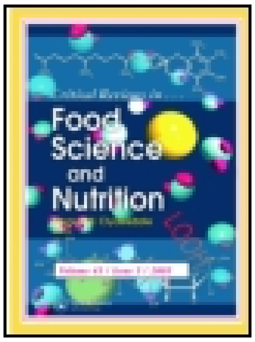

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Traditional consumption of and rearing edible insects in Africa, Asia and Europe

Dele Raheem[a,b], Conrado Carrascosa[c], Oluwatoyin Bolanle Oluwole[d], Maaike Nieuwland[e], Ariana Saraiva[f], Rafael Millán[c], and António Raposo[g]

[a]Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam; [b]Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City, Vietnam; [c]Department of Animal Pathology and Production, Bromatology and Food Technology, Faculty of Veterinary, Universidad de Las Palmas de Gran Canaria, Trasmontaña s/n, Arucas, Spain; [d]Department of Food Technology, Federal Institute of Industrial Research Oshodi, Lagos, Nigeria; [e]TNO, AJ Zeist, The Netherlands; [f]Pharmacy Faculty, University of Coimbra, Azinhaga de Santa Comba, Coimbra, Portugal; [g]CBIOS (Research Center for Biosciences and Health Technologies), Universidade Lusófona de Humanidades e Tecnologias, Campo Grande 376, Lisboa, Portugal

ABSTRACT

The traditional consumption of edible insects is common in one third of the world's population, mostly in Latin America, Africa and Asia. There are over one thousand identified species of insects eaten in some stage of their life cycle; and they play important roles in ensuring food security. The most common way to collect insects are from the wild, which is seasonal with limited availability and has an increasing demand resulting in a disruption to the ecosystem. There is a growing interest shown in rearing insects for commercial purposes, and an industrial scale production will be required to ensure steady supplies. Industrial production will need to take into account the living environment of insects, the nutritional composition of their feed and the overall efficiency of the production system. We provide a short overview on the consumption of and rearing insects in Africa, Asia and Europe. For Africa, a snapshot is given for Nigeria, Ghana, Central African Republic, Kenya and Uganda, while the following countries are reported for Asia: China, Japan, Lao People's Democratic Republic, Thailand and Vietnam. In addition, a list of insect species with the highest potential for food and feed in the European Union is provided with some reference to The Netherlands and Finland. The review concludes that there is need to better understand the rearing and farming procedures that will yield high quality edible insects in Africa, Asia and Europe.

KEYWORDS
Africa; Asia; edible insects; Europe; rearing; traditional consumption

1. Introduction

Entomophagy is eating insects as food. The term "entomophagy" comes from the Greek term "entomos", meaning "insects", and "phagein" meaning "to eat", and the combination of both term means "insect eating". People worldwide have been eating insects as a regular part of their diets for millennia (FAO 2013a). In developing countries, the traditional use of insects as food continues to be widespread as it provides significant nutritional, economic and ecological benefits for rural communities (DeFoliart 1999). Many tropical and subtropical countries, such as Zimbabwe, Mexico and Thailand, are well-known insect-eating regions, including parts of Japan and China. More than 1,900 insect species in the world are known to be edible (Van Huis 2013), and nearly 1700 insect species are documented as being used as human food (Ramos-Elorduy 2005), eaten by some 2 billion people worldwide (FAO 2013a). In Thailand, for instance, where edible insects are very popular, 164 insect species were collected en masse and sold in markets and supermarkets in Bangkok, as reported by (Yhoung-Aree and Viwatpanich 2005). The most commonly eaten groups are beetles, caterpillars, bees, wasps, ants, grasshoppers, locusts, crickets, cicadas, leaf and plant hoppers, scale insects and true bugs, termites, dragonflies and flies.

Insects are animals that form part of the arthropod group, which have a chitinous exoskeleton, a three-part body (head, thorax and abdomen), three pairs of jointed legs, compound eyes and two antennae. Insects are the only winged invertebrates, are cold-blooded, and undergo metamorphosis to be able to adapt to seasonal variations, reproduce quickly and have large populations. Their respiratory systems are tolerant to air and vacuum pressure, high altitude flight and radiation, and they do not often need parental care. Insects are found in nearly all environments, although only a few species occur in oceans. Insects are among the most diverse groups of organisms in the history of life (Chapman 2006; Novotny et al. 2002; Scaraffia and Miesfeld 2012), and are thought to account for over 70% of all species. Although about one million species of insects have been classified and named, their actual number is believed to range from 2.5 and 10 million (Van Huis 2003).

Many people live below the international poverty line and are unable to access quality food (Folaranmi 2012), which results in undernutrition, especially protein-energy malnutrition (PEM),

CONTACT António Raposo antonio.raposo@ulusofona.pt; Dele Raheem dele.raheem@tdt.edu.vn; Oluwatoyin Bolanle Oluwole oluwatoyinoluwole575@yahoo.com; oluwole.oluwatoyin@fiiro.gov.ng CBIOS (Research Center for Biosciences and Health Technologies) Universidade Lusófona de Humanidades e Tecnologias Campo Grande 376, 1749-024, Lisboa, Portugal.

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in Africa, Latin America and Asia (Siriamornpun and Thamamapat 2008). Furthermore, trends towards 2050 predict a steady population increase to 9 billion people, which forces increased food/feed output from available agro-ecosystems, and results in an even bigger pressure on the environment. Scarcities of agricultural land, water, forest, fishery and biodiversity resources, as well as nutrients and non-renewable energy, are foreseen (FAO 2017). Improvements in food production systems have been brought about by intensive farming policies, genetic selection, and recently by the development of genetically modified organisms (GMOs) (Belluco et al. 2013). Despite these improvements, to have a secure future food system, alternative food, and especially protein sources are needed. Edible insects already have high market values that are, at times, similar to, or even higher than, traditional livestock in some low-income African and Asian countries. Thus insects are a commodity with an existing market (McGill 2016). Using insects as food and feed falls in line with the sustainable diet context (Kelemu et al. 2015, Van Huis et al. 2013) for food and feed security. Eaten insect species range from ants to beetle larvae eaten by tribes in Africa and Australia as part of their subsistence diets, to the popular fried locusts and beetles enjoyed in Thailand.

Eating insects whole, or when their body parts are visible, can be difficult for those brought up in Western societies. In those societies, where insects have not been consumed for a long time, people prefer including insects into the food in such a way that they are not recognisable. Nevertheless, although a disgust factor exists for eating insects, people accept the idea that insects are valuable food (Mlcek et al. 2014). This shows that people, especially from North America and Europe, can eat insects if they do not know what they are eating, except for those individuals with allergic reactions. These factors suggest that 'hiding' insects in products will facilitate their consumption in the future. In practice, dried insects may be crushed or pulverised, and raw or boiled insects can be ground or mashed, which makes their insect form unrecognisable (Mlcek et al. 2014). In contrast, the whole insect remaining visible is preferred in other cultures, where insects are eaten for their delightful taste, while the process of collecting them is also enjoyed (Nonaka, 2009a).

Both in food security terms and to live more sustainably, insects for feed and food purposes can play an important role. They can help to fulfil the Sustainable Development Goals (SDG) by 2030 (DESA 2016). In particular, this is linked to: SDG 2, to end hunger, achieve food security and improved nutrition and promote sustainable agriculture; SDG 12, to ensure sustainable consumption and production patterns; SDG 13, to take urgent action to combat climate change and its impacts; SDG 15, to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

The fact that one third of the world's population eats insects, a practice that it is not only related to poverty, is creating industrial interest in Europe and North America (Dossey, Morales-Ramos, and Rojas 2016). Edible insects can be obtained in three ways: (1) wild harvesting; (2) semi-domestication (habitat manipulation to increase production); (3) farming (which can range from the single small cage scale to a large factory (Yen 2015). As wild harvested insects are still the main source in the Asia Pacific and African regions, commercialisation is increasing harvesting pressures in the wild. Raising insects in the household at small to medium enterprise levels is a time-efficient and low technology practice to produce a highly nutritious food that is already eaten locally in many African and Asian countries. Insects can be reared on land that is not suitable for other purposes, and can be raised on waste or side streams containing adequate nutrients. Water use in insect farming is minimal (Dossey, Morales-Ramos, and Rojas 2016) both because of low water requirements for feed production, and because many insect species require little or no drinking water as the moisture in their feed supplies sufficient water.

This review explores the rearing and utilisation of edible insects as food and feed in different regions of Africa, Asia and Europe, where the authors live and are affiliated to institutions. It focuses on the current and likely future scenarios in some selected countries of these three continents, although sources in other regions are also cited. After an introductory section about the traditional consumption of insects worldwide, this paper provides an overview of insect rearing/farming in Africa, Asia and Europe.

2. Traditional consumption of insects worldwide

Edible insects have played an important role as part of human nutrition in many regions around the world among which large parts of Africa, Asia and Latin America (Aletor 1995; Kelemu et al. 2015; Yi et al. 2010). More than 1,000 insect species, edible at some stage of their life cycle, are reported worldwide as being traditional human food. Insects represent major parts of the nutritional intake and economic resources of many societies (Illgner and Nel 2000). There are 524 species consumed in Africa, 349 in Asia, 679 in America, 41 in Europe and 152 in Australia (Ramos-Elorduy 2005). Mexico has the most registered species, followed by Thailand, Congo, Zaire, India, Australia, China and Zambia (Cerritos 2009). In Europe in particular, and the Western world in general, rearing or consuming insects is alien to today's culture.

Globally, the most commonly eaten insects are beetles (Coleoptera) (31%), which make up around one third of the total (Van Huis et al. 2013). This is not surprising because this group contains about 40% of all known insect species. Eating caterpillars (Lepidoptera) is especially popular in sub-Saharan Africa, and is estimated at 18%. Bees, wasps and ants (Hymenoptera) come in third place with 14%, and these insects are especially common in Latin America. Next come grasshoppers, locusts and crickets (Orthoptera) (13%), cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera) (10%), termites (Isoptera) (3%), dragonflies (Odonata) (3%), flies (Diptera) (2%), and other orders (5%) (Van Huis et al. 2013). Lepidoptera are consumed as caterpillars and Hymenoptera are harvested and eaten mostly in their larval or pupal stages. Both adults and larvae of Colepterans are eaten, while the Orthoptera, Isoptera and Hemiptera orders are eaten mostly as mature adults (Cerritos 2009; Ketemu et al. 2015). Variation in the most consumed insect order by continent, country and community is wide. For example, an estimated 96 insect species are eaten in the Central African Republic.

