenge is the cost price. A large part of the cost price is labor costs. For that reason, many companies are engaged in developing automation processes. This will require the cooperation of engineers (Kok 2017). The techniques and methods used are also called entotechnology which deals with: organisms and feeds, process types, reactor types, environmental requirements, heat and mass transfer, materials handling, process control, air conditioning, waste management, cleaning, strain breeding, culture maintenance, population synchronicity, and safety. Because a lot of trial and error is involved, the companies are very secretive about their production procedures. Another way to cut the cost price is the use of cheap organic side streams. For example, crickets can be reared on cassava leaves (Caparros Megido et al. 2016) and certain weeds (Miech et al. 2016). Also mealworms can be reared on organic side streams (Oonincx et al. 2015; van Broekhoven et al. 2015) and vegetable and fruit remains (Ramos-Elorduy et al. 2002), although in the last case the larvae were used as poultry feed. In the case of organic side streams, one has to be aware of food safety issues.

Although we know many insect species that are eaten in the world, only very few are currently on the western market. The reason is that those insect species were already reared as pet food. It will require some research to find out if we can also rear some of the more than 2000 edible insect species that are known to be eaten around the world.

To convince consumers to eat insect-derived products is another major challenge. According to Tan and House (2018), regular insect consumption is determined by previous experience, culinary knowledge, wider cultural associations, established routines of food provisioning and eating, and the availability, price, form, and taste of products. Insects may be eaten out of curiosity and that is often done once. However, making it a regular consumed food item is something else. The willingness to consume is not necessarily translated into sales. The importance of taste is often stressed (Van Thielen et al. 2018) and the target group are those consumers, who are open to try novel foods and interested in the environmental impact of their food choice (Verbeke 2015).

A major question often asked: what about insect welfare when insects are farmed as mini-livestock? The Council on Animal Affairs in the Netherlands produced a report (RDA 2018) in which they recommend to respect the intrinsic value of insects and to treat insects in captivity as "sentient beings." Although there is no scientific evidence to date that invertebrates are capable of suffering, there is no evidence to the contrary either. There are indications, however, that certain invertebrate families (such as octopuses and bees) can experience states resembling emotions. Investments in the welfare of insects would also seem to be in the producers' own interests. Adapting farms to suit the needs and developmental stages of certain species as much as possible not only increases production, but is also important for the social acceptance of the insect industry. This adaption has to do with husbandry requirements, welfare protocols, and killing methods for edible insect species.

Conclusion

Insects as food is a new upcoming agricultural sector and it has only been realized since about 10 years that this may be an interesting food source in terms of nutrition and the environment. In particular because the search for alternative proteins is considered a priority by many governments. Business as usual with regards to proteins is not an option anymore. Authorities may consider it a promising sector, but also a new one with much uncharted territory. The anticipated growth necessitates answers to questions regarding the relevant interests of humans, animals and the environment. For that reason, it is important that stakeholders nationally and internationally collaborate and challenge public institutions to create a conducive environment for the industry to develop.

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