There are some reasons why insects are eaten more in the tropics than in temperate areas of the world. The differences stem from differences in the size of insects between tropics and temperate areas, and in the distribution of insects. Insects use a series of tubes, known as a tracheal system, for breathing and, like humans, require oxygen and produce carbon dioxide as a waste product. Gases are mainly exchanged throughout the body by diffusion, which happens faster at higher temperatures, and this allows for bigger insects being produced in warmer climates (Kirkpatrick 1957). The larger size facilitates harvesting. In the tropics, insects often congregate in significant numbers, so large quantities can be collected during a single harvest. For instance, locust swarms settle for the night, which makes harvesting very easy in the evening and early in the morning. Caterpillars in forests congregate en masse by nature. In temperate zones, insects hibernate to survive cold winters. During this period no active insect species can be found and their development comes to a standstill.

Insects can be found abundantly throughout Africa and Asia. Insects form part of the traditional diets of millions of people and are also used as feed for farm animals. During the rainy season, when hunting game or fish is problematic, and when staples are scarce, edible insects play an important role in food security. Between 150 and 200 species of edible insects are consumed in SE Asia. Some insects are available all year round (e.g., dragon larvae, diving beetles, giant water bugs), including many aquatic species, while others are available only on a seasonal basis (e.g., grasshoppers, cicadas, weaver ants). The most popular edible beetle in the tropics is the palm weevil, *Rhynchophorus*, a significant palm pest of which different varieties are distributed throughout Africa, Southern Asia and South America. The palm weevil, *R. phoenicis*, is found in tropical and equatorial Africa, while *R. ferrugineus* is located in Asia (Indonesia, Japan, Malaysia, Papua New Guinea, the Phillipines and Thailand), with *R. palmarum* in the tropical Americas (Central America and West Indies, Mexico and South America). They are highly prized delicacies in many regions (Johnson 2010). Ants are also highly sought after delicacies in many parts of the world, and they render important ecological services, including nutrient recycling, while they serve as predators of pests in orchards (Del Toro, Ribbons, and Pelini 2012). The weaver ant (*Oecophylla* spp.) is used as a biological control agent in various crops, such as mangoes (Van Mele 2008), and the larvae and pupae of the reproductive form (Queen brood), also called ant eggs, are a popular food in Asia. Indeed in Thailand, they are sold in cans. Shen et al. (2006) have reported that the black weaver ant (*Polymachis dives*) is widely distributed in subtropical South-eastern China, Bangladesh, India, Malaysia and Sri Lanka. It is used as a nutritional ingredient, and is processed into various tonics or health foods that are available on the Chinese market. The State Food and Drug Administration and the State Health Ministry of China have approved more than 30 ant-containing health products since 1996.

Different ethnic groups have distinct edible insects preferences; for example, Mofu-Gudur in Cameroon eat a number of grasshopper species (*Acoeypha picta, Acorypha glaucopsis, Acrida bicolor*), which are not eaten by Hausas in Niger, and some insect species are consumed by Hausa people in Niger, which are not eaten by Mofu-Gudur. There are also some prohibitions to eat insects; for example, pygmies eat the larvae and nymphs of the goliath beetle (*Goliathus* spp.), but do not eat the adult because it is considered sacred and it is used in fetish preparations (Bergier 1941). Insects are often eaten whole, but can also be processed into granular or paste forms. Extracting proteins, fats, chitin, minerals and vitamins is also possible (Van Huis 2003).

2.1. Africa

The African diets consist of a vast variety of wild foods, which include edible insects. Figure 1 and Table 1 below show the diversity of edible insects in Africa. There are over 1,500 species of edible insects across Africa. As the price of beef, chicken and fish continue to rise across the world, a marvellous opportunity has emerged for insects to meet the animal protein needs of mankind and livestock now and also in the future. The demand for edible insects is growing in Africa, mainly because animal protein is becoming more expensive and scarce. The demand for healthier alternatives and insects has grown and has a huge potential in animal feed production. A variety of insects is consumed.

The desert locust, the migratory locust, the red locust and the brown locust are all eaten. Grasshoppers and locusts are generally collected in the morning when temperatures are cooler, causing these cold-blooded insects to be relatively immobile. In Niger, it is not uncommon to find grasshoppers for sale in local markets or sold as snacks on roadsides. Unfortunately given their status as agricultural pests, they may have been sprayed with insecticides in governmental control programmes or by farmers.

In Southern Africa alone, the animal trade value of the mopane worm is over $85 million. Endemic to the mopane woodlands in Angola, Botswana, Mozambique, Namibia, South Africa, Zambia and Zimbabwe, the caterpillars' habitat covers about 384,000 km^2 of forest (FAO 2003). An estimated 9.5 billion mopane caterpillars are harvested annually in Southern Africa. Malaisse (1997) has identified 38 different species of caterpillar across the Democratic Republic of the Congo, Zambia and Zimbabwe, while Latham (2003) has documented 23 edible species from the Bas-Congo, a western province of the Democratic Republic of Congo. In Malawi, it has been reported that beekeeping is more than 3 times as profitable as growing maize, a staple crop (Munthali and Mughogho 1992). In Table 1, the most widely eaten insects in Africa are shown.

Every country has its own entomophagy habits, and differences in entomophagy can even be observed between regions in countries. A selection of countries is discussed below.

2.1.1. Nigeria

Nigeria is very rich in forest edible insects due to its marked ecological and climatic diversity. Alamu et al. (2013) have compiled a list of 22 insect species that are eaten from six orders (Table 2). Of these, 27.3% were Lepidoptera (moths), 27.3% Coleoptera (beetles), 22.7% Orthoptera (grasshoppers, crickets), 13.6% Isoptera (termites) and 9.0% Hemiptera and Hymenoptera (bees). Most edible insects in Nigeria depend largely on forest to survive. Within Nigeria, every region has its own habits. Fasoranti and Ajiboye (1993) have reported the consumption of seven edible insect species by people in the Kwara state, while (Agbidye, Ofuya, and Akindele 2009) have reported

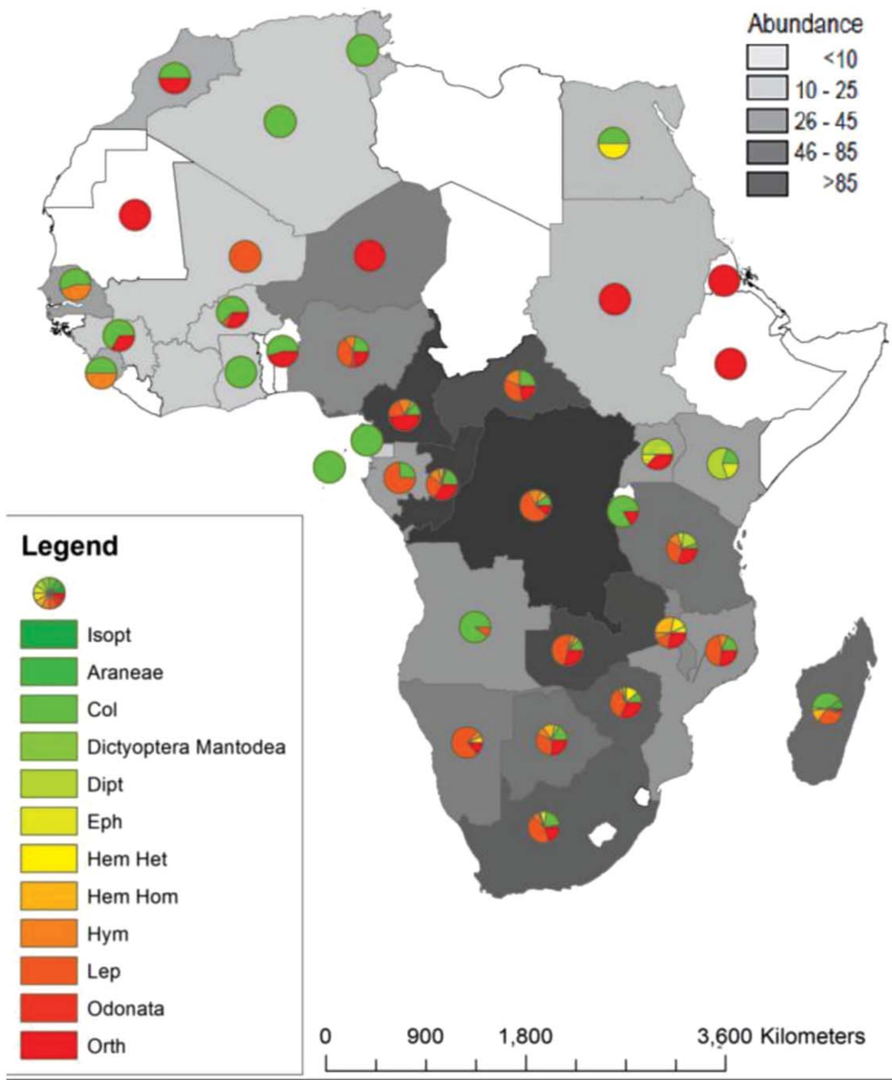

Figure 1. Diversity and abundance of main groups of edible insects in Africa. Source: Kelemu (2016).

four commercially marketed edible forest insects in the Benue state. DeFoliart (1989) has indicated that edible insects are usually included as a regular part of the diet when in season, or throughout the year if available. Edible insects are highly prized, much sought after and not used merely to ward off starvation. In the Benue state, termites (*Macrotermes natalensos* Haviland) is the most prevalently eaten insect, followed by the large African cricket (*Brachytrupes membranaceus* Drury), while the pallid emperor moth (C*irina forda* Westwood) comes in third place in edible insects consumption trend terms (Agbidye, Ofuya, and Akindele 2009). At the same time, members of the Ire clan in Nigeria, who are predominantly blacksmiths, do not eat crickets because the worshipped iron god of Ogun does not accept animals without blood (Fasoranti and Ajiboye 1993). Adeduntan and Bada (2004) and Ashiru (1989) have also reported the African Silkworm, *Anaphe venata* being eaten by rural dwellers in the Ondo state, Nigeria, where this insect is collected from forests.

2.1.2. Ghana

According to a study by Anankware et al. (2016), nine edible insects have been identified in Ghana. Of these, the scarab beetle (2%), field cricket (5%), shea tree caterpillar (8.7%), house cricket (9.5%) and locust (10%) are the least consumed, whereas the larvae of palm weevil (47.2%), termites (45.9%), ground crickets (*Scapteriscus vianus*, 33.3%) and grasshoppers (30.5%) are more commonly eaten. These percentages correspond to the number of responses given by the participants in the applied survey, which could indicate more than one insect species. Northern Ghana currently dominates in entomophagy, especially the upper west and upper east regions where eight of the nine identified edible insects are eaten. Termites have been reported to be consumed in all ten regions of Ghana. Palm weevils have been reported to be eaten mainly in the middle belt and Southern Ghana, where palm trees thrive. Termites, field crickets, ground crickets, grasshoppers and locusts are eaten by almost all the tribes in Ghana (Anankware et al. 2015) as shown in Table 3.

2.1.3. Central African Republic

An estimated 96 insect species are eaten in the Central African Republic. Orthoptera (locust and grasshoppers) is the most consumed class with 40%, followed by Lepidoptera

Table 1. The most consumed insect species in Africa. Countries and regions of Africa where species are mostly consumed.

Order	Scientific and Common Names	Countries
Coleoptera	*Oryctes owariensis* (Palisot de Beauvois) (Rhinoceros Beetle)	DRC, South Africa, Congo, Ivory Coast, Sierra Leone, Guinea, Ghana, Equatorial Guinea, Guinea Bissau
	Rhynchophorus phoenicis (Fabricius) (African palm weevil)	DRC, Cameroon, Congo, CA Republic, Nigeria, Angola, Ivory Coast, Niger, São Tomé and Príncipe, Guinea, Togo, Liberia, Benin, Guinea Bissau
	Oryctes boas (Fabricius) (Boas rhinoceros beetle)	Nigeria, Ivory Coast, Sierra Leone, Guinea, Liberia, Guinea Bissau DRC, Congo, South Africa, Botswana, Namibia
Hemiptera	*Encosternum delegorguei* (Spinola) (Stinkbug)	South Africa, Swaziland, Mozambique, Malawi Zimbabwe, Botswana, Namibia
Hymenoptera	*Apis mellifera mellifera* Linnaeus (European dark bee)	DRC, Zambia, Botswana, Nigeria, Tanzania, Senegal, Sierra Leone, Ghana, South Sudan, Togo, Lesotho, Benin
	Apis mellifera adansoni (Latreille) (Africanised honey bee)	DRC, Zambia, CA Republic, Nigeria, Tanzania, Sierra Leone, Ghana, Benin
	Carebara vidua (Smith)	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi, Sudan, Kenya, South Sudan
	Carebara lignata (Westwood)	Zambia, South Africa, Zimbabwe, Botswana, Sudan, Mozambique, Namibia, South Sudan
Isoptera	*Macrotermes* spp. (African mound-building Termites)	DRC, Zambia, Zimbabwe, Nigeria, Tanzania, Malawi, Senegal, Uganda, Côte d'Ivoire, Guinea, Ghana, Togo, Burundi, Benin
	Macrotermes bellicosus (Smeathman) (Termites)	DRC, Cameroon, Congo, CA Republic, Nigeria, Côte d'Ivoire, Kenya, São Tomé and Príncipe and Príncipe, Guinea, Togo, Liberia, Guinea Bissau, Burundi
	Macrotermes subhyalinus (Rambur) (Mendi Termite)	Zambia, Angola, Kenya, Togo, Burundi
	Macrotermes falciger (Gerstäcker)	Zambia, Zimbabwe, Burkina Faso, Burundi, Benin
	Macrotermes natalensis (Haviland)	DRC, Cameroon, Congo, CA Republic, Nigeria, Burundi, South Africa, Zimbabwe, Nigeria, Malawi
Lepidoptera	*Bunaea alcinoë* (Stoll) (African moth)	Democratic Republic of Congo (DRC), Zambia, South Africa, Cameroon, Congo, Central African Republic (CA Republic), Zimbabwe, Nigeria, Tanzania
	Anaphe panda (Boisduval) (Silk moth)	DRC, Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Nigeria, Tanzania
	Cirina forda (Westwood) (Emperor moth)	DRC, Zambia, South Africa, Botswana, Burkina Faso, Nigeria, Mozambique, Namibia, Ghana, Togo, Chad
	Dactyloceras lucina (Drury) (Drury's Owl Moth)	DRC, Zambia, South Africa, Cameroon, Congo, Angola, Gabon, Sierra Leone, São Tomé and Príncipe, Equatorial Guinea
	Platysphinx stigmatica (Mabille) (Red spot moth)	DRC, Zambia, Congo, CA Republic, Sierra Leone, São Tomé and Príncipe, Equatorial Guinea, Rwanda, Burundi
	Cirina butyrospermi (Vuillot) (Shea tree caterpillar)	DRC, Zambia, South Africa, Zimbabwe, Burkina Faso, Nigeria, Mali, Ghana
	Epanaphe carteri (Walsingham)	DRC, Zambia, Angola, Gabon, Sierra Leone, São Tomé and Príncipe, Equatorial Guinea
	Imbrasia belina (Westwood) (Mopane caterpillar, mopane worm, emperor moth)	DRC, Zambia, South Africa, Zimbabwe, Botswana, Malawi
	Gynanisa ata (Strand) (African moth)	DRC, Zambia, Malawi, South Sudan
	Eumeta cervina (Druce) (Bagworm)	DRC, Cameroon, Congo, CA RepublicAngola, Gabon, Sierra Leone, São Tomé and Príncipe, Equatorial Guinea, Rwanda, Burundi, Liberia
	Imbrasia ertli (Rebel) (Confused Emperor)	Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Botswana, Angola
	Anaphe venata (Butler) (African silkworm)	Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Botswana, Angola
	Imbrasia epimethea (Drury) (African moth)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe
	Urota sinope (Westwood) (Tailed Emperor)	DRC, South Africa, Zimbabwe, Botswana, Gabon, Mozambique, Namibia
Orthoptera	*Schistocerca gregaria* (Forskål) (Desert locust)	Zambia, South Africa, Cameroon, Congo, Botswana, Tanzania, Sudan, Uganda, Ethiopia, Kenya, Sierra Leone, Morocco, Guinea, Lesotho, Mauritania, Somalia, Eritrea, Guinea Bissau
	Acanthacris ruficornis (Fabricius) (Garden Locust)	DRC, Zambia, South Africa, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Malawi, Mali, Niger, Togo, Benin
	Brachytrupes membranaceus (Drury) (Tobacco cricket)	Zambia, Cameroon, Congo, CA Republic, Zimbabwe, Burkina Faso, Nigeria, Tanzania, Angola, Togo, Benin
	Nomadacris septemfasciata (Serville) (Red Locust)	Zambia, South Africa, Congo, Zimbabwe, Botswana, Nigeria, Tanzania, Malawi, Uganda, Mozambique
	Ruspolia differens (Serville) (Longhorn grasshopper)	DRC, Zambia, South Africa, Cameroon, Zimbabwe, Kenya, Uganda, Tanzania, Malawi
	Zonocerus variegatus (Linnaeus) (Variegated grasshopper)	DRC, Cameroon, Congo, CA Republic, Nigeria, Côte d'Ivoire, São Tomé and Príncipe, Guinea, Ghana, Liberia, Guinea Bissau
	Locusta migratoria migratorioides (Reich & Fairmaire) (Migratory locust)	Zambia, Cameroon, Congo, Zimbabwe, Sudan, South Sudan
	Locustana pardalina (Walker) (Brown locust)	Zambia, South Africa, Zimbabwe, Botswana, Malawi, Libya
	Gastrimargus africanus (Saussure) (African grasshopper)	Cameroon, Congo, Niger, Lesotho, Liberia
	Phymateus viridipes brunneri (Bolivar) (Gaudy grasshopper)	Zambia, South Africa, Congo, Zimbabwe, Botswana, Mozambique, Namibia
	Gryllus bimaculatus (De Geer)	Guinea Bissau, Sierra Leone, Guinea, Liberia, Benin, Togo, Nigeria, DRC, Kenya, South Sudan, Zambia
	Anacridium melanorhodon melanorhodon (Walker)	Cameroon, Sudan, Niger
	(Sahelian tree locust) *Paracinema tricolor* (Thunberg)	Cameroon, Malawi, Lesotho
	Acheta spp. (Crickets)	Zambia, Zimbabwe, Kenya

Source: Kelemu et al. 2015.

(caterpillars, 36%), Isoptera (termites, 10%), Coleoptera (beetles, 6%) and others, such as cicadas and crickets with 8% (Roulon-Doko 1998). Logo-Arokaya in Northern Central Africa have rules that determine termite consumption, which take into account consumers' state of being married or pregnant, as well as the swarming behavior of termites (Costermans, 1955).

2.1.4. Kenya

Traditional plant and animal foods, among which the insects eaten in Western Kenya may constitute the cheapest sources of macronutrients and micronutrients, and provide minerals, carbohydrates, protein and polyunsaturated fatty acids (Ayieko et al. 2012; Johns and Kokwaro 1991; Kinyuru et al. 2010; Orech et al.

Table 2. Commonly eaten insects in Nigeria.

Order	Family	Scientific name	Common name	Consumption
Coleoptera	Cerambycidae	*Analeptes trifasciata*	Stem girdler	Larvae
	Scarabaeidae	*Oryctes boas*	Rhinoceros beetle	Larvae
	Scarabaeidae	*Oryctes monoceros*	Rhinoceros beetle	Larvae
	Scarabaeidae	*Aphodius rufipes*	Dung beetle	Larvae
	Curculionidae	*Rhynchophorus phoenicis*	Palm weevil	Larvae
	Dynastidae	*Heteroligus meles*	Yam beetle	Larvae
Hemiptera	Pentatomidae	*Nezara viridula*	Stink bug	Adult
Hymenoptera	Apidae	*Apis mellifera*	Honey bee	Egg, larvae, pupa
Isoptera	Termitidae	*Macrotermes nigeriensis*	Termite	Winged adult, queen
	Termitidae	*Macrotermes bellicosus*	Termite	Winged adult, queen
	Termitidae	*Macrotermes natalensis*	Termite	Winged adult, queen
Lepidoptera	Notodontidae	*Anaphe venata*	African silkworm	Larvae
	Notodontidae	*Anaphe infracta*	African silkworm	Larvae
	Notodontidae	*Anaphe recticulata*	African silkworm	Larvae
	Saturnidae	*Bunaea alcinoe*	Emperor moth	Larvae
	–	*Lepidoptara litoralia*	–	Larvae
	Saturnidae	*Cirina forda*	Pallid emperor	Larvae
Orthoptera	Gryllidae	*Brachytrupes membranaceus*	Giant African cricket	Adult
	Gryllidae	*Gymnogryllus lucens*	Cricket	Adult
	Acrididae	*Cytacanthacris naeruginosus*	Short horned grasshopper	Adult
	Pygomorphidae	*Zonocerus variegatus*	Grasshopper	Adult
	Gryllotalpidae	*Gryllotalpa africana*	Mole cricket	Adult

Adapted from Alamu et al. 2013.

2007), are essential for optimal infant growth and development. In Table 4, the most commonly eaten insects in Kenya are shown.

2.1.5. Uganda

In Uganda, the most commonly consumed insects are termites (*Macrotermes* spp.) and grasshoppers (*Ruspolia nitidula*). Market surveys have revealed that the wholesale or retail price of some edible insects could exceed traditional animal meat products if edible insects are collected solely from the wild (e.g. grasshoppers in Uganda are marketed at prices that are 40% higher than beef) (Agea et al. 2008).

2.2. Asia

The entomophagy practice is commonplace in many Asian countries. According to Ramos-Elorduy (2005), 349 insect species are eaten in 29 Asian countries. In the Asia Pacific region, information on edible insects is available for some countries, although it is fragmented (Yen 2015). There is very little published information for peninsular Malaysia, Myanmar, Nepal, Pakistan, several Pacific islands, and Taiwan (Johnson 2010), and knowledge gaps exist in Australia, Indonesia, Papua New Guinea, Philippines, and Vietnam. Declining insect consumption has been reported in countries with a long-standing history of this practice as diet has shifted to a more westernised-type diet, accompanied by a population shift to urban areas (Van Huis 2013). However, an exception to this trend is found in Southeast Asian parts (Yhoung-Aree, Puwastien, and Attig 1997).

2.2.1. China

China has a long-standing tradition of consuming edible insects that dates back more than 3,000 years (Chou 1980; Zhou 1982). One hundred and seventy-eight insect species from 96 genera, 53 families and 11 orders are commonly eaten in China (Chen, Feng, and Chen 2009). Eaten insect forms range from eggs to adults, but restaurants mostly prepare larvae and pupae. Preparation of edible insects includes frying, braising, stewing, stewing after frying, boiling and roasting (Feng et al. 2017).

The Chinese Ministry of Health has included silkworm pupae among its new food sources, which has boosted scientific interest in this topic. These insects were already consumed as a silk industry by-product and, after a period of decline, have recently regained importance. For this reason, toxicological studies have been performed to evaluate PSP (protein of silkworm pupae) safety by Zhou and Han (2006). They ran an

Table 3. Major edible insects of Ghana.

Order	Family	Common name	Scientific name	Local name in Ghana	Stage Consumed
Coleoptera	Curculionidae	Palm weevil larva	*Rhynchophorus phoenicis* (Fabricius)	Akokono in Twi/ Akan,	Larvae and adult
	Scarabaridae	Scarab beetle larva	*Phyllophaga nebulosa* (Harris)	Chibio nabra in Kasem	Larvae
Isoptera	Termidae	Termite	*Macrotermes bellicosus* (Smeathmen)	Kwena in Kasem	Adult
Lepidoptera	Saturniidae	Shea tree caterpillar	*Cirina butyrospermi* (Vuillot)	Kantuli in Frafra and Dagari	Larvae
Orthoptera	Acrididae	Locust	*Locusta migratoria* (Linnaeus)	Gbameda in Ewe	Adult
Orthoptera	Pyrgomorphidae	Grasshopper	*Zonocerus variegatus* (Linnaeus)	Manchogo in Kasem	Adult
Orthoptera	Gryllidae	House cricket	*Acheta domesticus* (Linnaeus)	Cheri in Kasem	Adult
Orthoptera	Gryllidae	Field cricket	*Gryllus similis* (Chopman)	Paan-terkyiirae in Dagoan	Adult
	Gryllotalpidae	Ground cricket	*Scapteriscus vianus* (Scudder)	Tiga chari in Kasem	Adult

Source: Anankware et al. 2015.

Table 4. Traditional Animal Source Foodstuffs and their edible parts consumed in Western Kenya.

Common Name	Luo Name	Scientific Name	Edible Parts
Winged termite	Sisi	*Pseudacanthotermes militaris* (Hagen)	Whole: de-winged
Winged termite	Riwo	*Macrotermes bellicosus* (Smeathmen)	Whole: de-winged
Winged termite	Agoro	*Macrotermes subhylanus* (Rambier)	Whole: de-winged
Winged termite	Oyala	*Pseudacanthotermes spiniger* (Sjostedt)	Whole: de-winged
Black ant	Onyoso	*Carebara vidua* (Smith)	Abdomen: de-winged whole
Long-horned grasshopper	Senesence	*Ruspolia differens* (Serville)	Whole: de-winged

Sources: Kinyuru et al. 2012, 2013.

acute toxicity test, a mutagenicity test (Ames test, mouse bone marrow cell micronucleus test, and mouse sperm abnormality test) and a 30-day feeding study before concluding that 1.50 g/kg body weight of PSP daily can be regarded as safe.

Insects are also often used as health food in China. The most famous example is caterpillar fungus, which is believed to enhance immunity and have anti-cancer properties (Bok et al. 1999; Chen et al. 1997; Gong et al. 1990; Jia et al. 2005; Toshio, Oikawa, and Haruki 1977; Wang et al. 2005; Yoshikawa et al. 2004). Furthermore, it has been reported that ant alcohol can enhance immunity and improve sexual ability (Liu, Sun, and Li 2004).

The active substances extracted from male *Antheraea pernyi* moths are also a popular insect health food that has been recorded in Chinese traditional medicine to improve sexual ability (Chen, Feng, and Chen 2009). Research has shown that the termite *Macrotermes annandalei* can enhance immunity and was processed to obtain fine powder capsules that are on the market (Wu and Wang 1995). High-protein and amino acid drinks or powder of edible insects have been studied and developed in China (Feng et al. 2017).

2.2.2. Japan

Entomophagy has generally declined in Japan. Still, insects are consumed in mountainous areas of Japan in autumn. The most popular edible insect in Japan is the grasshopper, *Oxya yezoensis* or *O. japonica*. Grasshoppers are collected in Japan's many paddy fields, which are very common because rice is a staple component of the Japanese diet (Nonaka 2010). However, it has been noted that there has been a decline in grasshoppers in Japan due to the use of pesticides (Payne 2014).

Following grasshoppers, the larvae of yellow jacket wasps (*Vespula and Dolichovespula* spp.), locally known as hebo, are commonly consumed. During the annual Hebo festival, food products made from the larvae of wasps are popular delicacies (Nonaka, Sivilay and Boulidim 2008), so much so that the local supply is insufficient and imports from Australia and Vietnam are needed to keep up with demand.

Pupae and female adults after the oviposition of *Bombyx mori* are also eaten. Pupae are rich in nutrients. All these insects are cooked with soya sauce and sugar, and are sold as canned foods. In addition to these insects, the larvae of cerambycid beetles are preferably eaten in the countryside. The larvae of the dobsonfly, *Protohermes grandis* (Neuroptera), have been taken as traditional medicine.

2.2.3. Lao People's Democratic Republic

The percentage of the Lao People's Democratic Republic population that regularly eats insects is among the highest in the world, and the government has identified non-wood forest products as a priority (Boulidam 2010). The most preferred and most frequently consumed insects in Lao People's Democratic Republic are weaver ant larvae and pupae, wasps, bamboo caterpillars, short-tailed crickets, house crickets, grasshoppers and cicadas. Most of these edible insects in Lao People's Democratic Republic are traditionally collected from wild habitats, and local people possess a rich body of traditional knowledge on harvesting practices, the timing of collection and the management of insect resources (Hanboonsong and Durst 2014). Farming and semifarming are starting to play a more important role in Lao People's Democratic Republic after its long insect eating history.

2.2.4. Thailand

One hundred and ninety-four edible insect species are reported in Thailand. Among them, beetles are the main group (61 species), followed by Lepidoptera (47 species), crickets and grasshoppers (22 species), bees, wasps and ants (16 species), cicadas, leafhoppers, planthoppers, scale insects and true bugs (11 species), sucking insects (11 species) and dragon flies (4 species) (Sirimungkararat et al., 2008). Rural Thai communities, especially those from Northern and North-eastern Thailand, where over half the Thai population lives, have a long cultural history of eating insects. In this region, socio-cultural and economic limitations have impeded the use of more commonplace protein sources, such as pork, beef, poultry, milk and eggs (Yhoung-Aree 2010). Edible insects are readily available and commonly eaten by rural people and serve as an important protein source (Raksakantong et al. 2010). Along with wasps, honey bees are the most important insects eaten in Northern Thailand. Bee brood features commonly in local diets and is in high demand on markets (Chen et al. 1998). A limited number of studies have shown that bee brood (eggs, larvae and pupae) and adults of a number of bee families are edible, including Bombycidae, Meliponidae and Apidae (Banjo, Lawal, and Songonuga 2006; Ramos- Elorduy 2006). An extensive nutritional analysis conducted by Finke (2005) has shown that bee brood (presumably of *Apis mellifera*) is an excellent source of energy, amino acids, essential minerals and B vitamins.

The bamboo caterpillar (*Omphisa fuscidentalis*), also known as the bamboo borer or bamboo worm, is another popular food promoted by the Thai Department of Forestry of the Ministry of Agriculture and Co-operatives as an increasingly viable source of income (Yhoung-Aree and Viwatpanich 2005). Bamboo caterpillars have been traditionally collected by cutting down entire bamboo clumps to harvest caterpillars, but a more sustainable collection without cutting bamboo trees is now starting to be practised by local people (Hanboonsong, Jamjanya, and Durst

Table 5. Seasonal availability of edible insects on local Thai markets.

Scientific Name	Common English Name/Thai Name	Season of Sale
Oecophylla smaragdina Fabricius	Weaver ant/ Mod daeng	Mainly the dry season (February-April)
Oecophylla smaragdina Fabricius	Weaver ant (queen caste)/ Mae peng	Mainly the dry season (February-April)
Meimuwa opalifera Walker	Cicada/ Juk-jan	Mainly the rainy season (May-June)
Chondracris roseabrunner Uvaroy	Spur-throated grasshopper/ Tukkatan Tuckatan	Mainly the rainy season (May-October)
Termes sp.	Termite/ Malaeng mao	Mainly the rainy season (May-October)
Cybister limbatus Fabricius	True water beetle/ Malaeng tub tow	Mainly the rainy season (May-October)
Hydrous cavistanum	Water scavenger beetle/ Malaeng nian	Mainly the rainy season (May-October)
Copris nevinsoni Waterhouse	Dung beetle/ kud chi	Mainly the rainy season (May-October)
Holotrichia sp.	June beetle/ Malaeng kinoon	Mainly the rainy season (May-October)
Acheta confirmata	Ground cricket/ Ching reed, chi reed	A short period at the end of the rainy season (September- October)
Omphisa fuscidentalis	Bamboo caterpillar/ Rietdion, Duang mai pai	Season for harvesting rice (October- February)
Gryllotalpa Africana Beauvois	Mole cricket/ Krachorn	Season for harvesting rice (November- January)
Lethocerus indicus,	Cuant water bug/ Maeng dana	Most or all of the year
Tessaratoma papillosa	Longan stink bug/ Maeng Krang	Most or all of the year
Brachytrupes partentosus Lichtenstein	Short tailed cricket/ Ching Klong	Most or all of the year
Bombyx mori Linnaeus	Silk worm pupae/ Duck dae tua mai	Most or all of the year

Source: Siriamornpun and Thammapat 2008.

2013). In Northern and North-eastern Thailand, harvesting ants in the wild is undertaken using a long bamboo pole with a bag or basket attached to the top with strings. A hole is poked into the nest with the top of the pole, and is shaken so that larvae and pupae fall down into the bag. Then the bag is poured onto a plate or container, and some rice or tapioca flour is added to prevent the ants from climbing up to bite the collector. A branch is put on the plate for adult ants to climb back up the branch and it is whipped against a tree to release adult ants. The remaining larvae and pupae are removed to be eaten (Lewvanich et al. 1999). The house cricket (*Acheta domesticus*) is also reared and commonly eaten in Thailand, and is preferred to other species because of its soft body. In a study conducted in Thailand in 2002, 53 of the 76 provinces had cricket farms (Yhoung- Aree and Viwatpanich 2005) and as of 2012, there were about 20,000 cricket farmers in Thailand. Out of the four cricket species, only two species of edible cricket (*Gryllus bimaculatus* and *Acheta domesticus*) are economically farmed. The short-tail cricket (*Brachytrupes portentosus*), with a large body and a big head, is also quite popular for eating, but cannot currently be farmed and is, therefore, collected in the wild.

Silkworms are eaten in both larval and pupae stages. Aquatic insects, such as dragon flies, predacious diving beetles and water scavenger beetles, are eaten in the nymphal stage. Ants can be consumed in the egg, pupae and adult stages (Hanboonsong 2008). They can be cooked in various ways and served as side dishes, eaten with sticky rice. They can be deep-fried, fried with spices or roasted.

The characteristics of Thai edible insects and their seasonality are shown in Table 5, while some of the cooking methods used with Thai edible insects are listed in Table 6.

2.2.5. Vietnam

There are very few publications on insects used as food and feed in Vietnam, although the entomophagy practice forms part of the Vietnamese culture. Most harvesting is done in the

Table 6. Cooking of different edible insects available in Thailand.

Insect	Scientific Name	Local Style of Cooking
Ground cricket	*Allonemobius fasciatus*	Steamed, curried, fried, roasted
Short tailed cricket	*Anurogryllus arboreus*	Roasted, fried, toasted
Giant water bug	*Belostomatidae*	Chilli paste, roasted
Silk worm pupae	*Bombyx mori*	Fried, steamed, with chilli paste, lightly curried with vegetables
Cicada	Cicadidae	Roasted, fried, toasted, dipping (mixed with chilli paste), koy (chopped cicada cooked in Northeastern style)
June beetle	*Cotinis nitida*	Roasted, fried, steamed, lightly curried with vegetables, dipping
Mole cricket	Gryllotalpidae	Fried, curried
Water scavenger beetle	Hydrophilidae	Lightly curried, fried
Termite	Isoptera	Roasted (with salt), fried
True water beetle	Lethocerus americanus	Roasted, lightly curried, fried
Spier-throated grasshopper	Melanoplinae	Steamed, fried, roasted
Weaver ant	*Oecophylla smaragdina* Fabricius	Salad (yum khai mod daeng), lightly curried with vegetables
Weaver ant (queen caste)	*Oecophylla smaragdina* Fabricius	Roasted, curried, chilli paste
Bamboo caterpillar	*Omphisa fuscidentalis*	Fried, with chilli paste, lightly curried with vegetables
Dung Beetle	Scarabaeidae	Curry, chilli paste, fried
Longan Sting Bug	*Tessaraloma papillosa*	Roasted, curried, chilli paste

Adapted from Siriamornpun and Thammapat 2008.

wild and insects are commonly sold in markets. The most commonly eaten insects include crickets, bee larvae and silk worms (Bray 2010).

2.3. Europe

Although 80% of the world's population is used to eating insects, consumption of edible insects still remains unexplored and is unacceptable to many cultures. Insects are a new food, and information on the safety and nutritional value of edible insects is scarce, particularly since they comprise such a diverse category (Rumpold and Schluter 2013). To overcome the challenges associated with poorly accepting insects as food, the following strategies have been documented:

a. Increase familiarity with the product by providing consumers information about insects as a sustainable alternative food source (Lensvelt and Steenbekkers 2014, Van Huis 2013).
b. Make edible insects available and provide knowledge about how to prepare them (Looy, Dunkel, and Wood 2014).
c. Stress the systematic proximity in animal classifications between insects and crustaceans (Caparros-Megido et al. 2014).
d. Increase the frequencies of edible insect exposure and experimental testing (Lensvelt and Steenbekkers 2014; Looy, Dunkel, and Wood 2014).
e. Develop appropriate products to not only lower the barriers to sample, but to also improve taste and appeal (Tan et al. 2015).
f. Incorporate insects into familiar food items (Hartmann et al. 2015).
g. Use role models, such as promoting the consumption of edible insects (Van Huis et al. 2013).
h. Target children for education in entomophagy (Tranter 2013).

Next to increasing insect acceptance, it is also important to:

a. Understand the environmental impacts related to their harvesting and farming (Van Huis 2013).
b. Clarify and augment the socio-economic benefits that insect harvesting and farming have on enhancing the food security of the poor (Van Huis 2013).
c. Develop a clear and comprehensive legal framework to pave the way for more investments to lead development from a household to an industrial scale (Van Huis 2013).
d. Increase knowledge on sustainable insect harvesting; indigenous knowledge of edible insects; identification of edible insects; standard methods to determine nutritional value; mass-rearing techniques; trade and value chains and ethical issues (animal welfare) (Jansson and Berggren 2015).
e. Take in account insects susceptible to microbiological hazards if proper heat treatment or storage conditions are not applied. A short heating step is sufficient to eliminate Enterobacteriaceae, but some spore-forming bacteria survive in cooked insects (Klunder et al. 2012).

2.4. Consumer acceptance

Currently in Western societies, where protein still derives largely from domesticated animals (cow, pig, chicken, etc.) and proteinaceous seed (pulses), insects are virtually synonymous to nuisance: mosquitoes and flies invade homes, the former leaving behind unwanted bites; termites destroy wood possessions; some insects end up in meals, thus triggering the disgust factor (Van Huis et al. 2013). Certain insects are also transmitters of disease (Kellert 1993): a mechanical vector like a housefly, for example, can pick up an infectious agent on the outside of its body and transmit it to food (Van Huis et al. 2013). These could be some reasons why the European Society refuses to accept edible insects as food, and deliberate human entomophagy is rare in westernised societies (Yen 2009). With such a background, it is not surprising that insects in Europe are associated with dirt, fear of contamination and disease, along with a psychological and biased thinking regarding taste, odour and color (Deroy, Reade, and Spence 2015). With evidence that insects are clean, tasty, and nutritious (Gahukar 2013), there are opportunities to explore the farming of human-grade insects to be eaten and to increase the possibility of replacing animal products with insects.

The feeling of disgust to entomophagy in the West contributes to the common misconception that entomophagy in the developing world is prompted by starvation and is merely a survival mechanism (Van Huis et al. 2013). This is far from the truth as insects are often consumed as a delicacy, and insects are not inferior to other protein sources, such as fish, chicken and beef. Although it will require considerable convincing evidence to reverse this mentality, it is not an impossible feat (Pliner and Salvy 2006).

Furthermore, given the ecological advantages of insects compared to other animal protein sources, in countries with a high animal product consumption (Rumpold and Schlüter (2013), the strongest impact to switch from animal products to eating insects could be achieved. There are already signs that consumer attitudes in developed countries like the USA and the UK are changing (Jamieson 2015), and the barrier to include insect-derived materials in other products, in a powdered form for example (Little 2015), may not be so high. Some studies conducted in European countries like The Netherlands, (Lensvelt and Steenbekkers 2014) about accepting entomophagy have shown that people who have eaten insects before show a significantly more positive attitude to entomophagy than people who have not, and are more likely to eat them again. Thus it would appear important to encourage people to make "the first step" and to get them acquainted with eating insects. Therefore, "educating" consumers about entomophagy should be practiced in its broadest sense (Lensvelt and Steenbekkers 2014).

After consumer acceptance comes legislation, which is also an important aspect and one that faces numerous challenges.

2.4.1. Belgium

In Belgium, 10 species of edible insects are temporarily tolerated on the market (FASFC 2016). This tolerance is valid only for whole insects and products based on whole insects produced in the EU (Caparros-Megido et al. 2017). As no specific criteria are available for insects presently sold as human food in Belgium, the Superior Health Council (HSC) and the Federal Agency for the Safety of the Food Chain (FASFC) of Belgium have advised producers of edible insects to refer to the hygiene criteria of minced meat in EU regulation (EC) No. 1441/2007 (SHC&FASFC 2014; Stoops et al. 2016). Belgium imports at least three tonnes of mopane worms annually (Caparros-Megido et al. 2017).

2.4.2. France

Until the mid-1980s, mayflies (*Ephoron virgo*), also called manna, were collected in France in large quantities by local fishermen along the Saône River and were sold to traders to be mixed into animal feed mainly for farm birds (César 2010). However, developing river banks has very likely degraded the mayfly habitat. By rearing insects it is possible to eliminate the danger related to wild-harvested insects with an increased risk of parasites and fungi, as well as potentially dangerous levels of chemical and heavy metal contamination, particularly in areas with high levels of pesticides are used.

2.4.3. The Netherlands

In The Netherlands, citing the results of risk assessments on three different insect species is used to justify marketing whole insects as regular food (Verzijden 2015). Insects are sold freeze-dried in supermarkets, and are used in a few meat analogues.

2.4.4. Novel food regulation in European Union

The scope of this new Regulation (EU) 2015/2283 of 25 November 2015, which becomes effective on 1st January 2018, should in principle, remain the same as the scope of Regulation (EC) No 258/97. According to Article 1 (2) of Regulation (EC) No. 258/97, novel foods and novel food ingredients are foods that have not been used for human consumption to a great extent in the European Community before this Regulation came into force on 15 May 1997. Insects are classified as "novel food" in the European Union since there is no significant history of human consumption before 1997. However, based on scientific and technological developments that have occurred since 1997, it is appropriate to review, clarify and update the categories of food, which constitute novel foods in the European Union (EU). Those categories should cover whole insects and their parts as new food, which are subject to a pre-market approval. Safety assessments will be carried out either by a Member State food assessment body or the European Food Safety Authority (EFSA). Generic EFSA authorisation could encourage the use of novel ingredients on the European market, and thereby stimulate innovation in the food industry (de Boer and Bast 2018).

Hence the main innovation of the new Novel Food Regulation is that the EU legislator can put an end to legal uncertainty about whether 'whole insects & their preparations' are covered by current EU Novel Food legislation, which has resulted in various interpretations by EU Member States. Thanks to this new text, in the future all insect types will be subject to safety assessment and authorisation procedures, unless evidence is provided that they have been consumed before 15 May 1997. (Finardi and Derrien 2016).

Now the main question lies in establishing workable rules and providing sufficient guidance for insect-producing companies in the EU to implement new requirements (Feedstuffs 2017).

3. Rearing/farming insects

In most countries, wild harvesting is the commonest way to collect insects. The prices of insects can be higher than those of meat. Furthermore, insects may not be available all year round in the wild due to seasonal and geographical variations. Therefore, industrial scale insect production, helped by sustainable insect breeding, farming and processing technologies, can ease the constraints of insect availability, and lower the sale price of edible insects. As rearing or farming insects is currently a minor component of the edible insect market, the implications for their future sustainability remain unclear. The environmental benefits of farming include habitat conservation, but the natural environment needs to be retained as a source of renewal, and also as a safety net, and will still be important for local food supplies and livelihoods (Scherr and McNeely 2008). Given the growing interest in rearing insects for commercial purposes, adequate efforts to safeguard their supply to not degrade the ecosystem will be required.

4. From collection to rearing

In tropical African countries, most insect species are collected in the wild, and women usually do the harvesting. For example, palm beetle grubs are harvested from raffia or palm stems in the wild, and their availability is linked to seasonal variations. In traditional settings, the method of collecting insects from the wild depends largely on insect behaviour. Palm weevils can be attracted to artificially create breeding sites, while some cricket species can be located by the sound they make. Some night flyers, such as termites and grasshoppers, can be lured into traps by light. For some insects found in trees or bushes, glue smeared on top of a branch, twig, stick or stem can be used. In Africa, the Mofu-Gudur people in Northern Cameroon use glue from the sap of *Diospynos mespilitermes* (Barreteau 1999); children place a stick with glue at one end to catch crickets in their holes (Seignobos, Deguine, and Aberlenc 1996). In South Africa, children trap cicadas by climbing trees or using long poles, the ends of which have been dipped in glue (Malaisse 1997). Similarly, in Bali, Indonesia, the use of latex from jack fruit trees (*Artocarpus* spp.) has been reported to catch edible dragonflies (Pemberton 1995). The San women in Central Kalahari collect grasshoppers *Cyrtacenthecuis tatarica* and *Lamercleance cucullata* by hand in the morning and the evening from trees and huts (Nonaka 1996). To collect locusts and grasshoppers very early in the morning, Gbaya women in the Central Africa Republic use brooms made from leaves or branches to sweep the savannah vegetation that has been cut the previous day to catch jumping insects (Roulan-Doko 1998). At this time of the day, insects are easy to catch because of their low body temperature. People in the D.R Congo have a peculiar way of finding out the appropriate time to harvest edible larvae of weevil, longhorn and scarab beetles in palm trees (Ghesquière 1947). They listen to the sound made from nibbling beetles by putting their ears against the palm tree. A similar practice is observed in Cameroon, the Central African Republic and D.R Congo, especially for crickets.

A few instances on links between insect collection, the ecosystem and enforcing legislation are found in Africa. In the Central African Republic, present forest concession rules require loggers to leave at least one seed tree of sapelli for every 10 ha of logged forests to allow their regeneration (Vantomme, Göhler, and N'Deckere-Ziangba 2004). In the Benue State, Nigeria, 10 of the most preferred and consumed insect species have been identified, but deforestation, water pollution, and bush burning have reduced their availability (Agbidye, Ofuya, and Akindele 2009). Overexploitation may occur because of the higher demand from the growing human population or when harvesting is carried out by non-native and non-qualified independent harvesters. For example, when collectors did not respect the harvesting rotations of the weaver ant *Oecophylla smaragdina*, they depleted this resource in Indonesia (Césard 2004).

Insects supply only a very small, but fast growing, niche in the food market (FAO 2013b), and soon harvesting in the wild will not be enough to meet demand. Ecosystem degradation may occur in the wild, due to pollution (aquatic Hemiptera) or pesticide use (*Aegiale hesperiaris* in agave) (Ramos-Elorduy 2006). Therefore, in order to make insects a profitable dietary component for humans requires large quantities produced continuously, and both farming and processing need to be automated (Jansson and Berggren 2015).

Insect farming offers the possibility of simultaneously controlling pest insects by harvesting them as food or feed, as practiced in Mexico for grasshoppers in corn, bean and alfafa (Cerritos and Cano-Santana 2008). By harvesting insects instead of eliminating them, the risks of parasites and fungi, as well as potentially dangerous levels of chemical and heavy metal contamination, are eliminated particularly in areas with high levels of pesticide use (FCRN 2016). One disadvantage of insect farming is the potential of exotic species, introduced for farming purposes, to escape from their housing environment, settle and have detrimental impacts on the natural environment.

Insect farming can occur at different scales, from a simple single cage to a large semi-automated factory. Developing insect factories may encourage the use of fewer species, whereas the small farm model has the potential to breed a wider diversity of insects, reduce loss of genetic diversity, and cut the chances of insect disease destroying a whole colony. Farming insects for food and feed purposes is, therefore, a growing business. If widespread insect farming is adopted, it is important to utilise insect diversity and to avoid the global problems associated with dependency on limited numbers of species, as experienced with some food animals and crops (Khoury et al. 2014). There is also a growing worldwide interest in using insects as feed because this global demand increases and there is an ever-decreasing availability of fishmeal to warrant the need to find suitable alternatives, such as insects, which can be farmed in large quantities. An overview of farmed insect species is presented in Table 7.

5. Rearing insects

A starting point when considering insect rearing is the factors related to its substrates or feed and the housing of insects. These factors vary depending on the insect species. It takes only a few days to rear black soldier flies to maturity, but takes a few months to raise crickets (Wook-Jo et al. 2014). In the living environment, temperature has an effect on growth. The higher the temperature, the faster insect growth and development will be (Booth and Kindell 2007). The nutritional composition of feed is important; for instance, a very small amount of protein is not good for insect growth, while too much protein leads to the overproduction of dry uric acid (Van Broekhoven et al. 2015). The choice of feed is a delicate balance between cost and growth rate of the reared insect. Rearing is hampered by suboptimal diet, which can result in higher susceptibility to disease and cannibalism among animals, as has been observed for e.g. crickets and mealworms. When housing insects, it is important to consider the insect's feed requirements. The components available in feed play an important role. The availability of these components depends on pH, moisture, airflow, particle size, etc. For most insects, a smaller particle size in feed increases the availability of nutrients. However for easy rearing (feeding as well as cleaning), a coarser material is preferred. How often and at what times feeding takes place (feeding dynamics) is another factor to be considered; *ad libitum* feeding i.e. a continuous and endless supply of feed results in more greenhouse gas emissions during growth (Oonincx et al. 2010).

The success of cultivating insects as a sustainable form of protein depends on the efficiency of the insect production system. Therefore, its protein contribution and ecological impact also depend on the quality of insect diet (Lundy and Parella 2015). With fed grain-based diets on a scale of economic relevance, populations of crickets were found to show little improvement in protein conversion efficiency compared to broiler chickens that were fed similar diets (Lundy and Parella 2015). However, broiler diets have been optimised for decades, and cricket rearing efficiency may, therefore, increase with better feed. (Diener, Zurbrügg, and Tockner 2009) have suggested that black soldier flies (*Hermetia illucens*) are well suited to the bioconversion of low-quality organic side-streams to dietary protein.

In relation to animal welfare, Erens et al. (2012) have suggested that farmed insects should have access to appropriate quality nutrients, freedom to express natural behaviour, freedom from discomfort, pain, injury and disease, and a breeding environment that imitates their natural conditions as closely as possible. They also suggest killing techniques that ensure instant death. Freezing or deep frying is commonly used to kill insects, but studies on their impact on animal welfare and food quality are scarce.

Mass insect rearing for food and feed is still in its infancy and the risk of disease transmission needs to be further investigated (FAO 2013b). However, as insects are taxonomically distant from humans compared to conventional livestock, the risk of zoonotic infection is expected to be low. The FAO generally recommends that when starting mass rearing, irrespectively of the insect species, a parallel line should always be preserved in case of culture crashes (FAO 2013b).

The best methods to lead to insect survival and reproduction should be developed, e.g., providing food resources, creating suitable habitats, harvesting sustainably (e.g., allowing repairs to ant and wasp nests), and employing semi-rearing like that

Table 7. Examples of insect species known to be farmed on commercial basis, grouped by life-stage (adult, larvae or pupae) of utilizations and, secondarily, by closely related species if several are farmed. Note: the insect species within the scope of this risk profile were taken from the assessments performed by national authorities in Belgium (SHC & FASFC, 2014), in the Netherlands (NVWA 2014) and in France (ANSES 2015), from the websites of European companies active in the area of farmed insects and from information provided by relevant stakeholders that were invited to provide information as hearing experts at a working group meeting.

Groups and scientific names	Common name	Farmed for human consumption	Farmed for feed	Additional information, including estimated volumes
Species utilized in full grown (adult) stages				
Crickets				
Acheta domesticus	House cricket	X	X (pets)	Farmed for live pet feed in many countries, also in Europe. In Netherlands farmed to be marketed for human consumption. Widely farmed in Thailand, and neighboring countries. Farming promoted in Kenya. Production in USA.
Gryllodus sigillatus	Banded cricket		X (pets)	Farmed for live pet feed.
Gryllus assimilis	field cricket		X (pets)	Field cricket native in Asia.
Gryllus bimaculatus	Black cricket or field cricket	X		Widely farmed in Thailand, and also in Laos and Cambodia. Farmers change between *Gryllus bimaculatus* and *Acheta domesticus*.
Teloegryllus testaceus (*Gryllus testaceus*)	Common or field cricket	X		Field cricket native in Americas.
Grasshoppers/locusts				
Orthoptera group, such as: *Oxya* spp.; *Melanoplus* spp.; *Hieroglyphus* spp.; *Acridia* spp.		X	X (pets)	Various grasshopper/locusts species are produced as live pet feed in and outside Europe. Some species are marketed for human consumption in Netherlands. Worldwide grasshoppers are consumed from wild collection. Some tropical countries hesitate to promote farming due to crop pest risks if released.
Locusta migratora; *Schistocerca Americana*				
Species utilized in larvae stages				
Mealworms				Mealworms are easy to rear and are produced for live pet feed in many countries.
Alphitobius diaperinus	Lesser mealworm (larvae of lesser meal beetle/ darkling beetle)	X	X (pets)	Produced as pet food and in some countries also for human consumption
Tenebrio molitor	Mealworm (larvae of yellow meal beetle)	X	X (pets)	Same as above

Source: EFSA 2015.

done for wild silkworms. For example, the African wild silkmoth *Gonometa postica* was reared in semicaptivity by using net sleeves on the branches of host plants to protect larvae against predators and parasitoids (Ngoka et al., 2007). Therefore, possible measures to help conserve insect populations include documenting their significance to people's livelihoods, assessing links between insect collection and the ecosystem, and enforcing legislation. It has been suggested that developing regulations about the use and trade of insects for human consumption in many countries might be hampered by current uncertainty in terminology used to describe insect consumption (de-Magistris, Pascucci, and Mitsopoulos 2015). It is important to have a clear and comprehensive legal framework to support innovative ways to move from the household rearing of insects to the industrial scale.

5.1. Africa

Entomophagy is common in African countries. However, insects are generally harvested from the wild and, as such, are a seasonal product only. Insect farms are hardly present, although a few examples are found and the word is spreading. In South Africa and Nigeria, black soldier flies are reared for feed (www.agriprotein.com), while cricket rearing for human consumption is set-up both on small (in cooperatives of smallholder farmers) and large scales in Kenya and Uganda (www.flyingfoodproject.com, http://entoafrica.com/). In this initiative care is taken to also address the processing, marketing and distribution of the crickets, and to thus set up the whole value chain.

5.2. Asia

As in Africa, in Asia insects are generally harvested from the wild, but semi-domestication and farming are also becoming more commonplace. The most popular insects reared for food are: grasshoppers (*Locust migratoria*), both common crickets (*Gryllus brimaculatus*) and house crickets (*Acheta domesticus*) and flies (*Musca domestica vicina*). Other common species are palm weevils larvae and beetles, such as *Rhynchophorus ferrugineus*, while *Rhynchophorus palmarum* is more common in Latin America. Palm weevil larvae and beetles (*Rhynchophorus phoenicis*) are highly appreciated throughout Africa, and can be reared on cheap substrates (Ebenebe and Okpoko 2016)

A summary on the extent of entomophagy in 15 Asian countries is summarised in Table 8, which indicates the production mode and utilisation. Wild harvesting is still very widespread among the countries for both subsistence and commercial purposes, even though farming is more likely to boost commercialisation (Yen 2015). Semi-domestication involves some manipulation in insects' habitat to increase their production.

The rearing of insects in five Asian countries (China, Japan, Lao People's Democratic Republic, Thailand and Vietnam) is briefly discussed in the next subsections.

Table 8. Insects as food in some Asian countries.

	Wild harvesting		Semi-domestication		Farming		
Country	(S)*	(C)*	(S)	(C)	(S)	(C)	References
China	X	X	X			X	(1 – 7)
India	X	X	X			X	(8–14)
Indonesia	X	X	X				(15–20)
Japan	X	X	X	X			(21–24)
Laos	X	X	X		X		(25–29)
Malaysia	X		X				(30)
Myanmar	X	X					(31)
North Korea	X						(32)
Pakistan	X						(33)
Philippines	X						(34)
South Korea	X	X			X	X	(35, 36)
Sri Lanka	X						(37, 38)
Taiwan	X						na
Thailand	X	X	X	X	X	X	(39)
Vietnam	X				X	X	(40–46)

*S, subsistence *C, commercial. Adapted from Yen 2015.

References: (1–7): Chen, Feng, and Chen 2009, 2010; Demick 2013; Feng et al. 2010; Yi et al. 2010; Zhang, Tang, and Cheng 2008; (8 – 14): Alemla and Singh, 2004; Chakravorty, Ghosh, and Meyer-Rochow 2013; Doley and Kalita 2012; Imtinaro, Chadurvedi, and Ao 2012; Meyer-Rochow 2005; Meyer-Rochow and Chakravorty, 2013; Sarmah 2011; (15–20): César 2004; Edwards 1998; Lukiwati 2010; Rana 2014; Shugart 2010; (21–24): Mitsuhashi 2005; Nonaka 2009b, 2010; Pemberton 2003; (25–29): Boulidam 2010; Hanboonsong and Durst 2014; Nonaka 2009a; Nonaka, Sivilay, and Boulidam 2008; Van Itterbeek et al. 2014; (30): Chung 2010; (31): DeFoliart 2002; (33): Meyer-Rochow 2013; (34): DeFoliart 2002; (35–36): Pemberton 1994, 2003; (37–38): DeFoliart 2002; Tennent 1861; (39): DeFoliart 2002; (40–46): Boongird 2010; Hanboonsong 2010; Hanboonsong, Jamjanya, and Durst 2013; Leksawasdi 2010; Prachaiyo 2000; Sirimungkararat et al. 2010; Yhoung-Aree 2010); na, not available (personal communication).

5.2.1. China

Insect farming is a unique breeding industry in rural China and is a source of income for local people (Feng et al. 2009). Depending on the type of relationship the insect has with humans, plants and the environment, different farming strategies are used (Chen, Feng, and Chen 2009). In China, insects are reared and bred for human food, medicine and animal feed by two approaches: they are either fully domesticated or reared completely in captivity, or are partially raised in captivity and the insect habitat is manipulated to increase production (Chen, Feng, and Chen 2009).

Mass production is attempted for the insects sold or used in health food on the Chinese market. One example is the ant *Polyrhacis vicina*. The sales of ant foods in China were estimated at $100 million in 1994 (Kantha 1994). Similar efforts have been made with the housefly, *Musca domestica vicina* (Chen and Akre 1994). It is important to encourage the industrial utilisation of insects that takes advantage of knowledge from both the social and scientific communities which promote using insects as food and feed in China.

5.2.2. Japan

In Japan, a model for the future mass production of edible insects was proposed by Mitsuhashi (2010), a facility based in Okinawa with the capacity to produce 40 million matured melon fly larvae (*Bactrocera cucurbitae*) every week, where the procedures for raising larvae are automatically controlled.

5.2.3. Lao People's Democratic Republic

Traditionally, Lao people have always collected insects as non-wood forest products in the field. However, factors related to development, commercial farming, changing land use and climate change have necessitated edible insect farming to ensure that adequate quantities are readily available for consumption (Durst et al. 2010). The seasonal and geographical availability of insects is particularly evident for vendors. Developing insect farming habits may contribute to generate income, particularly among women, to increase yearly availability, and to help cushion the impact of extensive harvesting on the environment. The first national survey of edible insects in Laos has shown that insect consumption remains popular, and is well accepted despite a decreasing trend in such consumption over the last decade (Barennes, Phimmasane, and Rajaonarivo 2015). Next to starting up farms, an FAO-supported project has also included components related to 'sustainable insect harvesting' to help enhance the long-term viability of insect harvests from the wild and to maintain the cultural heritage of insect collection (Project "Sustainable insect farming and harvesting for better nutrition, improved food security and household income generation in the Lao People's Democratic Republic Project (TCP/LAO/3301)"). Standard protocols and techniques for the insect farming of four target species (house crickets, mealworms, palm weevils and weaver ants) have been developed.

5.2.4. Thailand

Eighty-one insects are reported to be eaten in Thailand, but the actual figure may be higher (FAO 2013a). Compared to other countries of Asia and the Pacific, Thailand appears to have been better studied. The most popular insects reared for food in Thailand are ants, beetles, black fly larvae, crickets and bamboo caterpillars (Durst et al. 2010). They are popular snacks in Thailand, and can be found in rural villages and on the crowded streets of Bangkok. Insects are sold fresh or canned. Canned products include cooked crickets, cooked silkworm pupae and cooked bamboo worms (FAO 2013a)

Thailand is one of the few countries in the world to have developed a viable thriving insect farming sector. And even there, despite the long entomophagy tradition, the market for insect rearing has only taken off in the last 15 years. The production model in Thailand involves a large number of individual farmers who produce crickets that are processed and distributed by an intermediary (Hanboonsong, Jamjanya, and Durst 2013). The establishment of a smaller farm model is relevant to a large part of the Asia Pacific region because of cheaper establishment costs (compared to a factory), better access to a subsistence food product for farmers, and the ability to establish enterprises within a range of different environments: urban, periurban, rural and non-productive environments. This allows increased food production to be grown domestically and to increase in more ‘marginal’ or ‘fragile’ lands. Insects may not necessarily be the main form of food or income for farmers, but insect farming provides a potentially longer-term resilient food supply (Barthel and Isendahl 2013). The success story is due largely to support from university research and by being coupled with innovative private-sector food processors and sellers, which have responded to the strong market demand in this country. The Insect Farming Learning Centre and the Edible Insect Learning Centre set up in North-eastern Thailand are good models that have led to extend insect farms in Thailand. Educational programmes have been used in many schools and edible insects have featured prominently in food fairs and restaurant promotions (Durst and Hanboonsong 2015). Nowadays, more than 20,000 insect farming enterprises are registered in the country, and most are small-scale household operations with an annual production of 7,500 tons (Hanboonsong, Jamjanya, and Durst 2013). Overall insect farming, collection, processing, transport and marketing have emerged as a multimillion dollar sector that provides income and employment for tens of thousands of Thai people, as well as healthy nutritious food for millions of consumers. As a way to understand the phenomenal development and evolution of the Thai edible insect sector, the FAO Regional Office for Asia and the Pacific collaborated with the Khon Kaen University to review and assess the trends, status and practices of insect collection and farming, processing, marketing and trade in the country (Hanboonsong, Jamjanya, and Durst 2013).

The house cricket (*Acheta domesticus*) was introduced from North America and is now the most commonly farmed species in Thailand because consumers prefer it for its better taste and texture. The techniques associated with cricket farming have changed, especially the types of cages and food used. Cricket farmers still have an issue with cricket food and rely mainly on high priced commercial chicken feed. Other issues faced by Thai cricket farmers are the future danger of cricket densovirus diseases (Weissmann et al. 2012) and inbreeding.

Besides crickets, thousands of small-scale producers to support the Asian region’s distinctive silk industry have reared silk worms. The eri silkworm is a wild silk moth species that can produce commercial quantities of silk. Several local scientists (Sirimungkararat et al.2005a, 2005b, 2001, 2000, Sirimungkararat, Thongpak, and Saksirirat 1994; Wongtong et al., 1980) have studied the eri silkworm in Thailand for rearing and silk production. The favourable properties reported by these researchers led to exploit the eri silkworm as animal feed, aquarium fish food and human food. Rearing is a common secondary activity among cassava growers. The removal of up to 30% of cassava leaves, used as the sole food of eri silkworms, significantly increased cassava tuber yields in the northeast (Sirimungkararat, Atthathom, and Saksirirat 2002). Given its high protein content, a simple rearing process that does not use chemicals and a wide range of host plants, eri food has been developed as a sustainable high protein food source (FAO 2013a). It has been found to be safe food with diverse cooking preparations and is ideal as high-protein food for schoolchildren, rural dwellers and local communities.

5.2.5. Vietnam

In Vietnam, focus lies on insect rearing for feed to alleviate import problems to meet feed demands. Globally, some 10% percent of fish production goes to fishmeal (i.e. either whole fish or fish remains that result from processing) and is used mainly in aquaculture (Vantomme et al. 2012). South America is the biggest producer of fishmeal thanks to its catches of anchoveta. Anchoveta catches are extremely variable because they depend on the El Niño climatic cycle. Fishmeal production is declining as a result of this climate problem. There is high demand, and consequently high prices. Together with increasing production pressure on aquaculture, this has led to research being done into developing insect proteins for aquaculture and livestock, which could eventually supplement fishmeal in Vietnam. Insects have a similar market to fishmeal as they can be employed as feed in aquaculture, livestock and the pet industry. Currently, a European company replaces fishmeal and engages in the business of black soldier fly insect rearing on organic biomass to produce meal, oil, organic fertiliser, and live and dried larvae (Byrne 2017).

5.3. Europe

The list of insect species reported to have the highest potential to be used as food and feed in the EU are: Common housefly (*Musca domestica*), Black soldier fly (*Hermetia illucens*), Mealworm (*Tenebrio molitor*), Giant mealworm (*Zophobas atratus*), Lesser mealworm (*Alphitobus diaperinus*), Greater wax moth (*Galleria mellonella*), Lesser wax moth (*Achroia grisella*), Silkworm (*Bombyx mori*), House cricket (*Acheta domesticus*), Banded cricket (*Gryllodes sigillatus*), African migratory locust (*Locusta migratora migratorioides*) and American grasshopper (*Schistocerca Americana*). Since the list is only used as guidance in the overall assessment conducted by (EFSA 2015), it should not be considered definitive or exhaustive.

As complimentary food sources to feed poultry, Ravindran and Blair (1993) have reported that grasshoppers, crickets, cockroaches, termites, lice, stink bugs, cicadas, aphids, scale insects, psyllids, beetles, caterpillars, flies, fleas, bees, wasps and ants have all been used. Many authors reported that the most popular and useful insects for feed, with the chance to expand to an industrial scale, include black soldier flies, common housefly larvae, silkworms and yellow mealworms. Grasshoppers and termites have also been reported as being viable, but to a lesser extent (Awoniyi, Adetuyi, and Akinyosoye 2004; Newton et al. 1977; Sheppard et al. 1994; Sheppard, Newton, and Burtle 2008; St-Hilaire et al., 2007).

Rearing insects is common in Europe (Table 9), where reared insects are generally used for pet feed. The market for feed and food is slowly starting up and is expected to take off once legal barriers have been overcome.

Table 9. Edible insects commonly bred in Europe.

Insect species	Common name	Described by
Acheta domesticus	House cricket	(Linnaeus, 1758)
Apis mellifera	European honey bee	(Linnaeus, 1758)
Bombyx mori	Silkworm	(Linnaeus, 1758)
Galleria mellonella	Honeycomb moth	(Linnaeus, 1758)
Gryllus assimillis	Jamaican field cricket	(Linnaeus, 1755)
Hermetia illucens	Black soldier fly	(Linnaeus, 1758)
Locusta migratoria	Migratory locust	(Linnaeus, 1758)
Musca domestica	Housefly	(Linnaeus, 1758)
Schistocerca gregaria	Desert locust	(Linnaeus, 1755)
Tenobrio molitor	Mealworm beetle	(Linnaeus, 1758)
Zophobas atratus	Giant mealworm beetle	(Linnaeus, 1755)

Source: Comby, 1990.

In The Netherlands, insect rearing has been used for pet feed for years. The most commonly reared insects are black soldier flies, maggots, lesser mealworms, yellow mealworms, morioworms, crickets and grasshoppers. Four of the species are also available for human consumption: lesser mealworms, for which a large plant for human consumption is currently being set up (www.protifarm.com), yellow mealworms, crickets and grasshoppers.

In other European countries, insects have also been reared for pet feed, but hardly for food. Recently, however, the trend seems to be changing, and more research is being conducted in this field, while companies are also starting to look into insect rearing and processing for food. One example is Finland, where insects are included among legumes and mushrooms in a large search for protein sources that can be locally produced (Sceno-Prot 2017).

Concluding remarks

Worldwide, a treasure of information is present on the life cycle of insects and on collecting, preparing and eating them. In this review, the diversity of entomophagy has been illustrated with numerous examples. In view of malnutrition and (future) food shortage, insect rearing may offer a new source of sustainable food. Indigenous traditional knowledge associated with wild harvesting and local insect consumption, especially in Africa and Asia, will complement scientific knowledge that is necessary to boost the supply of insects through large-scale farming. Furthermore, a better understanding of the different factors required to promote the rearing of high quality insects available all year round is required.

For rearing to be feasible, the standardisation of indigenous methods to rear and harvest edible insects, including their processing, preservation, storage and packaging, is necessary. These are critical for sustainable edible insect rearing, production and consumption for food and feed security and nutrition. Insect farms will provide employment opportunities and increased income, especially in lower-income countries. However, good agricultural practices and good hygiene practices need to be established and employed by edible insect farmers in all countries to prevent food safety-related issues. Then there will be the need for standard operating procedure manuals, and developing hazard analysis and critical control points (HACCP) for raw edible insects, their handling conditions, processing, preservation, storage and packaging and distribution until either the raw edible insect/semi-processed insect/processed insect as a finished product reaches the end customer's table in the safest and most nutritious forms. Consequently, specific measurable quality parameters for each edible insect and their products must be established and optimally utilised to ensure quality conformance that falls in line with established quality standards for meat and meat products, as documented by international food safety regulatory bodies, such as the Codex Alimentarius standard, and in agreement with WHO requirements. The overview of traditional consumption and rearing practices in this review is, therefore, only a first step in the direction of a new agricultural practice to rear insects as mini-livestock.

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